Proceedings

43rd International Symposium of CIB W062
Water Supply and Drainage for Buildings

23 - 25 august 2017
Haarlem, Netherlands

cib International Council for Research and Innovation in Building and Construction

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CIB W062 | 2017

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on

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Foreword CIB W062

At the **International CIB W062 Symposium "Water Supply and Drainage for Buildings"**, experts, scientific researchers and professionals from all over the world will gather to share their knowledge on how to maintain necessary quality standards for drinking water and sanitation in buildings, now and in the future.

Due to climate change, both the availability of sufficient water and the quality of drinking water sources are under pressure on a global scale. The awareness of this results in more and more initiatives in the field of alternative sources (rainwater and grey water) for drinking or other water supply to sanitary appliances. In parallel, appliances in existing locations are being replaced by water efficient versions. Experts however, encourage a holistic view of system performance is undertaken so as to ensure that optimum conditions and sanitary and public health expectations are met.

The 43rd edition of the CIB W062 symposium, held in the Dutch city of Haarlem from 23 to 25 August, will largely focus on complications in the provision of sanitary appliances and systems.

Results will be presented of research into the transport of solid waste in unchanged and modified systems when less flush water is used, and into the self-cleansing qualities of these systems when water saving methods are employed yet further.

Additional concerns relate to the sizing of water pipeline installations. Current calculation methods take little account of the consumptive behaviour of different groups of users, nor of the rapid technological development of water saving sanitation and other water-using devices. Existing calculation methods therefore result in over-sizing of water systems. Apart from a deterioration of the water quality, this may have adverse effects on the sustainability and energy efficiency of the water supply system. Research results from different countries will be presented and suggestions for new calculation methods will be outlined and discussed.

CIB W062, which is the world's most influential academic platform in the field, also present a wide range of other topics on the global stage of sanitation.

The symposium papers are categorized under the following sessions:
A. Water supply hygiene security;
B. Water saving and sustainable use;

C. Building water supply and drainage and intelligent systems;
D. Drainage sanitation and indoor environment pollution control.

In addition, the symposium will feature various poster presentations.

The organisation would like to thank all speakers and authors for their contributions to the symposium. We also thank the organising committee and the International Scientific Committee for their advice.

We finally gratefully acknowledge all sponsor organisations and commercial businesses who have made this symposium possible.

Professor Lynne Jack
Coordinator CIB W062

Walter van der Schee
Organiser, on behalf of
TVVL Expert Group Sanitation Techniques

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Session A Water supply hygiene security

A0 - Using a stochastic demand model to design cold and hot water installations inside buildings

Mirjam Blokker (1), Claudia Agudelo-Vera(2), Andreas Moerman (3)
1. mirjam.blokker@kwrwater.nl
2. claudia.agudelo-vera@kwrwater.nl
3. andreas.moerman@kwrwater.nl
(1, 2, 3) KWR Watercycle Research Institute, Nieuwegein, The Netherlands

Abstract

The design of a drinking water installation (DWI) requires selecting specific pipe lengths, pipe diameters and pipe materials, and a water heater. This process heavily depends on expected water use during the life time of the DWI. As future demand is typically unknown, and limitations in comfort of water use is undesired, in the design stage often a large safety factor is taken into account. The downside of this, is that the designed DWI is much larger than needed, and this results into higher costs of installation, a potential negative effect on water quality during operation, and higher energy (and potential environmental impact) costs for water heating. A better prediction of water demand, with a smaller safety factor allows the design of a better fit DWI. A stochastic demand model has the advantage of providing insight into expected demand, including the uncertainty or variation in demand (Jack et al., 2017). In this paper, the contribution of SIMDEUM is illustrated in three cases: (1) development and validation of design rules based on SIMDEUM simulations, (2) evaluation of heating efficiency for drinking water installation design of individual households and the use of SIMDEUM to simulate peak energy demands for validation of future low-temperature district heating solutions and (3) a study on the supply-demand balance of residential grey water and rainwater systems to gain insight into the effect of dynamic patterns (using SIMDEUM) on storage capacity and efficiency of these systems.

Keywords

SIMDEUM; cold and hot water, design rules, water (heat) demand, heating efficiency, rainwater harvesting, grey water.

1 Introduction

The design of a drinking water installation (DWI) requires selecting specific pipe lengths, pipe diameters and pipe materials, and a water heater. The design is a trade-off between requirements on energy and sustainability, water quality and comfort. The design process heavily depends on expected water use during the life time of the DWI. As future demand is typically unknown, and limitations in comfort of water use is undesired, in the design stage often a large safety factor is taken into account. The downside of this, is that the designed DWI is much larger than needed, and this results into higher costs of installation, a potential negative effect on water quality during operation, and higher energy (and potential environmental impact) costs for water heating. A better prediction of water demand, with a smaller safety factor allows for the design of a better fit DWI. A stochastic demand model has the advantage of providing insight into expected demand, including the uncertainty or variation in demand.

The stochastic drinking water demand model SIMDEUM was developed for residential and non-residential buildings (Section 2). It has been applied to develop design parameters for Dutch apartment buildings, hotels, offices and nursing homes. The SIMDEUM based design parameters were verified by extensive measurements. This is further described in Section 3. SIMDEUM was then extended to also calculate the energy needed for heating the water (SIMDEUM HW), depending on the water use, the type of water heater, the energy losses and potential heat recovery. This is further described in Section 4. SIMDEUM was also extended to calculate the discharged wastewater, and its nutrient load and thermal energy (SIMDEUM WW). This tool was used to balance supply and demand of grey water, as further described in Section 0.

2 SIMDEUM explained

SIMDEUM® is a model that supports this understanding. SIMDEUM stands for "SIMulation of water Demand, an End-Use Model." It is a stochastic model based on statistical information of end uses, including statistical data on water appliances and users (Blokker et al., 2010b). SIMDEUM's philosophy is that people's behaviour regarding water use is modelled, taking into account the differences in installation and water-using appliances. This means that in each building, whether it is residential, like a house, or non-residential, like an office, hotel or nursing home, the characteristics of the present water-using appliances and taps are considered as well as the water-using behaviour of the present users. For each person, his presence is modelled and when he uses water and for which reason. The characteristics of each appliance are defined, like the flow rate, duration of use, frequency of use and the desired temperature. The duration and frequency may vary depending on the users: a teenager showers more frequently and longer than an elderly person. Moreover, the duration, frequency and the desired temperature of an appliance depends on the type of appliance (e.g. particular type of washing machine) and the particular application. For example, a kitchen tap can be used for filling a glass (15 s, 0.167 l/s, 10°C) or for washing dishes (45 s, 0.25 l/s, 55°C). SIMDEUM calculates for each appliance at what time it is used, by whom and for which purpose. This results in a demand pattern for cold and hot water at each appliance. By the addition of the demand patterns of all appliances, the demand pattern of a house, apartment building, office, hotel or nursing home is obtained. The characteristics of the users and the appliances are different for each type of building and are extensively described in Blokker et al. (2010b), Blokker et al. (2011). Measurements of cold and hot water patterns on a per second base in different types of buildings show that SIMDEUM renders a reliable prediction of both cold and hot water demand (Pieterse-Quirijns et al., 2013).

SIMDEUM's basis gives insight in the reason for which the water is used and at what temperature this water needs to be. Therefore, it also provides information of the wastewater quantity, temperature and quality that will leave the building through the sewage system (e.g. shower water at 35°C with soap residue, or toilet water at 15°C with medicines, hormones and nitrates).

3 Case I: Design rules for cold and hot water in residential and non-residential buildings

3.1 Intro

In general, pipe diameters and water heating systems in buildings are oversized to guarantee a high expected water demand and to meet the desired comfort wish (Pieterse-Quirijns et al., 2013). Badly designed systems can cause stagnant water with health risks, and are less energy efficient and therefore more expensive to operate. The main reason for the bad designs are the outdated guidelines with extra safety factors to warrantee no lack of comfort, that generally overestimate the peak demand values required for design and that do not give any insight into the hot water demand.

3.2 Method

SIMDEUM was originally developed for an accurate prediction of the maximum drinking water demand and hot water demand (Blokker et al., 2017). These parameters can then be used in the design of drinking water distribution systems (Vreeburg et al., 2009, Blokker et al., 2010a) and (domestic and non-domestic) drinking water installations (DWIs). This application requires a small temporal scale; the maximum flow per minute can be 80 % of the maximum flow per second for a demand of 100 homes. SIMDEUM has been used for the design of the DWIs in apartment buildings and non-domestic buildings (Pieterse-Quirijns et al., 2014, Pieterse-Quirijns and Van der Schee, 2010, Pieterse-Quirijns et al., 2013).

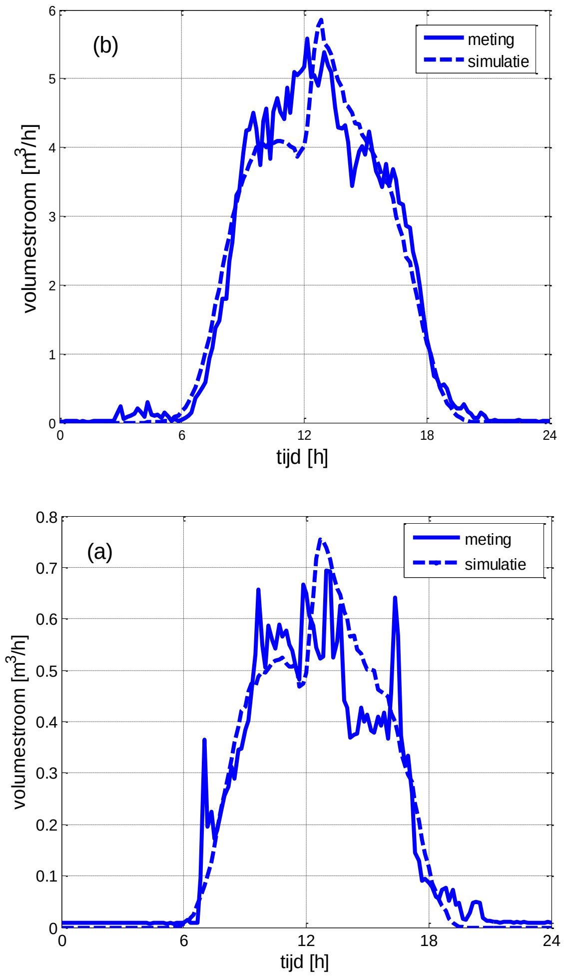


Figure 1 Measured (--) and simulated (- -) demand patterns (y-axis; flow) based on 30-50 measurement days for two different offices (a and b, with resp. 250 and 2000 employees), shown using a 10-minute interval.

The following steps were taken:

1. The input parameters for SIMDEUM for apartment buildings, offices, hotels and nursing homes were defined.
2. A SIMDEUM simulation was done for various sizes.
3. Characteristics values for maximum demand of hot and cold water, and hot water demand for various time intervals were extracted.
4. A (linear) curve was fitted on the characteristic values depending on the size of the building.
5. Measurements were done in buildings of each type, with different sizes. One type of measurements consisted of measuring cold and hot water use in two buildings of each type in order to validate the simulation results (step 3; **Figure 1**). Another type of measurements consisted of taking a survey to validate the input parameters (step 1).
6. The results from step 4 were put into design rules.

7. The design rules (step 6) were applied to some example buildings, and were compared with the actual design.
8. The design rules were included in the revised version of the design guidelines.

3.3 Results and discussion

The results for the various steps are as follows:

1. For households, and thus for apartment buildings the input parameters were obtainable (Blokker et al., 2010b). For the non-domestic buildings, input parameters are more difficult to obtain (Blokker et al., 2011). The important parameters determining the size of a building are number of apartments, number of employees, number of hotel rooms and number of residents, respectively (Pieterse-Quirijns and Van der Schee, 2010).
2. The results are a set of random diurnal demand patterns.
3. The characteristic values that are important are the maximum (or 99 percentile) daily drinking water demand (L/s) and the maximum daily hot water demand (L/s) and the maximum demand volume (L) for hot water in 10 min, 1 h and 1 day. The maximum flows for these buildings, together with a requirement for the minimum and maximum flow velocities, leads to a certain pipe diameter. The maximum hot water volume is used to determine the most appropriate type and size of water heater.
4. The best fit is a linear relation between building size and characteristic values (Pieterse-Quirijns and Van der Schee, 2010).
5. For each building 30 days of flow measurements with a 1 minute time resolution were collected. Surveys for a few more buildings were filled out. The flow measurements showed that the simulations fitted the measurements well. The surveys showed that the estimates for the input parameters were reasonable (Pieterse-Quirijns et al., 2014).
6. The linear relations from step 4 together with a small safety factor, and a restriction to minimum and maximum building sizes were defined as the design rules.
7. The application of the new guidelines will lead to selection of smaller diameters. Also the water heater capacity can be reduced with a factor 2 to 4 compared to suppliers proposals, while still meeting the desired need and comfort. The impact on energy use due to a better selection of the water heater is significant (Pieterse-Quirijns et al., 2013). The impact on water quality seems to be limited as the pipe volume is typically emptied in a few times of opening a tap, or flushing a toilet.
8. The design rules following from SIMDEUM are now in the official Dutch guidelines for the design of DWIs in apartment buildings and non-domestic buildings (ISSO-kontaktgroep, 2015).

3.4 Conclusion

Applying the new design guidelines with reliable predictions of water demand results in saving both materials (of pipes and water heater) and energy (Pieterse-Quirijns et al., 2015).

4 Case II: Evaluating heating efficiency considering primary energy, costs and carbon emissions

4.1 Introduction

At the end of the 20th century the residential heat demand in the Netherlands was predominantly determined by heat demand for space heating. Norms for building requirements enforce better insulation for new residential buildings to decrease the heat demand. This requirement is typically expressed in the EPC (Energy Performance Coefficient). Disappointing results for energy consumption of new buildings caused by inefficient tap water heating shows that the attention for tap water heating efficiency so far has been insufficient. There are two main drivers which make better understanding of heating efficiency necessary:

(A) Current building standards: The current EPC calculation method estimates the tap water heat demand based on the buildings' floor space, which can result in significant under- or overestimation of the tap water heat demand. This can cause (respectively) discomfort or energy inefficiency.

(B) Future building standards: In the current Dutch situation natural gas is mostly used as an energy source for water heating. Climate change and resource depletion enforce the use of renewable energy (RE) sources. To drive the energy transition without fossil fuel use, concepts for residential energy demand need to be (further) developed. The applicability of these concepts should be validated for the water heat demand as is explained in the following:

1. The power required for water heating differs much from the power demanded for space heating, due to the higher temperature for tap water heating (min. 55 – 60°C).
2. Heat pumps are often used to bridge the temperature gap between the required minimum temperature for hot water and the available low-temperature from RE- sources, like ATES (Acquifer thermal energy storage). These systems are more sensitive to demand changes than traditional systems (e.g. gas boilers) and there are typically more demand changes for hot water than for space heating.
3. Future RE-systems for heat supply on district level will typically be based on lower temperatures (30 – 50 °C) compared to traditional district heating systems (70 – 90 °C). Although this temperature range is directly applicable for space heating of new buildings (which meet the current requirements) these RE-systems should be validated on hot water peak demands for groups of residential buildings (consideration of power statement (1) above) since peak demands for hot water are much higher than for space heating (due to coinciding shower use).

For both current (A) and future (B) challenges SIMDEUM-HW can be a very effective method to:

1. Enhance understanding of heating efficiency for specific user groups and situations for today and future scenario's to improve decision making in DWI design.
2. Calculate peak demands (and corresponding exceedance frequencies) for groups of residential buildings to validate new concepts for tap water heating in the circular economy.

4.2 Method

As mentioned in section 1 SIMDEUM was extended with the HotWater (HW) module. This module enables the calculation of the energy demand for heating the simulated amounts of hot tap water. This is the so-called 'final energy': the amount of energy which is theoretically necessary to heat the water to the desired temperature and to bridge the heat losses between the water heater and the tap. The final energy is calculated per tap location based on:

1. The desired temperature at the tap;
2. The temperature of the water which enters the DWI (seasonally dependent);
3. The heat losses during transport in the DWI.
4. The availability of a shower heat recovery (SHR) system.

In an earlier study the annual sum of final energy was calculated for 72 scenario's which were different in (a) household type, (b) DWI design, (c) water temperatures (see points 1 and 2 above) and the use of SHR (Pieterse-Quirijns et al., 2015).
To calculate the primary energy which is demanded for water heating the efficiency of heating should be considered in the energy demand calculation. The result of this calculation is the primary energy. Based on the Dutch NEN 7120 norm for efficiency of water heaters, quality assessments of specific water heaters and final energy calculated by SIMDEUM-HW annual total values for primary energy, costs and carbon emissions were calculated (Figure 2), (Pieterse-Quirijns et al., 2015). To calculate the total efficiency for electrical driven water heaters (i.e. heat pumps) the efficiency of power generation at the power plant was considered by using a value of 39% (from NEN 7120).

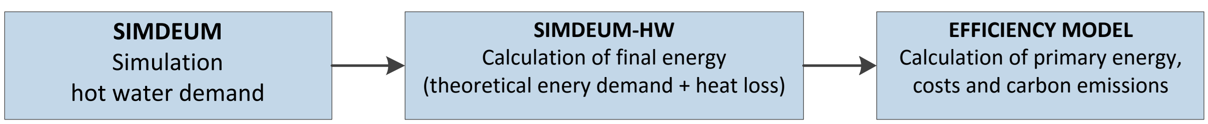


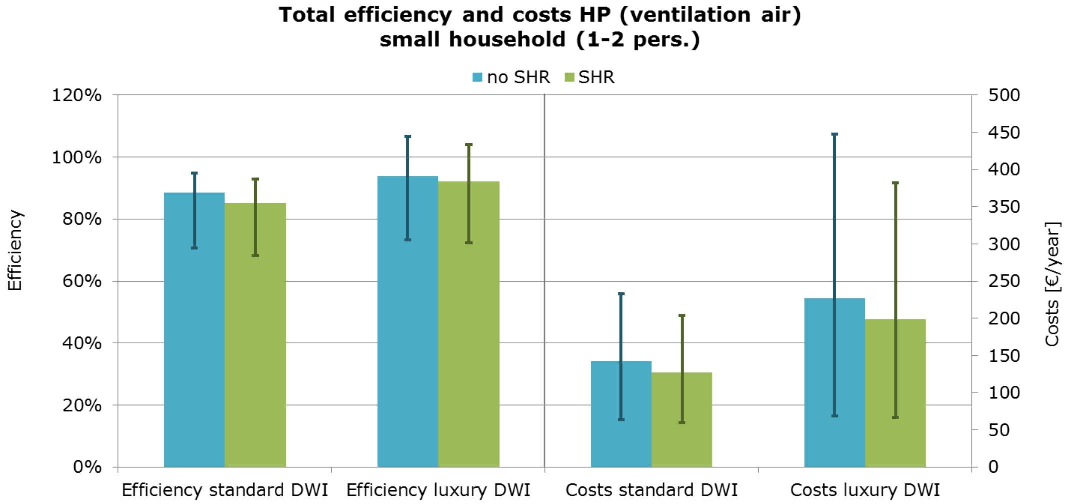
Figure 2 Steps for calculation of primary energy demand using SIMDEUM-HW

4.3 Results and discussion

From the total efficiency the primary energy, costs and carbon emissions were calculated. Average values of 0.23 €/kWh and 0.65 €/m^3 were used for electricity and gas (price level 2015). Figure 3 shows the total efficiency and annual costs for various scenarios considering household size, DWI design and SHR use by use of an electrical heat pump with ventilation air as heat source. The 10-90 pct. bandwidth shows the variation around the 'average' household (50-pct.). It is shown that (based on costs) there are large differences between household types. The use of luxury DWI's (rain showers, baths, etc.) can result in a factor 2 higher costs compared to a standard DWI design. Obviously the results are largely depending on the household size (number of inhabitants). The effect of people's behaviour (i.e. short/long showering) is expressed in the bandwidth. The combination of heater type and people's behaviour seems to be determinative for the extent to which energy savings are realised using SHR. Figure 3 shows that for very economical people (10^{th} pct.) the savings of SHR are minimal. For an average user (50^{th} pct.) the savings can sum up to several tens of euro's a year.

For larger households cost reduction of SHR can sum up to 150 €/year. These savings obviously depend on the energy (electricity/gas) price.

Note: the total efficiency is the efficiency in the heat supply chain for water heating. Due to the use of heatpumps (which transport more energy than they use, expressed in the Coefficient Of Performance (COP)) the calculated total efficiency for water heating could be larger than 100%. This value is obviously different from the thermaldynamic efficiency (which represents the conversion of heat to work, not the transport of heat).



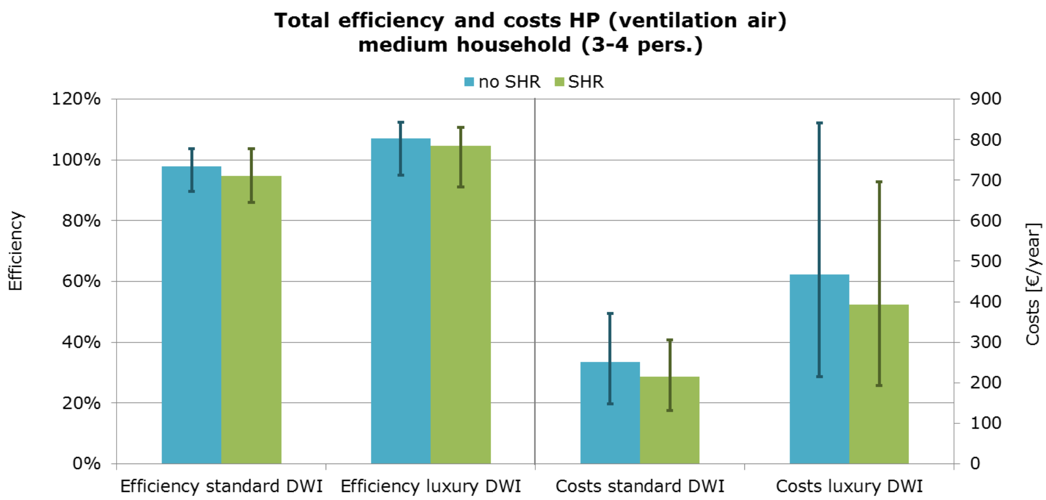


Figure 3 Efficiency and yearly costs based on SIMDEUM-HW and efficiency model results for household, DWI and SHR scenarios. A heat pump (ventilation air as heat source) was chosen as heater type.

4.4 Conclusions and future work

With SIMDEUM-HW, natural variation of hot water demand was modelled and studied, leading to realistic demand patterns (with insight into the variability) of energy where other methods can result in under- or overestimation of energy demand. Moreover, a model as SIMDEUM is essential to study the effect of different scenarios on water heater performance in terms of total efficiency, costs and carbon emissions. As a follow-up, the model can be developed into an online tool for consumers, e.g. to calculate the savings potential of taking shorter showers, using water-saving shower heads or SHR, or showering at lower temperatures. The current work with SIMDEUM-HW shown in section 4.3 focuses on individual households. The stochastic nature of SIMDEUM(-HW) will be necessary in future work on calculation of peak demands of multiple households to validate the design of future low-temperature district heating solutions. To calculate realistic peak demands, it is necessary to consider the effect of people's behaviour (in i.e. different scenarios), for which SIMDEUM(-HW) shows good opportunities. Based on results of earlier work it could be concluded that it is (technically) possible to apply the functionality of SIMDEUM-HW for non-residential hot water energy demand (Pieterse-Quirijns et al., 2013, 2014).

5 Case III: Customized design of residential grey water and rainwater systems

5.1 Introduction

In the transition towards more sustainable urban water systems, increasing attention is given to decentralised facilities, e.g. grey water recycling and rainwater harvesting. Current Dutch design guidelines (ISSO-kontaktgroep, 2002, ISSO-kontaktgroep, 2001) are based on daily averaged water consumption and they do not differentiate between type of buildings or consumers. Residential demand and supply of local resources have a dynamic pattern fluctuating over time, influenced by household size, building characteristics and weekly and seasonal factors. Determining the adequate storage capacity to match supply and demand is crucial for the functioning of these systems. Often averaged hourly or daily consumption are used for dimensioning, which can overestimate or underestimate the system efficiency.
Different variables determine the actual harvest of local resources: spatial variables depending on building typology (e.g. single houses versus apartment blocks); seasonal and location-bound variables (e.g. yearly rain patterns, depending on locations) and temporal variables (demand and supply patterns that fluctuate through the day – day/night, within the week –working days/weekends, and within the year – seasons). Our objective was to gain insight into the effect of dynamic patterns on storage capacity and efficiency of the systems.

5.2 Method

The stochastic drinking water demand model SIMDEUM was applied to design a residential grey water and rainwater systems for two building types, a free standing house and a mid-rise apartment flat (**Table 1**). SIMDEUM was used to determine the residential water demands and the waste water production per hour during a year, considering household occupancy and presence of water using appliances. We focused on supplying non-potable demand (toilet and laundry) by recycling light grey water (from the shower and bath) and harvesting rainwater. For the scenarios including recycling, two storage units and a treatment unit are required. For rainwater harvesting, a single tank is considered, Figure 4. The hourly rainfall pattern of an average year – 2010 – was used as recorded for the Netherlands.

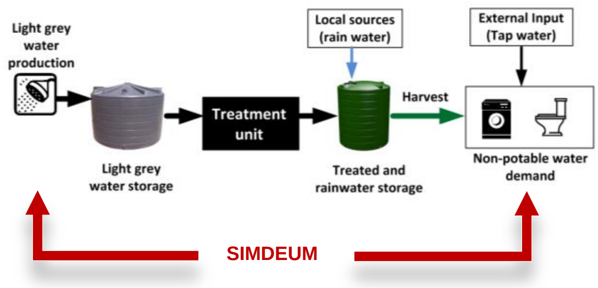


Figure 4 Description of the modelled storage and treatment system

Table 1 Overview of the characteristics of two buildings

	Free standing house	Mid-rise apartment flat
Roof area (m²)	60	640
Occupancy	1 family – 4 people	56 people: 28 apartments x 2 people
# of toilets	2	28 (1 per apartment)
# of laundry machines	1	28 (1 per apartment)
# of showers	1	28 showers (1 per apartment)
# of bathtubs	1	No bath
Roof type	Pitched	Flat
Grey water system	Single house collection	Shared collection
Rainwater collection	Single	Shared

5.3 Results

Although the yearly water demand per person is similar for both types of households, they do not satisfy the superposition principle, meaning that the water demand pattern of the four-people households is not two times the pattern of the two-people households. This non-linearity is, among others, caused by differences in (use frequency of) water appliances related to household size and family composition (adults/children). The simulated patterns show a large difference for the two demand scenarios: conventional and with water saving appliances, Figure 5.

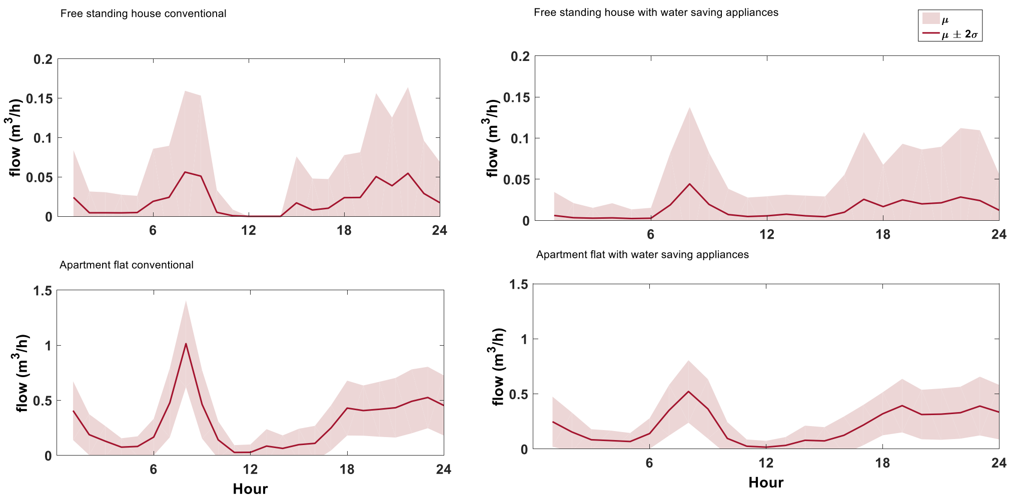


Figure 5 Overview of the average pattern (μ) and their variation (μ +/− 2σ)

The studied strategies include demand minimization, light grey water (LGW) recycling, and rainwater harvesting (multi-sourcing). Results showed that water saving devices may reduce 30% of the conventional demand. Recycling of LGW can supply 100% of the toilet flushing and washing machine demand, which represents 36% of the conventional demand or up to 20% of the minimized demand. Rainwater harvesting may supply approximately 80% of the minimized demand in case of the apartment flat and 60% in case of the free standing house (Agudelo-Vera et al., 2013). To harvest these potentials, household specific systems are required.

SIMDEUM can be used to simulate the storage facilities and to determine an adequate storage volume considering the specific water demand. The case studies showed that building and occupancy characteristics largely influence the efficiency of these systems. In the two specific (Dutch) cases that were studied the largest positive effect was found from reducing the residential water demand, the second largest was reusing grey water, the use of rain water contributed only to a small extent to the sustainability goals.

A comparison between recycling and multi-sourcing shows that for the same storage capacity, recycling is more beneficial. If recycling and multi-sourcing are combined, the maximum yield is achieved with a smaller storage capacity. Comparing the two building units, for a storage capacity of two tanks of 50 litres per person, the yield of recycled water is 39 m^3/year = 10 m^3/person•year for the free-standing house, meanwhile the same storage capacity will yield 709 m^3/year = 12.7 m^3/person•year for the apartment building. A detailed description of the analysis is reported by Agudelo-Vera et al. (2013).

5.4 Discussion

A proper choice of the storage capacities results in optimization of local harvest of resources and in minimization of the overflows. Overflows minimization will reduce the wastewater production. Selecting the optimal storage capacity involves trade-offs, because it depends on space availability and cost. Moreover, if the storage capacity is small, it will be most of the time full being volumetric effective, but if you have a minimized demand, a lot of rain or greywater will be wasted as overflow going to the sewer because the production/supply is much larger than the demand.

Overall, our results show that there are two main determinants for the design of grey water and rainwater systems:

1. The availability of local resources. Constraints to meet non-potable demand are determined by inequality between grey water production patterns and demand patterns, and to limited availability of rain water related to local context (i.e. climate, season, roof areas).
2. Practical limitations in harvesting the available resources. In this case, the harvest of available resources is constrained by the availability of space to meet the required storage capacity and water treatment capacity.

5.5 Conclusion

Understanding water demands (and temporal water demand patterns) of different buildings, related to different occupancies and building characteristics is essential information to design and optimise on-site recycling and multi-sourcing measures. Variations in daily production and demand patterns showed large effects on the efficiency of the resources harvested. Notice that similar on-site systems configuration will perform different according to occupancy. The extent to which resources can be harvested depends also on storage and treatment capacities.
SIMDEUM helps understanding the process dynamics relevant for water resources management in the built environment. We have studied the urban water balance at building level and evaluated implementation of various measures: demand minimisation, recycling of light grey water and harvesting of rainwater to supply non-potable demand. SIMDEUM also allows simulation of blocks or neighbourhoods. Simulating residential patterns using SIMDEUM can be used by urban (water) managers and decision makers to better understand the urban water system. Better understanding of urban flows will allow the design of customized solutions for existing and new buildings, because an optimal scale of management of certain flows can be identified. In the future, this type of information can support the implementation of real time control measures to shave peak demands and to achieve smart water grids.

Acknowledgments

The research has been funded by the Dutch drinking water companies and the Dutch installation sector for sanitation. Part of the research was funded by the European Commission through the 6th Framework Programme – SWITCH Project.

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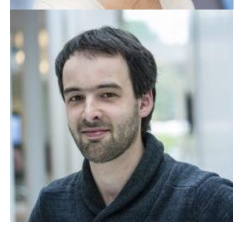
7 Presentation of Authors

Dr. E.J.M. Blokker: Mirjam Blokker is principal scientist at KWR in the area of drinking water distribution. Her speciality field drinking water demand and applying that in drinking water installations and drinking water networks.

Dr. Claudia Agudelo-Vera is a scientific researcher at KWR in the area of drinking water distribution. Her expertise is modelling the distribution network and analysing the impact of urban properties, as well as the interactions and transitions of socio-technical systems.

Andreas Moerman M.Sc. is a scientific researcher at KWR in the area of drinking water distribution. His expertise is modelling and analysis in the area of drinking water distribution and the energy-water nexus.



A1 - Bridging the gap between model estimates and field measurements of probable maximum simultaneous demand – a Bayesian approach

L.T. Wong (1), K.W. Mui (2)

1. beltw@polyu.edu.hk
2. behorace@polyu.edu.hk

(1), (2) Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

Abstract

This paper proposes a Bayesian approach to bridge the gaps between model estimates and field measurements of probable maximum simultaneous water demand using loading units. Based on best available data in the open literature, it presents an application example with a chosen sample size not large enough for superseding the model estimates. Theoretically, the proposed approach is flexible to adopt estimates as its prior values from a wide range of existing water demand models with relevant measurement data. Further investigations on the applicability of this Bayesian approach for determining the design flow rates in water systems are thus recommended.

Keywords

Probable maximum simultaneous demand; demand models; measurements; Bayesian estimates.

1 Introduction

Accurate instantaneous flow rate estimation is essential to the design of water supply systems in buildings [1]. However, many water supply systems are still routinely and substantially over-sized as the prospect of system failure is commercially and professionally unthinkable [2]. Regarding the choice of the most appropriate design flow rate for future sustainable development in buildings, there is no conclusive data to favor either model or measurement outcome. To update our current beliefs about design flow rate, this study presents a Bayesian approach and demonstrates its usefulness through the use of contemporary field survey data and the Hunter's fixture unit approach. The findings provide a solution to the choice of design flow rates in future water systems.

2 A Bayesian approach

Bayes' theorem, which relates the conditional and marginal probabilities of stochastic events A and B (where B has a non-vanishing probability), asserts that the probability of an event A given an event B depends not only on the relation between events A and B but also on the marginal probability of occurrence of each event. This theorem can be applied to a sample size not large enough for decision-making purposes, yet relevant enough for statistical analysis. Its general formulation and various applications are available in the open literature [3]. This study employs a Bayesian approach to predict the probable maximum simultaneous demand for the total fixtures installed, using the readily available model predictions (event A) and the measurements from a compatible installation (event B).

The posterior estimate of a fractional design flow rate $q^*_{d,1} \sim \mathrm{N}(\theta_1,\phi_1)$, given the measured value, is expressed by the following Bayesian rules [4], where p is the probability, and θ and ϕ are the mean and variance of a normal distribution function N respectively,

$$p\left(q^*_{d,0} \mid q^*_x\right) = p\left(q^*_{d,0}\right) p\left(q^*_x \mid q^*_{d,0}\right) \quad \ldots (1)$$

$$\phi_1 = \left(\phi_0^{-1} + \phi^{-1}\right)^{-1};\ \theta_1 = \phi_1\left(\frac{\theta_0}{\phi_0} + \frac{q^*_x}{\phi}\right) \quad \ldots (2)$$

where, the fractional design flow rate q^*_d is defined as the ratio of the probable maximum simultaneous discharged flow rate of all connected appliances q_d divided by the possible maximum flow rate $q_{\max}$ due to all appliances discharging simultaneously,

$$q^*_d = q_d / q_{\max} \quad \ldots (3)$$

The prior fractional design flow rate $q^*_{d,0}$ and the measured (observed) fractional probable maximum flow rate q^*_x are both assumed normally distributed,

$$q^*_{d,0} \sim \mathrm{N}(\theta_0, \phi_0);\ q^*_x \sim \mathrm{N}(\theta, \phi) \quad \ldots (4)$$

3 Parameter β (n_∞, α, ε)

In Equation (1), where the weights are proportional to their respective variances, the posterior mean is a weighted average of the prior mean and the measured value given. This posterior mean can be characterised by the ratio of standard deviations and expressed as a parameter β,

$$\beta = \sqrt{\frac{\phi}{\phi_0}} \quad \text{… (5)}$$

Combining Equations (1) and (5) and taking θ_0 as the best estimate of $q^*_{d,0}$ and unity ϕ_0, the posterior estimate $q^*_{d,1}$ is given by,

$$q^*_{d,1} \sim \theta_1 = \left(q^*_{d,0} + q^*_x \beta^{-2}\right)\left(1+\beta^{-2}\right)^{-1} \quad \text{… (6)}$$

The parameter β can be determined by the target sample size n_∞, the acceptable error of the final estimate ε_∞, and the ratio of the measured value to the prior estimate α [5],

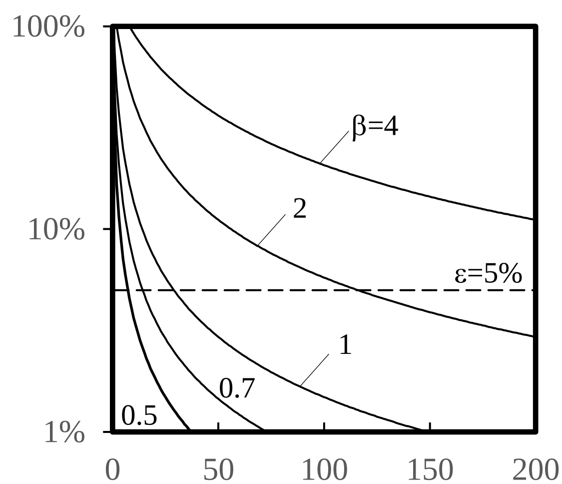
$$\beta = \beta\left(n_\infty, \varepsilon_\infty, \alpha\right) \quad \text{… (7)}$$

The target sample size n_∞, for the repeated measures of flow rate (q^*_x), is a finite value deemed large enough to adopt the measured flow rate for design calculations.

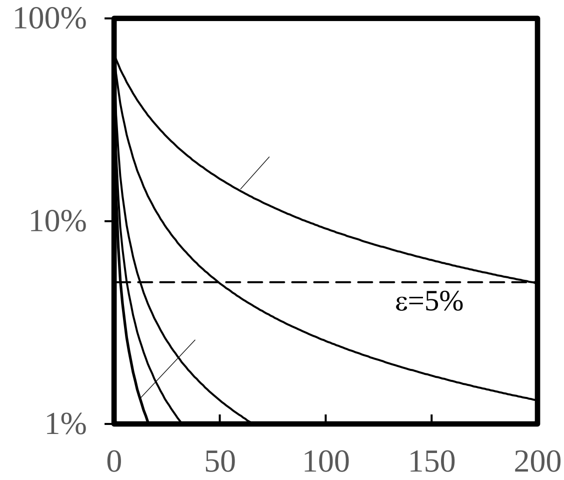
$$\varepsilon = \varepsilon(n) = \frac{q^*_{d,1} - q^*_x}{q^*_x};\ \varepsilon_\infty = \varepsilon(n = n_\infty) \quad \text{… (8)}$$

$$\alpha = \frac{q^*_x}{q^*_d} \quad \text{… (9)}$$

Figure 1 illustrates the examples of β (ranged between 0.5 and 4) for a sample size n, with errors ε and α=0.4 and 0.6.



(a) α=0.4



(b) α=0.6

x-axis: Sample size *n*; y-axis: Error ε (%)
Figure 1 - A posteriori error estimates

4 An application example

To illustrate the practicality of the proposed approach, design flow rates corresponding to loading units *U* in a multi-story apartment building as reported by Murakawa [6], together with the α values calculated using Equation (9), are presented in Table 1. As no significant association between α and *U* was found (p=0.25, *t*-test for correlation), a constant α over the *U* range shown can be proposed. Assuming all 19 data values (i.e. n=19) are independent and compatible to the probable maximum simultaneous flow rate given by the Hunter's method, the posterior estimate $q^*_{d,1}$ for the design flow rate $q^*_{d,0}$ obtained through the Hunter's fixture unit approach can be determined by Equation (10), where α_n is the coefficient for the Hunter's estimate, and given that q_{max} applies to both $q^*_{d,0}$ and $q^*_{d,1}$ in Equation (8).

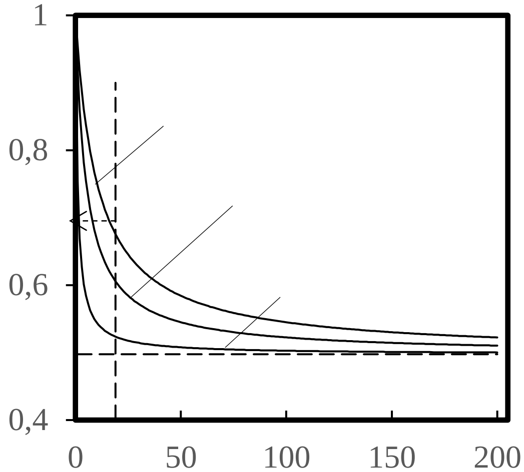
$$q_{d,1}(U) = \alpha_n q_{d,0}(U) \quad \dots (10)$$

Table 1 Design flow rates of loading units [6]

No.	Loading unit *U*	Hunter's estimated design flow rate q_d	Measured probable maximum flow rate q_x	α
1	90	2.9	1.2	0.4138
2	250	5.7	2.2	0.3772
3	500	8.5	4.2	0.4976
4	950	14.0	6.2	0.4450
5	1000	15.0	6.5	0.4333
6	1250	17.0	6.1	0.3588
7	2030	23.4	8.1	0.3462
8	2050	23.6	8.9	0.3771
9	2300	27.0	9.5	0.3519
10	2300	27.0	9.5	0.3519
11	2741	29.0	8.0	0.2759
12	3307	31.5	10.6	0.3365
13	3734	34.3	10.0	0.2915
14	4803	40.0	15.4	0.3850
15	5745	45.6	18.0	0.3947
16	6256	46.6	15.4	0.3305
17	6598	50.0	20.0	0.4000
18	7693	54.0	18.6	0.3630
19	10000	65.0	24.0	0.3692

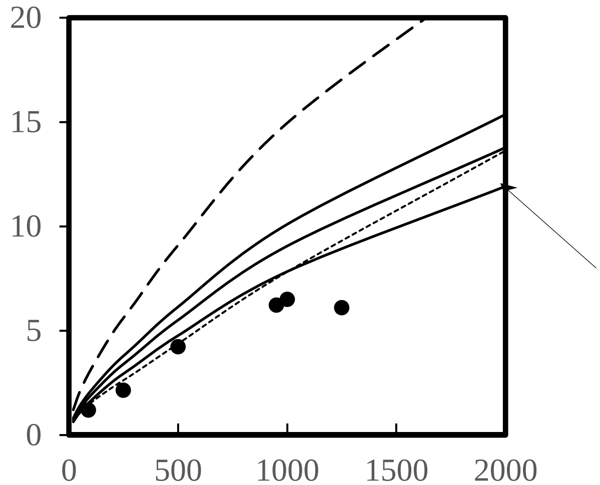
Figure 2 exhibits the calculated coefficients for n=19 and α=0.4976 (i.e. the maximum α value in Table 1). When n_∞=20, 100 and 200 with an acceptable error ε=0.05, the ratios of standard deviations are β=1.02, 2.283 and 3.228, while the corresponding coefficients are α_{19}=0.5237, 0.6058 and 0.6755, respectively.

The posterior design flow rate estimates for n_∞=20, 100 and 200 are graphed in Figure 3. Hunter's estimates, measurement data and estimates from Murakawa [6] are shown for comparison. The posterior estimates are very close to the estimates made by Murakawa [6]. In the case where the sample size n is close to the target sample size n_∞, the posterior estimates show a trend of approaching the maximum measured loading unit. For larger target sample sizes, the posterior estimates are closer to the prior estimates.



x-axis: Sample size *n*; y-axis: α

Figure 2 - Coefficients for Hunter's estimates



x-axis: Loading unit; y-axis: Design flow rate q_d (Ls^{-1})

Figure 3 - Design flow rates

5 Conclusion

This paper proposes a Bayesian approach to bridge the gaps between model estimates and field measurements of probable maximum simultaneous water demand using loading units. Based on best available data in the open literature, it presents an application example with a chosen sample size not large enough for superseding the model estimates. Theoretically, the proposed approach is flexible to adopt estimates as its prior values from a wide range of existing water demand models with relevant measurement data. Further investigations on the applicability of this Bayesian approach for determining the design flow rates in water systems are thus recommended.

Acknowledgment

The work described in this paper was partially supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region (HKSAR), China, (PolyU 5272/13E) and by four other grants from The Hong Kong Polytechnic University (GYBA6, GYL29, GYM64, GYBA7, GYBFN).

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7 Presentation of Authors

Dr. L.T. Wong is an associate professor at the Department of Building Services Engineering, The Hong Kong Polytechnic University.

Dr. K.W. Mui is an associate professor at the Department of Building Services Engineering, The Hong Kong Polytechnic University.

A2 - Minimising the hygiene risks associated with biofilms in hospitals

Eoin McQuone
eoin.mcquone@kohlereurope.com
Business Director – Rada, Kohler Mira Ltd., UK

Abstract

This paper examines the role that biofilm contamination of hospital water systems may play in Health Care Associated Infections (HCAIs), and discusses the impact that the design of water systems and of plumbing system components may have on reducing the risks from infections. A review was undertaken of published materials with the aim of gaining an understanding of biofilm formation and its role in supporting and protecting potentially harmful pathogens. While acknowledging that it would be extremely difficult to eradicate biofilms from hospital water systems, a broad set of principles is presented that, if followed, may help reduce the incidence of biofilm formation within the components of the water system. Using these principles, an idealised control valve for use in hand wash and showering is described.

Keywords
Biofilm; HCAI; Legionella; Pseudomonas, Hygiene.

1 Introduction

Of the over 6 million cases of Health Care Associated Infection (HCAIs) that occur in USA and Europe each year, around 136,000* will result in the death of the patient. A considerable proportion of these cases are the result of contamination of the water flowing from the hand wash and shower facilities provided by the hospital.

**Center for Disease Control 2013*

Contamination occurs in both older water systems and those that have been recently installed. Once an organism such as Legionella pneumophila has entered the water system (which in large hospitals may consist of miles of complicated pipework) it can become very resistant to conventional disinfection techniques.

The disinfection techniques used mainly target freely swimming, individual bacteria. However, it is now understood that most microorganisms that exist in water systems live in colonies of organisms known as biofilms. Biofilms provide both protection and nutrition for microorganisms, both of which make many of these techniques much less effective.

This paper aims to provide answers to the following questions:

1. Is it possible to develop a set of general principles that, when applied to water system design, can reduce the incidence of biofilms and thus make sterilisation measures more effective?

2. Can modern plumbing equipment sometimes contribute to the problem?

3. How can that equipment be re-designed to ensure that it is inherently resistant to biofilm formation?

To provide answers, a review was undertaken of published materials including scientific papers, codes of practices and guidelines from recognised bodies and investigation reports of instances in which biofilm formation has resulted in water contamination leading to illness or injury. The following is a summary of what we found.

2 Biofilms **

The role of bacteria as disease causing agents has been understood since the 1860s, and since then much research has been conducted trying to understand their nature and to develop ways of controlling them. However, until very recently, most of this research has been conducted on bacteria either in their planktonic state – floating freely in water – or growing as a pure culture in a solid nutrient medium.

Planktonic bacteria are very rare and pure cultures like those found in a laboratory almost never exist in nature. Most bacteria (99% or more) live in biofilms - complex polymeric structures composed of material excreted by the bacteria themselves.

Biofilms provide both protection and nutrition for microorganisms, which makes many disinfection techniques much less effective.

2.1 What are Biofilms?

Biofilms form when bacteria adhere to a surface and, within minutes, begin to excrete a sticky gel (Extracellular Polymeric Substances (EPS)) which forms the structure of the biofilm. This forms a protective medium for the bacteria to reproduce, and attracts other free-floating organisms. These become part of a colony which may eventually grow to contain hundreds of different species of bacteria living together almost as if they were a multicellular organism. Once established, the biofilm becomes a source of infection for the rest of the system (Figure 1).

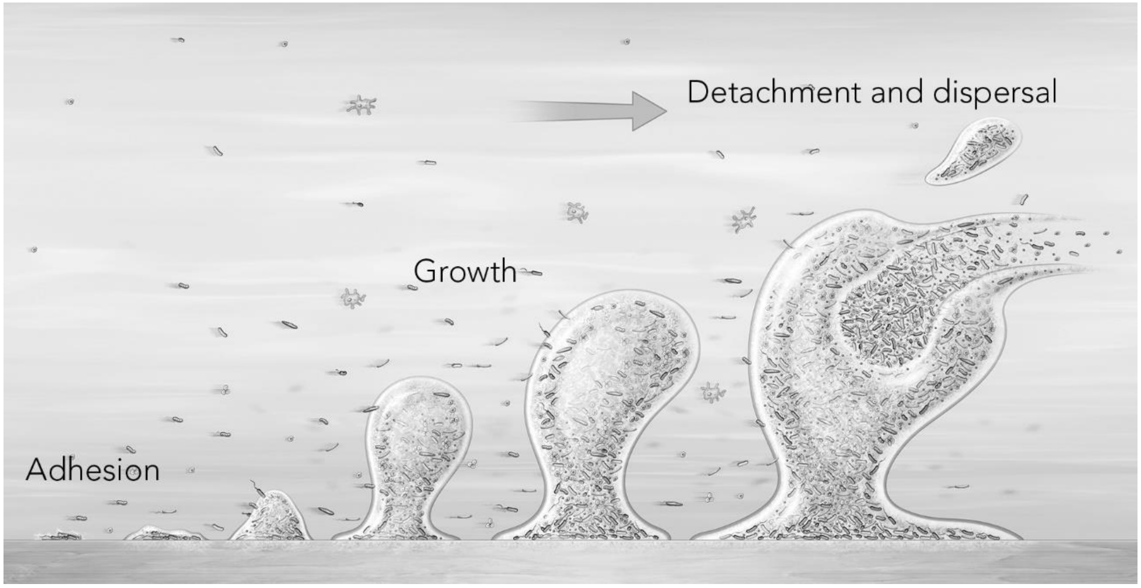

Figure 1. Lifecycle of a biofilm from initial adhesion to detachment and dispersal

2.2 How do biofilms provide protection to microorganisms?

There are several different mechanisms that allow the biofilm to provide protection. These begin with basic mechanical protection. The EPS provides insulation from heat and resists the penetration of chemicals. This means that both heat and chemical based disinfection measures must be applied for much longer than the research into planktonic bacteria would suggest.

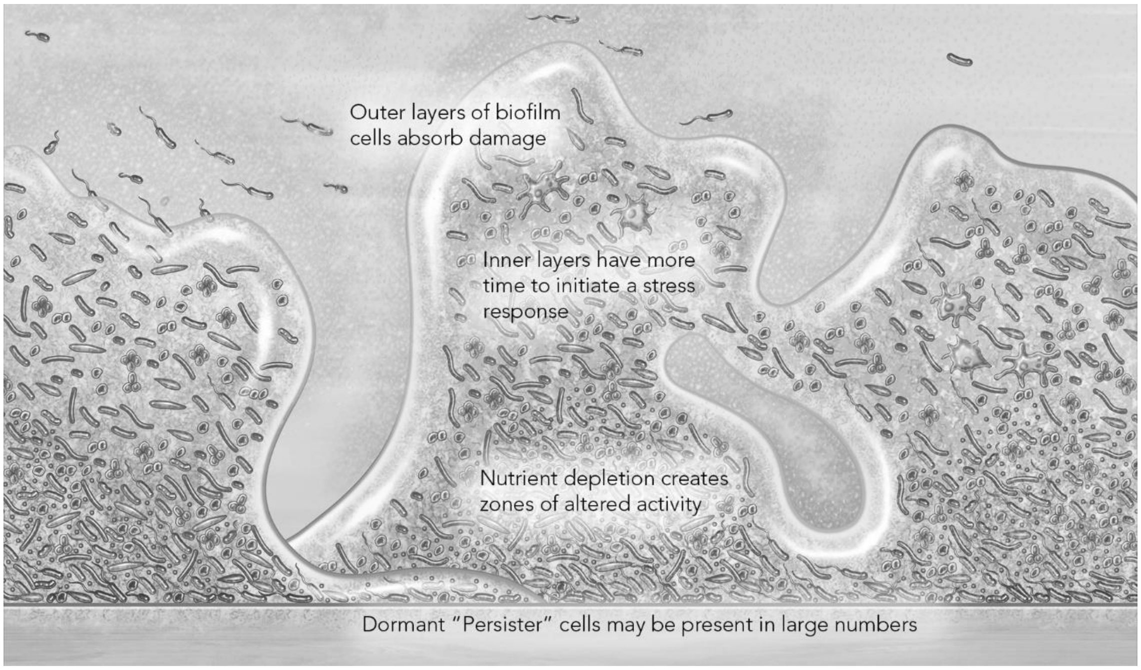

Figure 2. The multidimensional structure of biofilms provides a variety of protective mechanisms.

It is thought that there is also a much subtler mechanism in play. As the biofilm grows, it develops a complex three-dimensional structure (fig 2) which allows nutrients and oxygen to diffuse through some parts, but resists diffusion in other parts. The result of this is that each species may exist in the biofilm in a variety of states, ranging from rapidly growing to dormant. Dormant (or Persister) bacteria are much more resistant to antimicrobial measures and this greatly increases the chance that there will be survivors from any attempt at disinfection.

3 Water system design for biofilm resistance

Biofilms are both ubiquitous and persistent, and can flourish in very extreme environments. It is extremely unlikely that we could eradicate them completely from a large water system.

However, there are techniques that have been demonstrated to minimise the growth of biofilms. The approach focuses on three general aims:

1. Prevent bacteria from adhering to surfaces.

2. Minimise the availability of nutrients.

3. Maintain temperature ranges outside those that promote bacterial growth.

Controlling biofilms requires the use of a combination of design techniques. These include:

- The design and physical layout of pipework.

- Careful choice of materials that are in contact with the water.
- Reviewing the systems and operating procedures used to manage the system.
- Changing the internal design of taps, shower controllers and valves.

3.1 Pipework layout

Most hot water systems in large buildings consist of a centralised water heater connected to a circulating system of pipework. Hot water is pumped around the system to ensure that it is available to any of the outlets without an appreciable delay. The design and configuration of the pipework system can have a considerable influence on biofilm control.

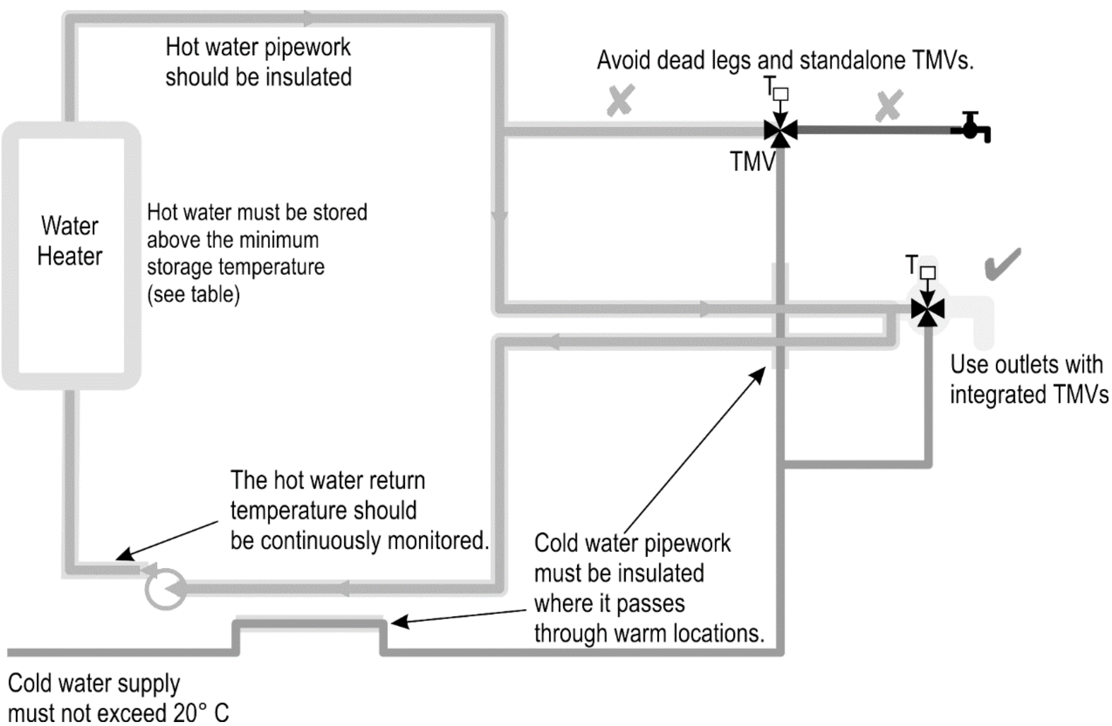

Figure 3. Pipework layout features that can help resist biofilm growth

3.2 General approach to system design

In general, the pipework system must comply with the following:

- Arrange the pipework to minimise stagnation, eliminate airlocks, avoid turbulence and maximise the rate of flow throughout the system.

- Hot water pipework should be insulated to minimise heat loss and maximise the circulating water temperature (National guidelines regarding this differ, e.g. in the Netherlands there should be at least 1m of uninsulated pipe from the circulation loop to the outlet).

- The return temperature of the hot water should be monitored and, if it falls below the required value, the temperature should be adjusted accordingly.

- Cold water pipework should be run through the building in a way that avoids sources of heat (such as hot water pipes) and, if these are unavoidable, the pipes must be insulated at these locations.

- The system should be designed in a way that allows a routine regime of both hot and cold flushing to be carried out. If possible, valves that can provide automatic flushing regimes should be used.

3.3 Circulating water temperature

To prevent the build-up of HROs, the water circulating through the pipework must be maintained at high temperature. The recommended minimum temperature varies by jurisdiction, but is generally above 50°C and can be 60°C or more (see table 1).

Table 1. International guidelines for hot water temperatures

Guideline	Country	Min. Storage temp	Min. Temp at outlets	Min. Return temp
L8	UK	60°C	50ºC within 1 minute	N/A
ASHRAE Guideline 12	USA	60°C	N/A	51°C
ISSO 55.1	Netherlands	60°C	60°C	60°C
W551	Germany	Not specified	55°C	55°C
WHO	International	60°C	50ºC within 1 minute	50°C

3.4 Thermostatic Mixing Valves

Water at these temperatures presents a risk of scalding to the users, even after exposure of only a few seconds. Thermostatic Mixing Valves (TMVs) blend hot water with cold to deliver an outlet temperature which is in the safe range for users (typically between 38-41°C). For biofilm resistance, the TMV must be integral to the tap.

3.5 Dead legs and dead ends

Dead legs (Long sections of pipe outside of the circulating system) must be avoided. During normal use they may never reach the temperature required for disinfection, and an occasional injection of hot water may help them to maintain a temperature in the range (32°C to 41°C) where bacteria such as Legionella pneumophila can multiply. Dead ends (sections of pipe through which there is no water flow), must be removed.

3.6 Check valves

Check valves located in the pipework close to any outlet device that mixes hot and cold water are essential to prevent the back-flow of potentially contaminated water to the main water system (figure 5). However, many currently available designs have complicated internal surfaces and contain polymers which in combination provide an ideal environment for a biofilm to form.

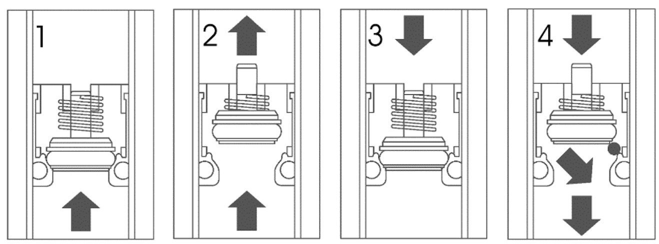

Figure 4. Check valve operation

1. Outlet closed: the check valve is closed and no flow occurs.

2. Outlet opened: water can flow through into the mixing device.

3. Higher pressure on the outlet: the check valve prevents water flowing in the wrong direction.

4. Biofilms can build up and combine with debris to the extent that they cause the valve to malfunction and allow water to backflow in to the system.

Check valves fail in this way without any visible indication. It is not possible to detect a faulty check valve from external inspection. As a result, check valves need to be regularly checked and cleaned. This is a difficult, costly and time-consuming procedure.

3.7 Polymers and elastomers

Many modern, electronically controlled thermostatic taps make extensive use of polymers and elastomers in their construction. These can support biofilm growth, [ii, iii] particularly in areas where there is a slow or stagnant flow.

This may be due to the manufacturing methods rather than some inherent property of the material. For instance, the elastomer EPDM (Ethylene Propylene Diene Monomer) has been associated with contamination of water when used to provide extruded rubber flexible hoses. Investigation has indicated that this is a problem with the way that EPDM was manufactured and used, not with the material itself. [viii] Different grades of materials such as EPDM are available that differ in their ability to resist microbial growth. [ii, iv]

Relatively few national standards require a test for resistance to microbial growth and the ones that do (see table 2) use very different methods that may yield different results for the same material. Prudence suggests selecting materials that meet all 3 of the published standards.

Table 2. National water quality standards that include a test for resistance to microbial growth

Standard	Country	method
BS6920	UK	MDOD
NVN1225	Netherlands	BPP
W270	Germany	SP

3.8 Anti-microbial metals

Some metals, such as copper and copper/zinc alloys such as brass, have anti-microbial properties. In pipework, these properties diminish over time due to a gradual build-up of biofilms, limescale and corrosion, but studies have shown that the presence of copper can have a significant impact on hygienically relevant bacteria such as Pseudomonas aeruginosa. [ii, iv]

4 Water system management

The systems and operating procedures used to manage the water system have an important role to play in biofilm control. The most significant part of this is the establishment of a regular and effective flushing regime.

4.1 Biofilm control with flushing regimes

Regular flushing of both hot and cold parts of the water system is one of the most effective ways to minimise both biofilms and harmful organisms. [i] Flushing helps to eject organisms from the system, but also helps the system to reach temperatures that can inhibit or destroy biofilm and bacterial growth. It can also help ensure that chemical disinfectants reach all parts of the water system when used.

4.2 Cold flushing

Cold flushing is important for water systems with long pipe runs that exist in warm areas, or are exposed to heat sources. Regular cold flushing can help maintain the temperature of cold water pipes below 20°C – needed to prevent Legionella from growing.

4.3 Thermal disinfection using hot flushing

Water temperatures above 60°C are required for effective disinfection of Legionella and temperatures above 70°C can effectively disinfect Psuedomonas aeruginosa. [v, vii] If biofilms are present sufficient time must be allowed for the heat to penetrate them. In some jurisdictions, the higher the temperature the less time is required to complete the disinfection.

Table 3. National regulations for thermal disinfection

Territory	MIN. temp (ºC)	MIN. time (Minutes)	Time reduction
UK	60	5	No
Netherlands	60	20	65ºC = 10mins 70ºC = 5mins >70ºC = 5mins
Belgium	60	2	65ºC = 1min 70ºC = 30secs >70ºC = 30secs
USA	70	30	No
Germany	60	20	65ºC = 10mins 70ºC = 5mins >70ºC = 5mins
Scandinavia	No standard - calculated for each site		

Thermal disinfection uses large amounts of water and energy and presents safety hazards which means the process must be manually activated and supervised at each outlet. It can be time consuming and expensive to carry out and this means that it is often only used as a measure of last resort or as a remedial measure.

4.4 The duty flush

A duty flush is a simultaneous hot and cold water flush where the combined temperature at the outlet is within safe limits. Regular flushing prevents water stagnating within the valve. It will only disinfect the hot water system up to the point where it blends with the cold water system, and is most effective where the TMV is integrated in to the tap body.

Table 4. National guidelines for duty flush

GUIDELINE	COUNTRY	TEMPERATURE	FREQUENCY	DURATION
L8	UK	Blend	Weekly	Several minutes
ISSO 55.1	Netherlands	Flush until temperature is stable	Daily or Weekly depending on risk	10 seconds at stable temperature
W551	Germany	Blend	At least 72 hours after last use	Not specified

4.5 Maintenance, monitoring and record keeping

To be effective it is essential that flushing is carried out regularly. Missing routine flushes can result in an increase in bacteria levels at the outlet when flushing is resumed. [i]

A verifiable record keeping system must be maintained. If the water delivered does not reach the required temperature for the required time this must be flagged so that the process can be repeated.

5 Outlet valve design principles

The pipework for a biofilm resistant system can be constructed from existing and readily available materials. However, several studies into the way that biofilms form and grow have suggested that the design of existing water outlet devices (taps, showers and thermostatic valves) may create opportunities for biofilm growth. [v, vi]

A re-design, focussed on minimising the opportunities for biofilm growth, could be a significant step towards reducing the number of HCAIs that occur annually. There are many aspects to outlet design, but the core component is the water mixing valve which controls the flow and temperature of the water. This is often the source of contamination and is where the design effort should be focussed.

There are four basic techniques that can be employed:

1. Reduce the wetted surface area and the internal water volume. This puts limits on both the number of potential bacteria and the opportunities for them to adhere to a surface.

2. Keep flow velocities high. Bacteria need to be in good contact with a surface as they adhere. High water velocities help deny the opportunity for this to take place and prevent the formation of long/loose biofilms that can then easily slough off in large chunks.

3. Eliminate stagnant areas within the waterway. The internal volume of the outlet must be flushed completely on every use.

4. Use materials that reduce the risk of biofilm development within the valve.

The following example is a mixing valve that combines all the features needed to resist the formation of biofilms and thus minimise water borne pathogens.

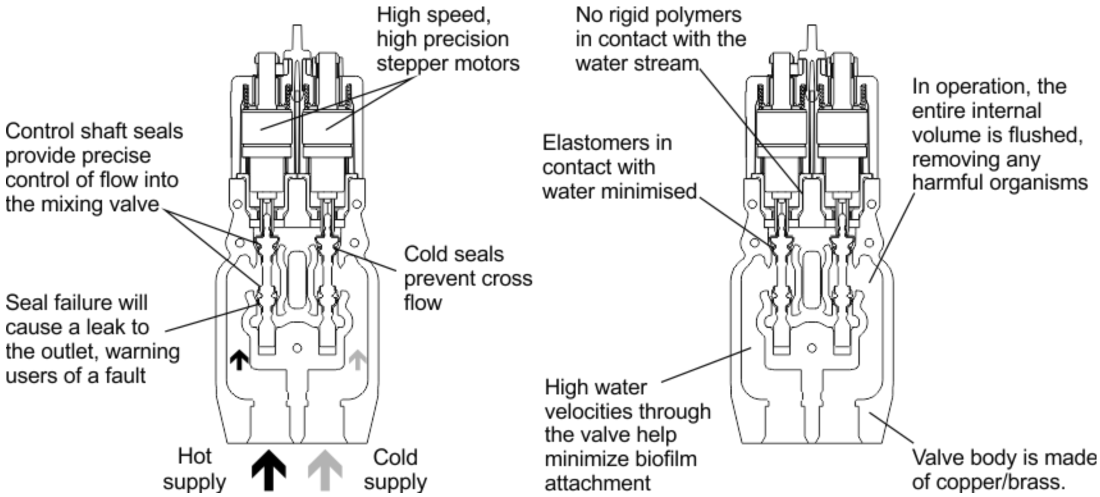

Figure 5. Digital valve operation

5.1 Precision temperature control

A pair of control shafts independently control the flow of hot and cold water through the valve. They are driven by high speed, high precision stepper motors. A temperature sensor monitors variations in the output temperature. These are fed back to a microprocessor that governs the control shaft motors. This system ensures that there is very little deviation in the output temperature of the valve, despite large variations in the supply pressures and temperatures

5.2 Precision Flow Control

The mechanism allows control over water usage allowing, for instance, a low flow rate to be set during normal use, for water saving, and a high flow rate to be used during flushing for pathogen control. This enables control over the flow rate without needing to use complex outlet inserts, which can harbour microbial contamination. [v]

5.3 No need for check valves

The valve's ability to independently shut off both hot and cold supplies provides two significant advantages over a conventional design:

- A single seal failure will not result in cross flow (Both seals on the hot and the cold inlet must fail for cross flow to occur).
- If either seal does fail there will be a permanent leak through the outlet of the valve, providing an immediate visual indication of a maintenance problem.

Because of this there is no longer a need to fit additional check valves to the incoming pipework, and no further need for regular maintenance of them.

5.4 Automatic water management functions

The use of a digital control valve allows fully automatic flushing with verified record keeping and fault monitoring. The thermostatic function can be temporarily overridden to enable thermal disinfection of the valve and outlet to take place when required.

6 Conclusion: some general principles for water system design

1. The pipework must be installed in a way that minimises the growth of biofilms, both in the choice of materials and in the layout of pipe runs.

2. The layout and equipment must facilitate regular flushing of both hot and cold water systems.

3. As far as possible, the pipework and valves must be constructed from biofilm resistant materials. Metals should be used for water contact parts wherever possible, and any polymers used should comply with the toughest national water quality standards that include a test for the ability to support microbial growth.

4. Control measures, such as duty flushing, as required by national guidelines (or identified through risk assessment) should be consistently applied and monitored.

5. Internal channels of valves must be designed to minimise stagnation and maximise flow velocities. They should present the minimum possible wetted surface area and have the minimum internal water volume.

7 Acknowledgments

The Center for Biofilm Engineering MSU-Bozeman and Public Health England were invaluable in helping us to understand the risk factors around biofilm formation and in validating our conclusions.

8 References and further reading

** For an introduction and general reading on the topic of biofilms, we recommend *Biofilm Basics* from the Center for Biofilm Engineering, Montana State University. (http://www.biofilm.montana.edu/biofilm-basics/index.html)

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Presentation of author

Eoin McQuone, Commercial Business director at Rada, has been in the washroom product and water control industry for over 15 years in a variety of roles. He is involved in a wide range of water control industry forums and organisations, and is passionate about promoting user safety in healthcare, and the sustainability of washroom products. He is currently general manager of Rada and oversees the design, development, testing, and manufacture. of the Rada range of water flow controls and washroom products.

A3 - A corrosion study of the effects of Copper and Silver Ionisation on galvanised pipes.

Conrad Chapman(1), Wiebe Pool(2) and Nikolaj Walraven(3)

1. conradchapman@hollandwater.com
2. wiebepool@hollandwater.com
3. n.walraven@geoconnect.nl

(1) Technical manager, Holland Water BV, Driebergen, Netherlands
(2) R&D manager, Holland Water BV, Driebergen, Netherlands
(3) Director, GeoConnect, Castricum, Netherlands

Abstract

Introduction and aim: Copper and Silver Ionisation (CSI) is a common *Legionella* prevention technique. The copper (Cu) and silver (Ag) ions are added directly to the water supply using electrochemical ionisation of (in this case) pure rods of Cu and Ag. One such system has been installed in a hospital in Belgium with a water consumption of ca. 30,000 m^3/year. Scientific literature exists that mentions an increase in corrosion rates of galvanised steel pipes, due to Cu and Ag dosing. The purpose of this study is to re-investigate the problem by applying modern ionisation technology in-situ with tightly controlled experimental conditions.
Method: Two standard corrosion racks were installed in a bypass of the mains supply. One rack before and one rack after the CSI unit and standard coupons were placed for a total of 127 days. The corrosion racks each had an ultrasonic flow meter and temperature sensor, and steps have been taken to equalise or remove all other types of corrosion. Corrosion rates were based upon weight loss but x-ray surface analysis was also performed.
Results and conclusions: On the 'before' coupons red iron oxide rust spots were observed on about 80% of the coupon surface. After removing all oxides using a glass bead blast procedure, the uniform corrosion rate was 0.11 mm/year. The 'after' coupons had exactly the same corrosion rate but were visually very different. The outer layer was much more uniform with significantly less rust spots. Ag had covered about 20% of the surface which is expected due to the replacement of the Zn ions with the nobler Ag ions. So, CSI using separate electrodes with dedicated current controllers such as the Bifipro do not affect the natural corrosion rate and furthermore it is expected that over time the build-up of Ag will act as a passivation layer, further reducing the corrosion rates.

Keywords
Corrosion, Copper, Silver, Zinc, Ionisation, Galvanised and Legionella

Introduction

Legionella bacteria, usually L. pneumophila serogroup 1, can cause Legionnaires' disease. This disease was first described in the 1970s [1]. In the period of 10 years, between 1995 and 2005, around 32,000 cases of Legionnaires' disease and around 600 outbreaks were reported to the European Working Group for Legionella Infections [2]. The 35 Countries participating in EWGLI reported in the period of 1 year, 2005 to 2006, a total of 11,980 cases, therefore, showing a continued increase in reported cases compared with earlier years [2]. 377 cases of these 11980 reported cases were fatal, giving a case fatality rate of 6.6% [2]. Legionella contamination can, amongst others, occur in distribution systems of drinking water, cooling water (e.g., in cooling towers), fountains and swimming pools. In particular, aerosolised water droplets from such contaminated water systems pose significant health risks to people [3]. Because Legionella can cause devastating disease in humans, it is important to prevent water systems from becoming contaminated and to control the risk of exposure [1].

A well-recognized method to control Legionella is copper-silver ionisation [4+5]. The method is based on channelling the water through a device that applies a DC current through copper and silver electrodes thus creating charged ions which act as a can kill Legionella bacteria. [1]. Based on a study by Loret *et al* 2005 [6], the Belgium authorities introduced a general warning about the increased corrosion effects on galvanised pipes due to Cu and Ag ionisation. The purpose of this study is to re-investigate the stated corrosion problem by applying modern ionisation technology in to a real environment but in tightly controlled experimental conditions. Copper and silver ionisation technology has moved on enormously since 2005 and the amount of control on dosing levels has increased significantly. The accuracy of dosing is at its greatest when using separate Cu and Ag electrodes and is even greater enhanced when using the Bifipro and its patented technology [7].

In the initial study, Loret *et al* used a series of circulation loops to test different disinfection techniques and also investigated the corrosion risk of each technique. They included dead ends and reported that there was no increased corrosion for the Cu/Ag loop, so for this study dead ends were not simulated. The corrosion analysis was not done using certified techniques so they only offered general observations, rather than corrosion rates.

There are many different types of corrosion, all of which are destructive to the Zn layer and ultimately the steel underneath. The only goal of this test is to investigate the influence of the copper and silver ions on the zinc coating. Steps have been taken to equalise or remove all other types of corrosion, especially galvanic and mechanical corrosion. Galvanic corrosion was removed by having the coupons un-attached to another metal and "floating" from the electrical ground. Mechanical corrosion was equalised by making sure the flow across the coupons was the same for both sets. Biochemical corrosion is assumed to be negligible because of the newly installed corrosion coupons. However, the copper and silver ions will prevent the formation of new biofilm and after prolonged periods of time, biochemical corrosion could have an impact on the before set of coupons.

Experimental setup

Two standard corrosion racks were installed in a bypass of the mains after the building's softener. One rack before and one rack after the Bifipro (CSI unit). The corrosion racks are delivered by BWT and supplied with hot-dipped galvanized steel coupons from Metalogic (Belgium company specialising in corrosion and material consultancy) conforming to UNS G10100 and ASTM D7091 standards. The corrosion racks were also fitted with an ultrasonic flow meter and temperature sensor coupled to a data logger to set and record the flow rate. Holland Water BV placed and retrieved the coupons which is considered normal in a study like this and was done using instructions from Metalogic to preserve the sample. All SEM/EDX measurements, corrosion analysis and conclusions were made by Metalogic.**Fout! Verwijzingsbron niet gevonden.** shows the construction of a corrosion rack and Table 2 shows the parts used. The ultrasonic flow meter has a maximum flow of 100 l/min. XRF analysis was performed on the coupons using a Therma Scientific Niton XL3t nergy dispersive analyser equipped with a silicon drift detector.

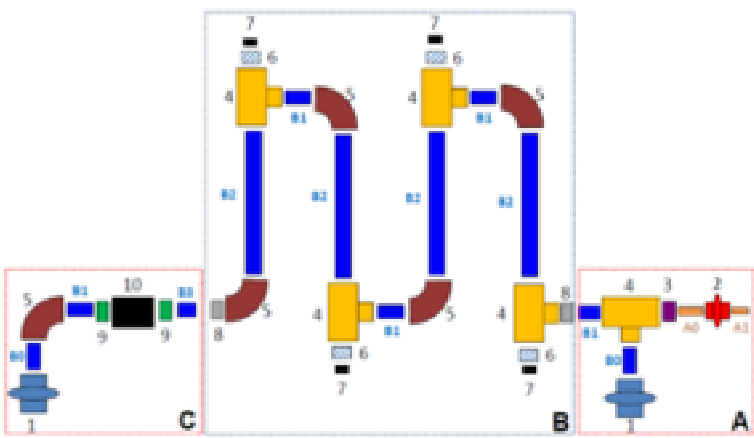

Figure 6- Setup and parts of the applied corrosion rack. Number 7 are the location of the coupons.

Table 2- Parts of the applied corrosion rack.

Code	Description	Quantity
1	Tap COLORO-355-PN16-DN25	2
2	Tap COLORO-355-PN16-DN15	1
3	Reducer, short 32/20	1
4	T-piece 90^0 DN25	5
5	Elbow joint 90^0 DN25	5
6	Adapter M/F DN25/20 1”*3/4”	4
7	Plug, male DN20-3/4”	4
8	Simple joint D32-DN15 F/F	2
9	Reducer, short 40/32	2
10	IFM, SU7 ultrasonic flowmeter	1
A	PVC D20 – DN15 pipe	A0 = 32mm, A1 = 100mm
B	PVC D32 – DN25 pipe	B0 = 44mm, B1 = 100mm B2 = 345mm, B3 = 160mm

The overall construction and placement of the equipment is shown in Figure 6 - Figure 8.

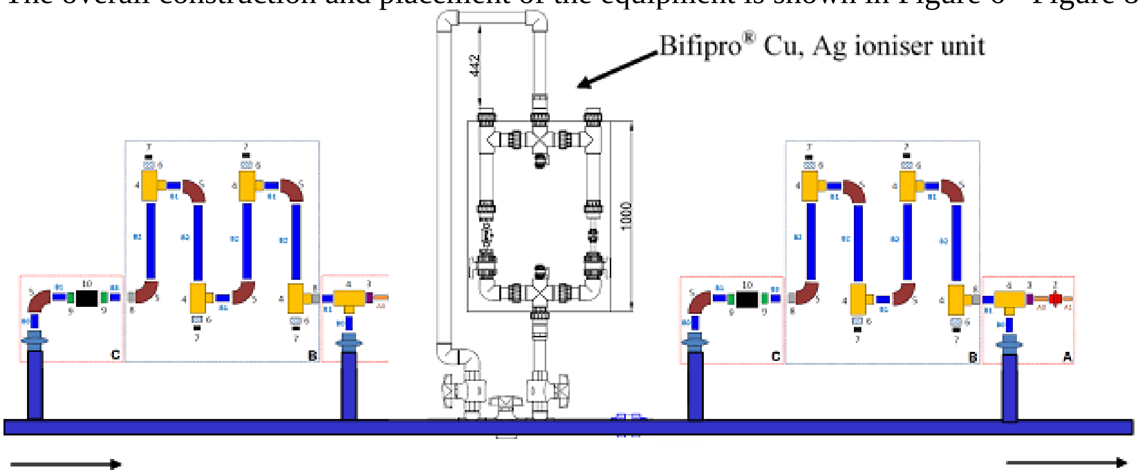

Figure 6 - Schematic Setup of the corrosion test with a rack before and after the Bifipro equipment (CSI unit).

Figure 7- The Bifipro equipment (CSI unit) with 6 copper and 2 silver ionisation cells. The input is located in the centre under the ionisation cells

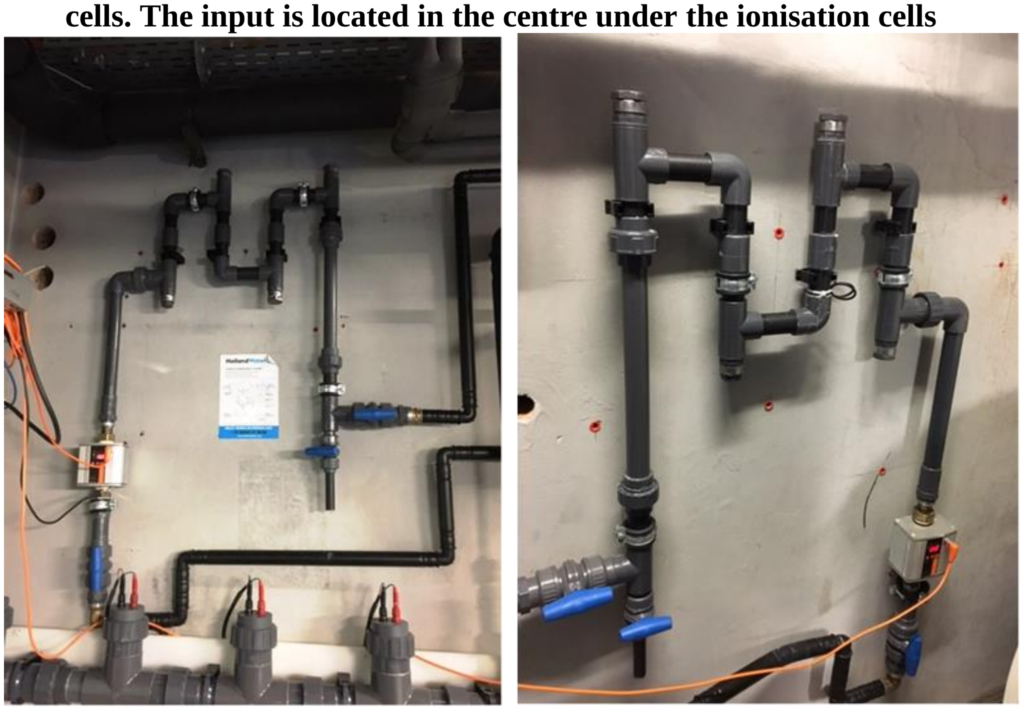

Figure 8- Left picture, shows the corrosion rack installed after the copper silver ionisation unit. The right picture shows the before rack.

The flow meters (Figure 8 far left and far right) are connected to a data logger, which measures every period of 5 minutes the average, maximum and minimum flow and the temperature of the water. The flow meters were installed 5 days after the coupons were first placed and originally there were two non-digital flow meters for flow equalisation.

Results

Before installing the coupons supplied by Metalogic a surface XRF scan was made. The results of these analysis are represented in Table 3. Geoconnect estimated the hot dipped coating is at least 50 µm thick.

Table 3- Result of the surface with the XRF (mg/kg).

Sample	Zn	Cu	Co	Fe	Mn	Cr	V	Ag
Coupon 1 side 1	94.619	<0.03	0.236	4.856	0.026	0.186	0.033	<0.03
Coupon 2 side 1	95.566	<0.03	0.185	4.081	<0.03	0.111	<0.015	<0.03
Coupon 1 side 2	96.434	<0.03	0.159	3.282	<0.03	0.092	<0.015	<0.03
Coupon 2 side 2	96.009	<0.03	0.155	3.641	<0.03	0.096	0.022	<0.03

During a period of 127 days (122 with ultrasonic flowmeter) the flow through the corrosion racks is presented in Table 4 and Figure 9. The column **Bifipro** in Table 4 comes from data collected by the Bifipro and shows how much water is passing in to the whole building.

Table 4- Overview water flow during the test period.

Rack before Bifipro	Rack after Bifipro	Bifipro	Unit
9.2	9.4	57.1	l/min average
1613.7	1651.6	10436	m3 total passed
44.6	52.9	233	l/min top flow
Test period		122	days

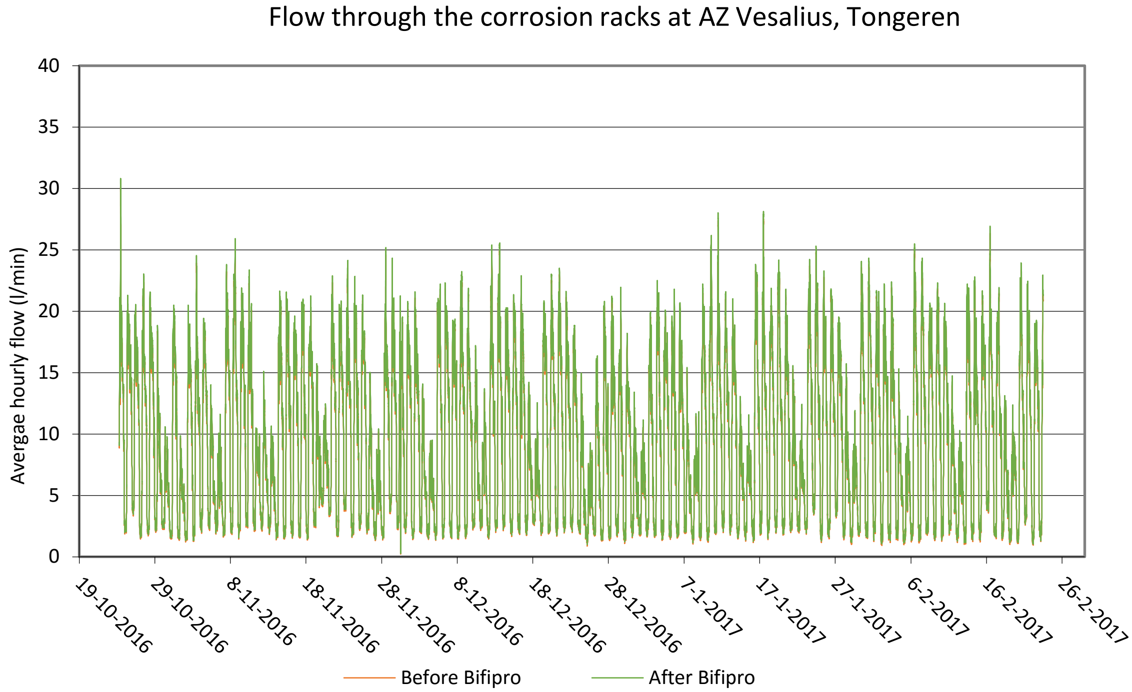

Figure 9- Flow of water passing through the racks, averaged per hour.

Table 4 and Figure 9 show that the two racks were treated identically with regards to flow, so much so that the data from “before” in Figure 9 cannot be seen because of the overlapping “after” data. The total volume of water through each rack varied by only 2 %. A 20% difference was noticed in the top flow of the before rack but this is considered of no consequence because top flow is a quick isolated event and The Bifipro has set dosing limits which are kept constant relative to a varying flow using a microcontroller. Only a technical fault will produce overdosing or under dosing for which there are alarms sent to the operators at Holland Water. The average flow at the location is ca. 55 l/min with a maximum of 300 l/min and a minimum of ca. 5 l/min. To prevent over dimensioning, the Bifipro installation is sized to dose at least 200 ug/l copper and 40 ug/l silver at the peak flow of 300 l/min.

The desired dosing concentrations are 200-400 ppb Cu and 20-40 ppb Ag. Those concentrations have been shown to be the most effective at legionella control eg [8+9]. The theoretically dosed Cu and Ag concentrations (based on 100 % conversion of the amount joules/l into ug/l) can be found in Figure 10 and are well within the expected ranges.

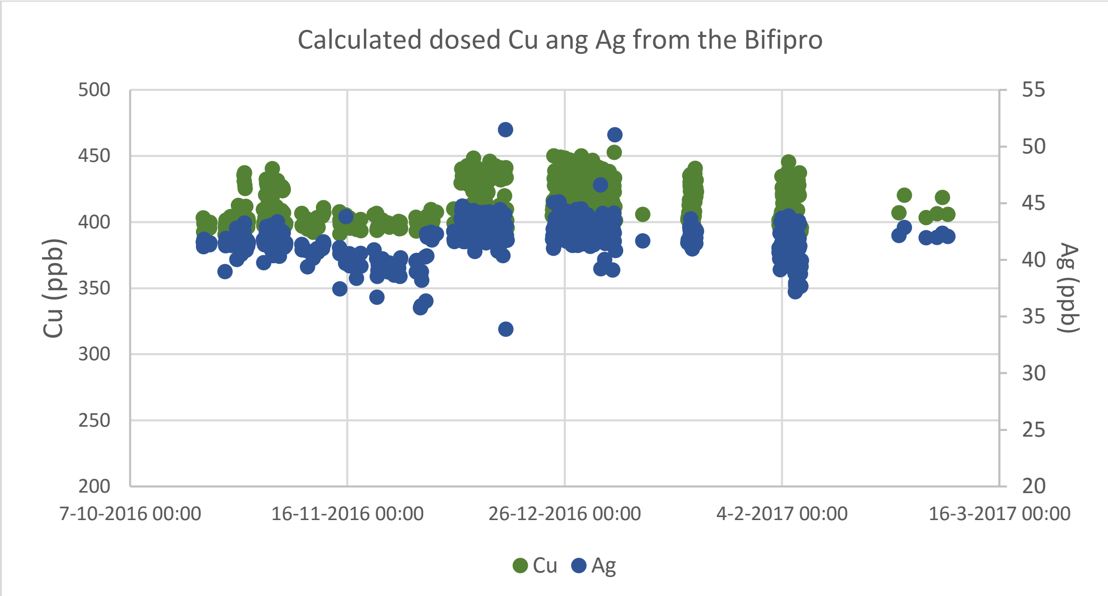

Figure 10- Graph showing the theoretical dosing concentrations using data extracted from the Bifipro.

The legal limits in Belgium drinking water are 2000 and 100 ppb for Cu and Ag respectively. Going below the set dosing levels will decrease the effectiveness of the Bifipro as a biocide and going above them has adverse effects on the building's water network. So the standard settings for the Bifipro were used. The Bifipro uses a set of efficiencies for dosing that allows for compensation from the theoretically dosed to the actual dosed. The efficiencies can vary depending on water conductivity and composition, but generally are similar if the conductivity is ≥ 200 and ≤ 1000 µS/cm. A pH > 9 will reduce the effectivity of the dosed copper and silver ions and will result in the (co) precipitation of hydroxides. The quality of the Belgium water supply is considered similar to the Dutch water and there are no known problems with low efficiencies and the 20 active locations in Belgium. The conductivity measured by Holland Water during maintenance varied at this location between 0.57 – 0.63 mS/cm. Table 5. Shows data from the water company.

Table 5- Average composition of tap water Tongeren from the local authorities [10].

Parameter	Concentration	Units	Limit
Aluminium (Al)	< 10	µg/l	200
Ammonium (NH_4)	< 0.3	mg/l	0.5
Calcium (Ca)	136.4	mg/l	270
Chloride (Cl)	48.7	mg/l	250
Flouride (F)	< 0.4	mg/l	1.5
Conductivity	765	µS/cm	2100
Iron (Fe)	31	µg/l	200
Potassium (K)	4.8	mg/l	-
Lead	< 5	µg/l	10
Magnesium (Mg)	16.3	mg/l	50
Manganese	< 5	µg/l	50
Sodium (Na)	14.7	mg/l	200
Nitrate (NO_3)	41	mg/l	50
Nitrite (NO_2)	< 0.15	mg/l	0.1
Sulphate (SO_4)	43	mg/l	250
Oxygen	7.1	mg/l	-

As part of the service routine of the hospital, all tap points are flushed every week or two. Samples for Legionella, colony forming units (cfu), Cu, Ag and in this situation Fe, are taken regularly to monitor the Legionella and the dosing levels of the Bifipro. The averaged metal data is presented below in Figure 11 and Figure 12. The starting points for both Cu and Ag are estimated because data doesn't exist from before the Bifipro was installed. Cu shows a steady increase over time currently sitting at 220 ppb and Ag shows an initial rise to 40 ppb and then drops to 20 ppb where it stabilises. These trends are not ideal but not unusual for new installations. They can be a sign of insufficient flushing regime but also precipitation of Ag and Cu and/or ion exchange with Zn, on the inner wall of the piping system. To maintain good concentrations and maximise the biocide efficiency, fresh water from the Bifipro has to be passed through all tap points regularly. Ag is especially sensitive to insufficient flushing due to the lower residence time of dissolved Ag compared to Cu. It can lead to very high concentrations found in samples due to Ag enriched scaling on the pipes getting in to the sample bottle. It can also lead to low Ag concentrations because the dissolved Ag cannot travel far enough to reach that tap point. The individual samples for Ag (not shown) vary between 5 and 60 ppb and this is a good indicator of poor flushing.

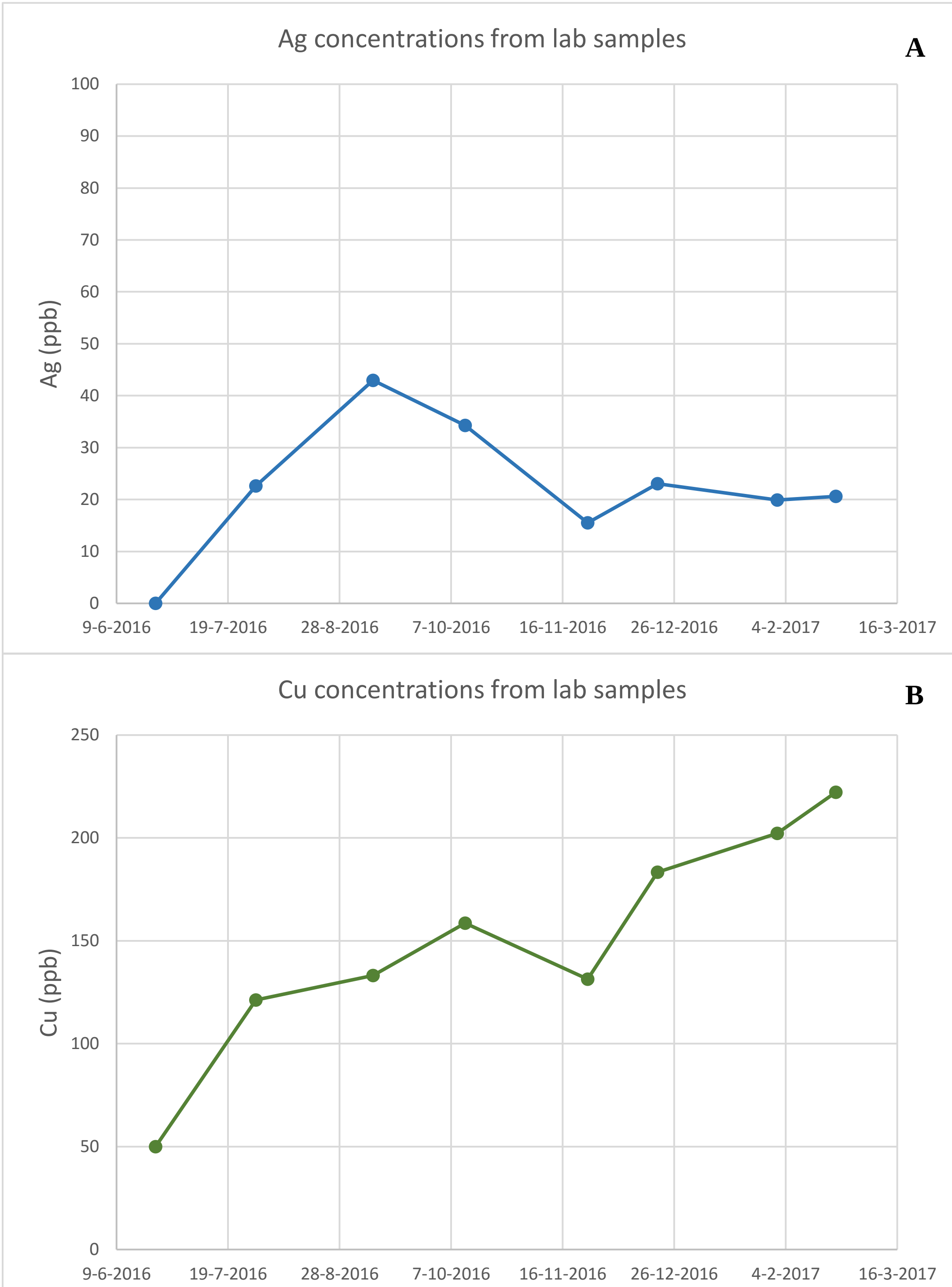

Figure 11- Graph showing the average (A) Ag and (B) Cu concentrations across mixed sample points (min 9 points)

An interesting observation from Figure 12 is the drop and then stabilisation of the dissolved Fe concentrations. The change is a factor of 5 different and could be a sign that corrosion rates are reducing in the water network due to the passivation of the pipes by the Cu and Ag.

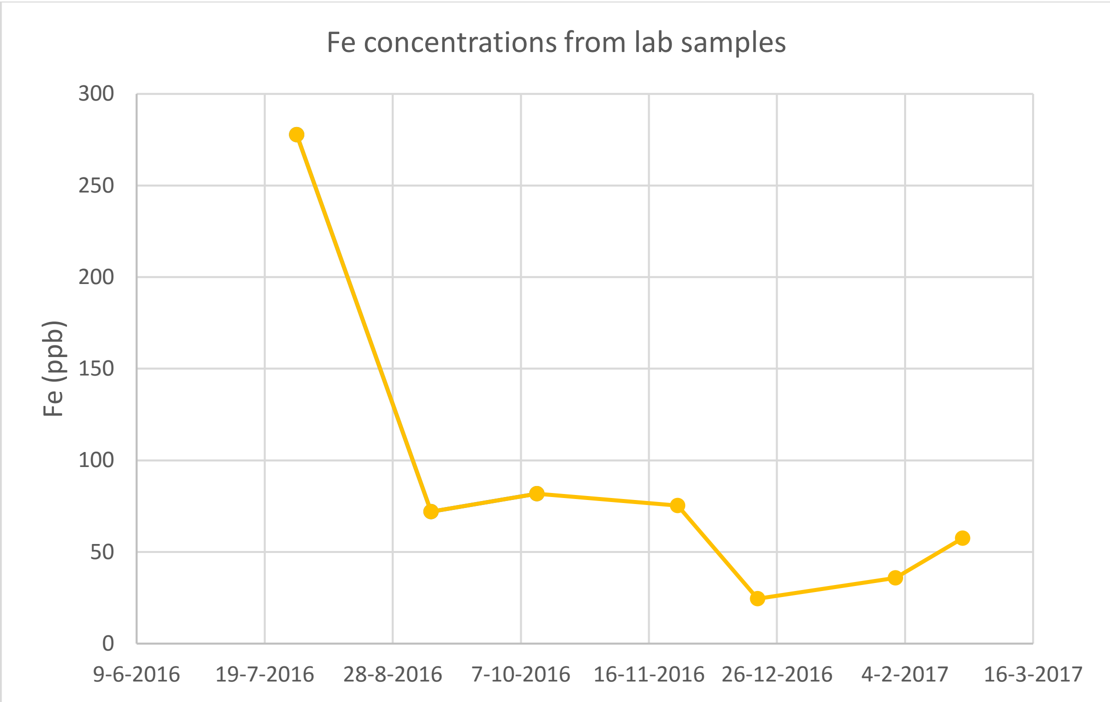

Figure 12- Graph showing the average Fe concentrations across mixed sample points (min 9 points)

Inspections of the coupons and calculations of the corrosion rates were carried out by Metalogic. Figure 13 and Figure 14 shows the uncleaned coupons from two time periods. After 58 days red iron oxide covered 70% of the “before” coupons and only 20% of the “after” coupons. The “after” coupons had a very uniform corrosion across the surface compared to the “before coupons and the “before” coupons had some areas of complete erosion of the Zn layer. There was a 7% coverage of Ag on the “after” coupons. The reported corrosion rates after 58 days were 0.11 and 0.14 mm/year for “before” and “after” coupons respectively. Metalogic noted that the “before” coupons could not have all the red rust cleaned off after chemical cleaning so the corrosion rate in reality would have been higher.

Figure 13 Coupons before Bifipro before cleaning. Top picture after 58 days, bottom picture after 127 days. Red spot indicates where sample for SEM/EDX was taken.

Figure 14 Coupons after Bifipro before cleaning. Top picture after 58 days, bottom picture after 127 days. Red spot indicates where sample for SEM/EDX was taken.

After 127 days there was red iron oxide covering about 80% of the surface of the "before" plates and about 60% of the after plates. The corrosion oxide layer for the "after" coupons was less uniform than the coupons from 58 days even though the Ag coverage for the after plates had increased to 20% from 7%. After removal of all oxide layers this time with a mild sand blating, the reported corrosion rates were 0.11 mm/year for both positions. The drop in steady state corrosion rate for the after plates is most likely due to the formation of protective Ag oxides and if the coupons were exposed for longer it is expected that the differences would be more contrasting.

Figure 16 shows the results of the SEM and EDX work. The dark patches in Figure 16 (B) are Ag deposits. Figure 16 (C+D) shows vie EDX the Cu and Ag coverage of the after plates. The more intense the colour the greater the concentration on the surface. It is worth noting the uniformity of the Ag coverage (D). Figure 16 (E +F) show macro photos after cleaning by sand blasting and clear pitting corrosion can be seen on the before coupon and the after coupon is much more uniform.

One of the striking observations from Loret *et al* was the effect of Cu on pitting corrosion after their experiment was switched off. The electrical equipment used in that study was inferior to modern standards and used alloys both of which are vital for accurate dosing Walraven *et al* 2015. The average Cu concentrations for the first month were ~2000 ppb Cu. As a direct result of this the authors noticed a large build-up of Cu deposits which ultimately caused pitting corrosion. The Bifipro used in this experiment has extensive micro-controller based safety measures built in to avoid such overdosing. After 127 days there was an average surface coverage of about 3% and uniform surfaces across the coupon, hence significantly less chance of pitting corrosion than the conditions in Loret *et al*.

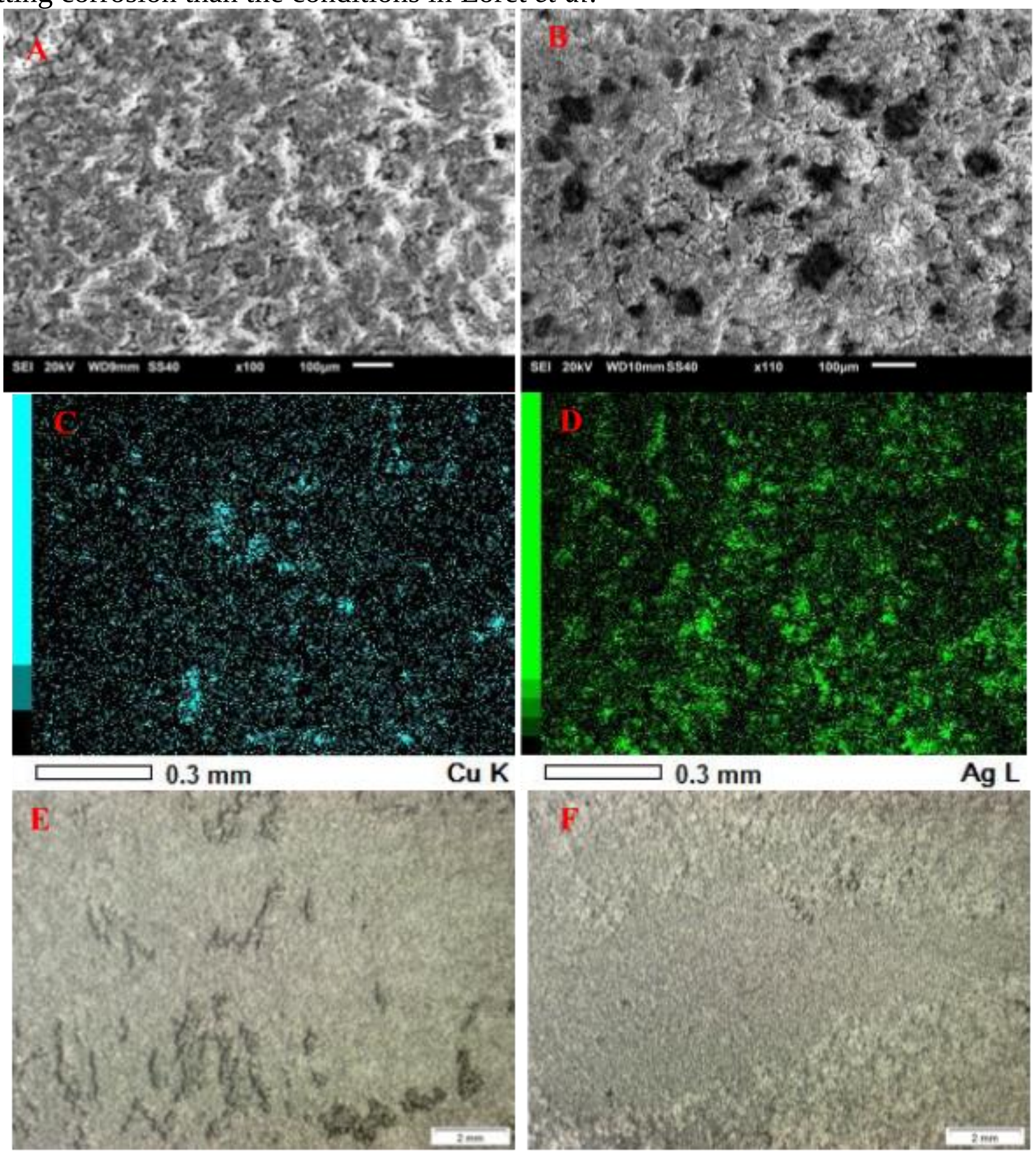

Figure 15 Different images of the coupons. A) SEM of "before" and B) "after", C+D) EDX mapping of the "after", E) Macro photo of before coupon after cleaning with glass beads, D) same as E but from the "after" position

Conclusions

The purpose of this study was to investigate if Cu and Ag ionisation in drinking water causes an increase in corrosion rates of galvanised pipes. It is very difficult and economically impossible to simulate all different water types and conditions but the authors believe that a setup was devised that allowed each set of coupons to be treated identically in every aspect except for the presence of Cu and Ag ions. The data shows no change in corrosion rates after 127 days due to Cu and Ag dosing, compared to the natural rates. The treated plates did have a decreasing corrosion rate over time but the non-treated coupons were stable. Corrosion during low flow and stagnant flow was not observed by Loret *et al* so was not considered important for this study.

It is possible that the combination of correctly applied Cu and Ag will coat the pipes in such a way that results in a reduction of the corrosion rates and extend the lifetime of the piping. Indeed the percentage coverage of Ag on the after coupons has increased from 7 to 20%. Ag is much nobler than Fe or Zn so a good coverage of Ag could lower the corrosion rate even more than natural rates. The falling Fe concentrations could be evidence of that. Loret *et al* commented that their Ag levels were probably (*not directly measured*) below 10 ppb and such low levels would not be as efficient at coating the pipes with the more noble Ag and hence reduce corrosion rates.

Acknowledgements

METALogic nv, for their expert, independent input to the corrosion analysis.

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Presentation of authors

Conrad Chapman is the Technology manager for Holland Water BV and has a background in environmental chemistry with a speciality in electrochemistry. Awarded his PhD in 2005 he went on to become a technologist with one patent and many new sensor designs. He advanced in to management and scientific app development with 1 app in the Google Play store.

Wiebe Pool is the R&D manager for Holland Water BV and has a background in geochemistry and a special interest in applied technology/electronics to environmental problems. He founded Geokentics BV in 1987 using electro-remediation of contaminated soils and since went on to design many other specialised equipment such as the Bifipro and holds numerous patents.

Nikolaj Walraven obtained a BSc in geology in 1991 and a MSc in geochemistry in 1996. In 2014 he successfully defended his PhD thesis on ‘Lead in rural and urban soils and sediments in The Netherlands’. Since 2005, Nikolaj Walraven is self-employed, running 2 businesses: GeoConnect and GeoConnect-Sensing BV. His main fields of expertise are soil science, water technology and sensor development.

A4 - Avoiding heat transfer from hot water connection to cold water connection at a mixer tap

Ulrich Petzolt (1),

1. upetzolt@kemper-olpe.de
(1) Head of Product Management, Building technology, Gebr. Kemper GmbH + Co. KG, Germany

Abstract

Introduction and aims: Even when all generally accepted codes of practice have been respected for the design and installation of a potable water system, heat transfer from hot to cold connections of mixing tap may not be avoided. The hot water circulation in combination with double drop ear elbows causes a temperature of appx. 60°C (140°F) at the hot water connection of mixing taps. The mixing tap is usually made of brass and therefore transfers the heat from the hot to the cold connection. The maximum temperature for cold water of 25°C (77°F) cannot be met, even when the cold water pipe has been installed below the hot water pipe. The resulting temperatures in the mixing tap will be in a range for increased microorganisms which is hygienically critical and needs to be avoided. **Method**: The KEMPER Thermal Separator Assembly Block is the result of a research study and avoids the critical heat transfer from a hot water connection to the cold water connection of a mixing tap. The heat transfer is avoided by two effects. One is the use of a barely heat conducting element between the hot water connection and the integrated drop ear elbow. The other effect is the avoidance of micro turbulences caused by temperature influenced density difference of the hot water as the hot water pipe runs above the drop ear elbow. **Results and conclusion:** The Thermal Separator avoids heat transfer from a hot water connection to the cold water connection of a mixing tap. Contributions: The area of critical temperatures that is beneficial for the growth of microorganisms is minimized.

Keywords

Water hygiene, thermal separator, mixing tap, water temperatures, valve temperature

1 Drinking water installation and point of use

Drinking water hygienists consistently find inadequate water hygiene in potable water installations. The problems (discrepancies of the parameters demanded from the EU- drinking

water directive 1. or from the national drinking water directive, law, code or guideline 2. (e.g Germany: TrinkwV 2001) occur in cold and hot water systems. The operator is responsible for the proper function of the water installation of his building. Professionals claim stagnation to be one of the main reasons for the change of potable water becoming non-potable water. Stagnation is a period of "non-use" of the water. The reason for stagnation can be old, unused pipework or periodically unused rooms of a building. These pipe sections are permanently stagnant and can be the origin of a hygienic problem. During this time water does not flow and is not consumed, it changes its physical, chemical an microbiological quality. Therefore it is usually recommended to remove the unused pipework from the potable water installation or to ensure that the whole installation is "used as intended". "Use as intended" means that an assumed frequency of water usage during the design period needs to be maintained after the realisation of the water installation. "Use as intended" means also, that originally planned use of water has to be used during the day (the basically calculated volume at the point of use has to be consumed). This fact leads to the logical consequence, that owners of buildings, who consume only a part of the originally planned amount of water, have to think about additional flushings in their drinking water systems to realise the the normal use.
Because of the mentioned stagnation effects drinking water in pipe systems change its properties, also the temperature of the pipe volume, called waterbody, in a short time (figure 1). The change of the temperature in drinking water is one of the most important influences concerning the microbiological growth in a drinking water system.
This is the reason, why laws, directives, norms an guidelines dealing about health and drinking water in Europe, tell us to keep cold water cold (PWC, potable water cold) and warm water warm (PWH, Potable Water Hot).

The reason for this important notes is the increase of microbiological population in pipes and components of sanitairy systems, if cold water PWC is getting warmer and warm water is getting colder. Following EN 806-2; (3.) cold water PWC has to be kept cold (best case: lower than 20 degree Celsius up to max. 25 degree Celsius), warm water PWH has to be kept hot in the most countries of Europe at 60 and in some countries at 65 degree Celsius. Because of the warmth transmission and the warmth transfer in the area of shafts and pre–installed drinking water installation in walls and because of the different room temperatures in buildings, it is allowed (actual EN 806-2), that water may have a temperature above 25 degree Celsius after opening a valve at the point of use (figure 2). During the first 30 s after opening a valve at the point of use (figure 1 and 3) the temperature is most times higher than 25 degree Celsius. In stagnation periods, when the mixing valve is not used, this means, that the temperature at the tap can be higher than 25 degrees. One of the biggest influence concerning the mixing valve at the tap is the hot water circulation in combination with double drop ear elbows, which cause a temperature presence of appx. 60°C (140°F) at the hot water connection of mixing taps. The mixing tap is usually made of brass and therefore transfers the heat from the hot to the cold connection.

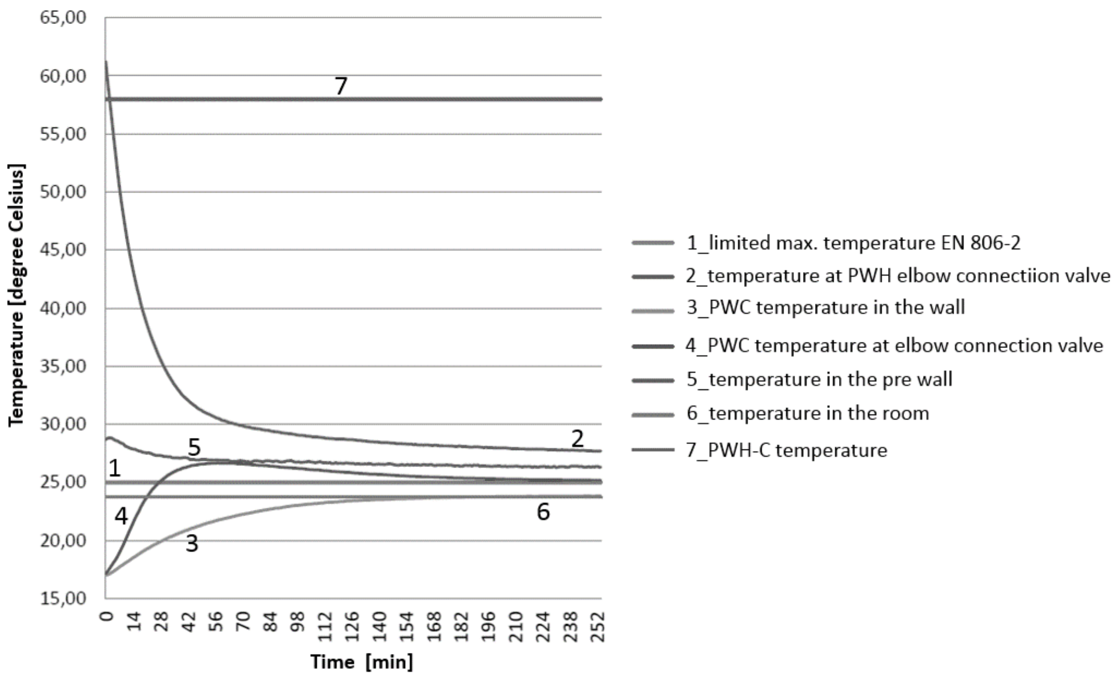


Figure 1 – Temperatures PWC / PWH / PWH-C in an installation wall and temperatures at PWC elbow connection [4]

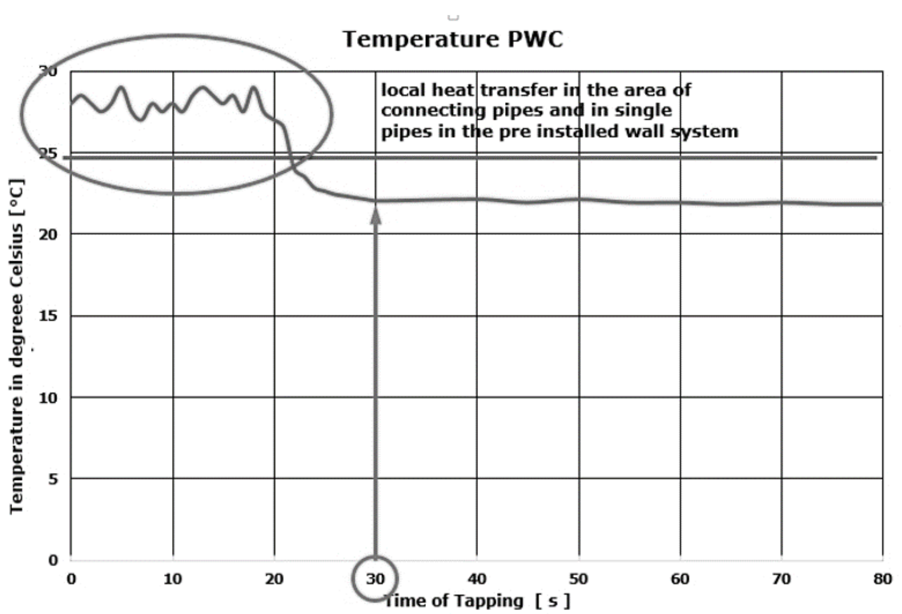


Figure 2 – Temperature measurement PWC at the point of use during phasing out

Reasons: Warmth transfer through wall- mounted mixing valve; convective warm transfer through surrounding air temperature; stagnation / not enough change of water in pipes

1.1 Avoiding heat transfer at the point of use (valve)

While taking samples in private and official buildings and analysing the water quality at different mixing valve for taps and showers following EN 19458, type B and C (4.) it was getting more and more clear, that the influence of connecting the mixing valve in combination with the PWH and PWC installation has to be more focussed. The measured temperature on the surface at a mixing valve beginning at the connection for PWH and PWC had a range from over 25 degree Celsius up to 35 degree Celsius depending on the type of mixing valve and on the temperature level of PWH-C (potable water hot- circulation).
During the last years the philosophy of drinking water installation has changed. Beneith the existing T-piece installation further types of installation like daisy chained or loop-installation were developed. The most important reason for this change was to achieve a better situation in drinking water hygiene. A further reason for the new ways of installation were the higher standards in comfort requested by the users.
Following the EU- drinking water direction and the national legislation in the EU-countries stagnation has to be avoided. In many cases PWH-C installations have been realized with drop ear elbows. Because of the circulation of PWH-C the connection at the mixing valve and the valve itself was constantly temperature (steadily flow) at 55 up to 60 degree Celsius.
Because of this effect, investigations in form of measurements at mixing taps started and the most important result was that the mixing valve and the water at the PWC connection was warmed up through the heated material of the valve itself and also through the fixing construction of the mixing valve in the installation area. The increase of temperature in PWC in the area of the valve and in the valve causes the best preconditions for the living area of legionella and other microorganisms. To find out more about the temperature regime at the mixing valve a bachelor study was started. For the investigations a test rig was installed, which had a pre-wall installation module with a shower and a mixing tap in front of the wall. The T-piece and the loop installation was investigated and compared. **The aim of the investigation was to find out a solution to reduce or stop the warmth- transfer from the connected warm water side into the mixing valve at the connection of the PWH.**
The first measuring in todays actual plumbing situation showed that in both installation types (T-piece and loop) the warmth transfer is taking place in the area of the connection of PWC (figure 3).

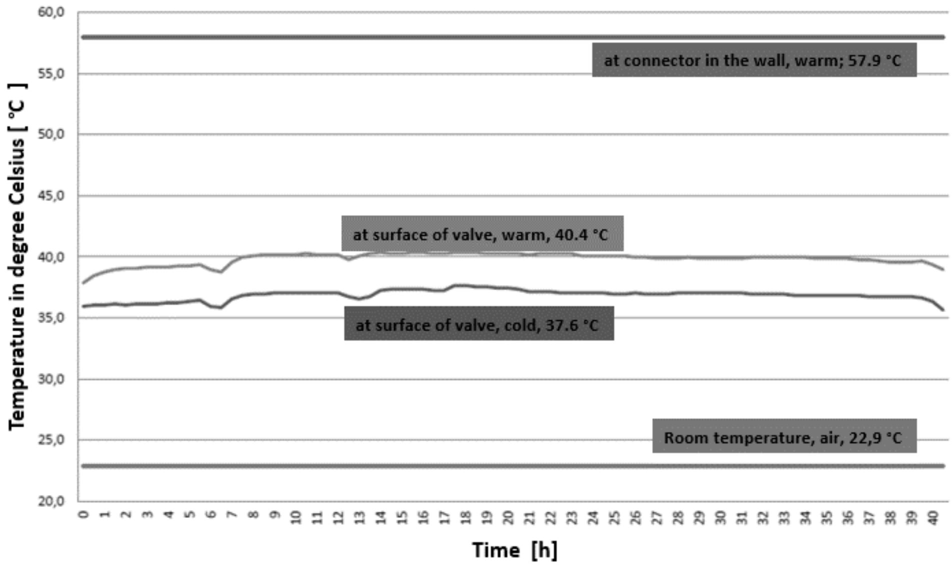


Figure 3 – Longtime Temperature measurement of mixing valve, surface PWC / PWH and connectors

During the investigations it was getting clear, that the metal-body of the valve has the biggest influence to warm up PWC at the PWC – connector and the installed PWC pipe. By using a plastic pipe material PPSU it was tried to reduce the warmth flow and the warmth transfer through the velve. Finally the solution to solve the problem was to build the connection with a short plastic pipe out of PE-X material to connect the circulation pipe coming from above the valve with the drop ear elbow. Through the effect of the density difference between hot and warm water the PE-X pipe cooled down more and more coming nearer to the connection of the valve. So finally the influence of the convection and warmth transfer of the hot PWC water could be eliminated.

The effect and the solution was further optimized to a plumbing product, so that the temperature requirements of the drinking water directive and the EU-standards in EN 806 - drinking water standardization could be achieved and fulfilled in sanitairy installations (figure 4, figure 5, figure 6, figure 7).

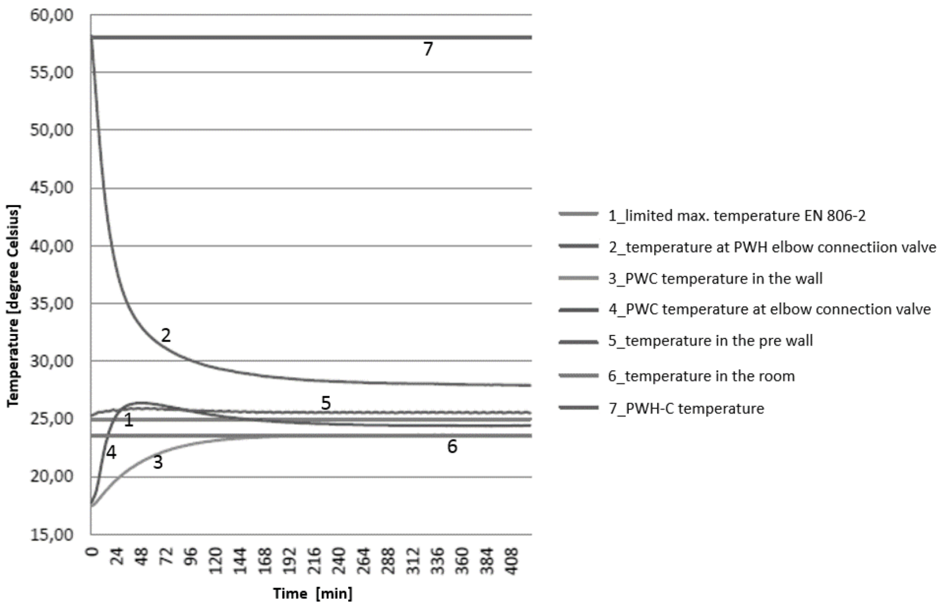


Figure 4 – Temperatures PWC / PWH , at surface PWC / PWH and at connectors with thermo separator

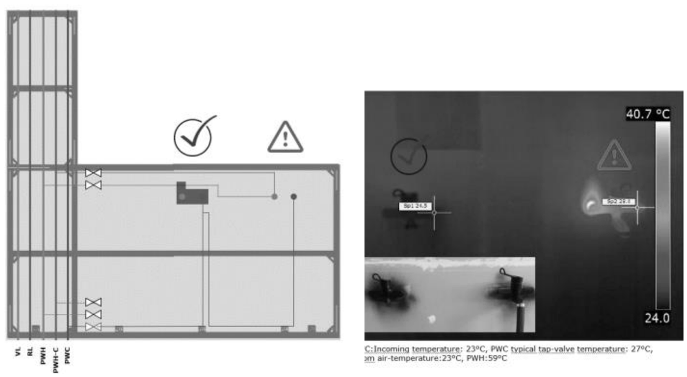


Figure 5 – Test rig and thermographic results: mixing valve with and without thermo separator (right side: hot with big warmth transfer; left: no warmth transfer PWC / PWH elbow connectors are at room temperature

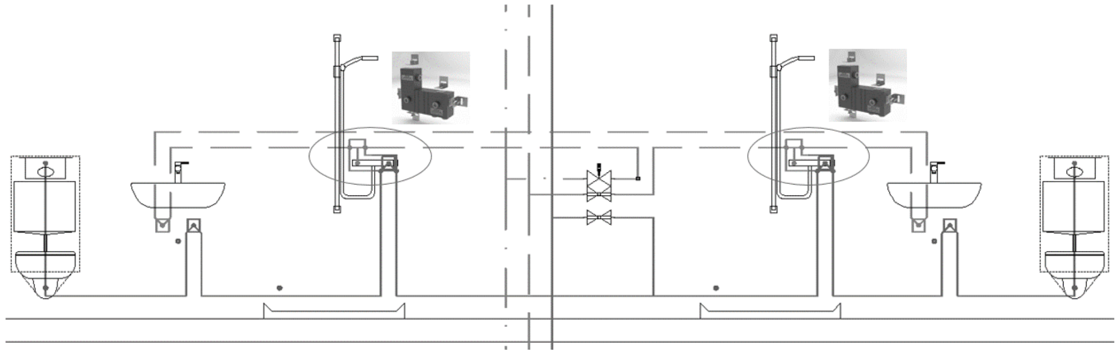
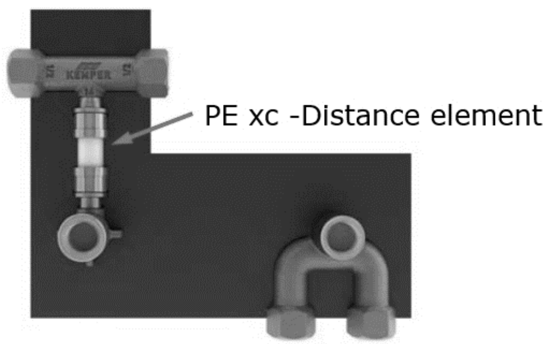


Figure 6 – Innovative way of drinking water installation in combination with thermo separator; PWC: area below; PWH /PWH-C: in the upper area of the wall



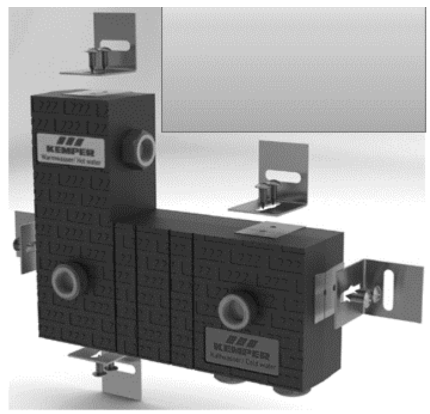


Figure 7 – Innovation: Product and Cut through a "Thermo separator" for drinking water installation

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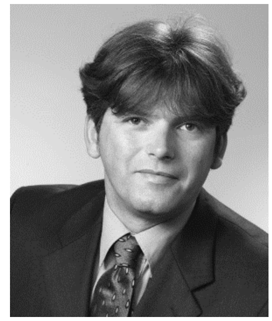
4 The Author



Ulrich Petzolt is Head of productmanagement for building technologies at Gebr. Kemper GmbH + Co. KG, Olpe, Germany. He is a former student of the Fachhochschule Gelsenkirchen - University of Applied Sciences-, Department of Utility Technologies. He is specialised in water supply, water saving and drinking water hygiene and in calculating water hydraulics. He is a member in different national working groups at DIN, DVGW, VDMA in Germany. He is a personal member at VDI in Germany.

A5 - Evaluation of the risk of *Legionella spp.* development in sanitary installations

K. Dinne (1), O. Gerin (2), B. Bleys (3), K. De Cuyper (4),
(1) karla.dinne@bbri.be
(2) olivier.gerin@bbri.be
(3) bart.bleys@bbri.be
(4) karel.de.cuyper@bbri.be
(1), (2), (3), (4) Belgian Building Research Institute (BBRI), Belgium

Abstract

In order to determine whether it is possible to reduce energy use for domestic hot water (DHW) production and distribution, without increasing the risk of *Legionella spp*. development in sanitary installations, a full-scale test facility was built, consisting of a 200 liters water tank, a circulation system of nearly 40 metres long and 2 draw-off pipes. On a daily basis, a consumption profile corresponding to the DHW use of a single family (4 persons) was applied separately using two tap pipes, one corresponding to a kitchen and the other to a bathroom. *Legionella spp*. was cultivated in a separate water tank and then introduced into the test facility. The DHW production temperature was kept at 45°C with a periodical heating to 60°C for different durations and different frequencies. *Legionella spp.* concentrations were measured, both in the water and in the biofilm. The influence of different parameters was studied: disinfection of the sampling taps, flow rate of sampling, disinfection of the circulation system only or in combination with the draw-off pipes.

This article discusses the first preliminary results of this study, which is still ongoing till mid-2018.

Keywords

Water supply hygiene, *Legionella spp.* development, domestic hot water (DHW), disinfection, biofilm

Introduction

As the energy-use for space heating continues to diminish due to better performances of the building envelope and the use of more efficient heating systems, the energy use for hot water production becomes increasingly relevant. Since the recast of the Energy Performance of Buildings Directive [1] stipulates that by 2020 all new buildings in the European Union should be almost near zero energy buildings, reducing the energy use for hot water production, whilst maintaining the desired comfort level for the buildings occupants, will become one of the challenges for the future in Europe.

Therefore it becomes ever more important to design hot water production and distribution installations inside our buildings in a more energy efficient way. In certain types of installations, for instance installations with heat pumps and in low temperature district heating [7], an extra pressure to reduce de DHW production temperature exists. A lower temperature is beneficial for the performance (COP) of most heat pumps for instance.

An optimal design [2] of the drinking water system (hot and cold) includes however also other aspects, of which some are even more important such as the hygienic quality of the water at the taps by avoiding for instance the development of *Legionella*, a pathogenic bacterium, which can lead to a severe pneumonia.

Knowing that the *Legionella* bacteria grows between 25°C and about 45°C while it is decimated above 50°C [3,6], the aim of the study was to evaluate whether it is possible to produce and distribute the domestic hot water at temperatures within the growth range of the bacteria - i.e. energy –effective, but still comfortable in use- in combination with systematic in time limited temperatures rises above 50°C in order to ensure hygienic quality.

While several authors reported studies on the influence of the temperature on the growth/death rate of Legionella bacteria in laboratory conditions [3,6] or in a pilot installation [4,5], the full-scale test facility offers the opportunity to study the effect of multiple controlled thermal chocks on the survival of *Legionella*.

At the BBRI, a full-scale test facility was built, consisting of a distribution loop of nearly 40 metres long, fed by a 200 liters water tank ("test tank") at 45°C and 2 draw-off lines. In this configuration, a consumption profile on a daily basis, corresponding to the DHW use of a single family (2 adults, 2 children), was simulated on the two draw-off lines, one corresponding to a kitchen and one to a bathroom (shower). *Legionella spp*. were, after cultivation in a separate water tank, introduced into the test facility to study the evolution of this contamination when applying a regular, in time limited, thermal disinfection of the tank and the distribution loop .

2 Test facility description

Figure 1 shows a global view of the test facility. There are 2 tanks (a 'culture' and a 'test' tank), one circulation loop of about 40 m, connected to the test tank and 2 draw-off pipes (with respectively a "kitchen" and a "shower" *consumption profile*).

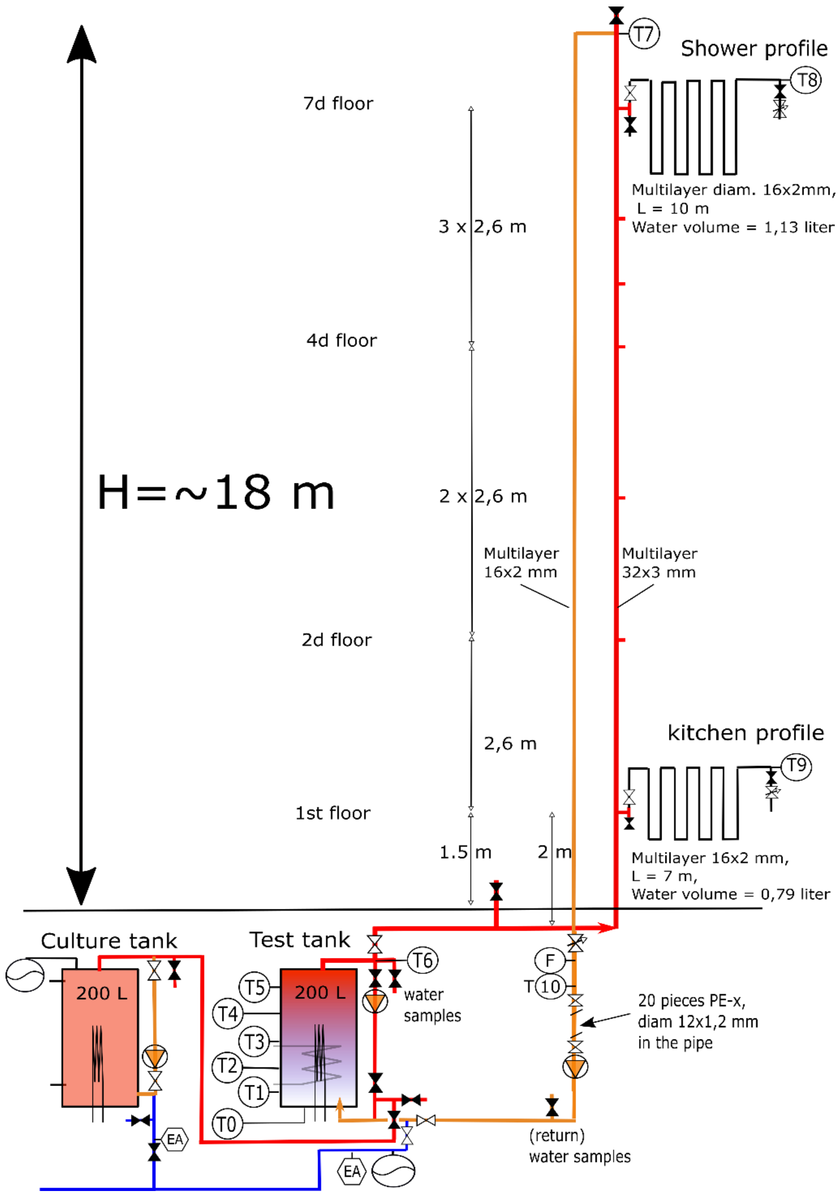


Figure 1 - Schema of the Legionella test facility.

The ‘**culture**’ **tank** (containing a stock solution of *Legionella* bacteria) is a 200 liter steel tank, with an electrical resistance placed in vertical position at the bottom of the tank. The tank was filled with fresh potable water from the district distribution and heated at 37°C. The homogenisation of the water temperature in this tank is obtained by a circulation loop over the tank. Two inoculations with *Legionella pneumophila* bacteria from a hospital facility and a daily draw-off of 127 liters - supplying fresh water - were necessary to obtain a stable stock solution of *Legionella pneumophila* at nearly 2.10^5 cfu/l.

The **“test” tank** (figure 2) is a 200 liters austenic chrome-nickel steel tank. The heating system is an electrical resistance of 6 kW placed in vertical position at the bottom of the tank. The

height of the tank is 136 cm. Temperature probes (thermocouples, precision +/- 0,1°K) are placed on its outside wall (under the isolation jacket): on the bottom of the tank and at different heights (respectively 13.6 ; 40.8 ; 68; 95.2 and 122 cm). Another temperature probe is also placed in the middle of the departure pipe (fig. 3 left).
This tank and its circulation loop was first directly fed with the contaminated water from the "culture" tank (2,64 liters each 30 minutes) during 2 weeks. During the second week, the temperature was changed from 40°C to 45°C over 5 days. After the 2 weeks, the water supply was connected directly to the district distribution of potable water. The DHW production temperature was then kept at 45°C and a realistic consumption profile (see further) was applied at the draw-off taps (= test phase). Samples of the water circulating in the loop were periodically taken via tap points on the depart of the loop and on its return near the boiler, in order to measure the development of *Legionella pneumophila*. After a couple of weeks, a stable concentration of *Legionella pneumophila*. was reached (nearly 5.10^6 cfu/l).

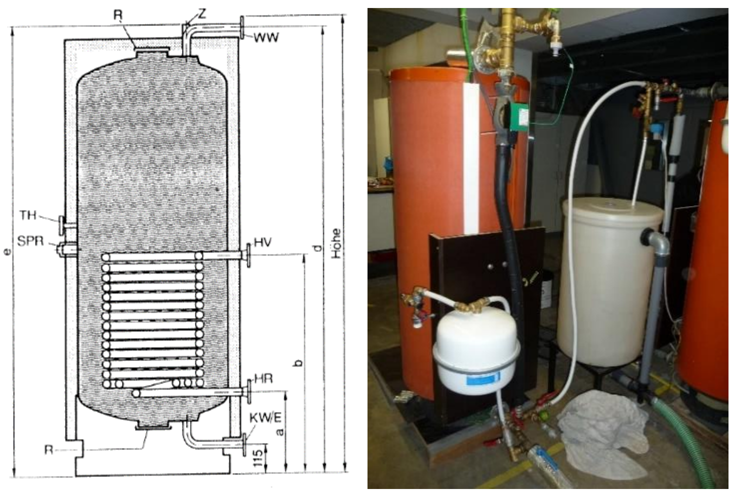


Figure 2 - test tank cross-section (left) and global view (right)

At the outlet of the tank, there is a flexible connection between the 'test' tank and the circulation loop. The *circulation loop* connected to the test tank consists of nearly 40 m isolated multilayers pipes (figure 1). The loop starts with a horizontal pipe DN50; the vertical pipe is DN32 with 20 mm insulation. The recirculation pipe is a DN16 with 15 mm insulation. Some temperatures probes were placed inside these DN32 and DN16 pipes. A flow regulation valve and a flowmeter were also placed on the last one. At the bottom of the recirculation pipe (1,5 m before entering the tank), another sampling valve makes it possible to take water samples of the "return" water.

2.1 Sampling facilities

Figure 3 shows some details from respectively a) the temperature probe and water sampling tap on the depart pipe and b) the sampling possibility on the recirculation pipe of the loop. The combination of sampling valves with flow regulation valves makes it possible to differentiate flow rates for sampling. Two flow rates were studied for sampling (0.5 l/min and 2 l/min). As

the aim is to test the global disinfection effect (free water and biofilm) of the thermal shock, the sampling flow rate at 2 l/min was maintained.
In order to avoid every possible contamination in the water samples coming from the flow regulation valves, a chemical disinfection of the valve has been conducted before sampling (using ethylic alcohol and rinsing with sterile water), since week 8. The trapped water volume (~5 ml) between the ball valve and the regulation valve (fig 3 right) has been analysed for *Legionella* (3 repetitions).

Figure 3 – Sampling points near the test tank : (left) temperature probe in the T-piece and sampling tap upstream a flow regulation valve on the departure pipe. (right) Sampling valve upstream of a flow regulation valve on the recirculation loop.

On the recirculation pipe, a section of pipe DN25 (length = 0,8 m) was also inserted (fig 4 left) containing 20 rings of PE-x pipe (ø 12 x 1,2 mm; height of about 29,7 mm) exposed to the recirculation water so that the biofilm can grow on it. When needed, such a ring piece can be taken (fig. 4 right) for the analyses of the biofilm.

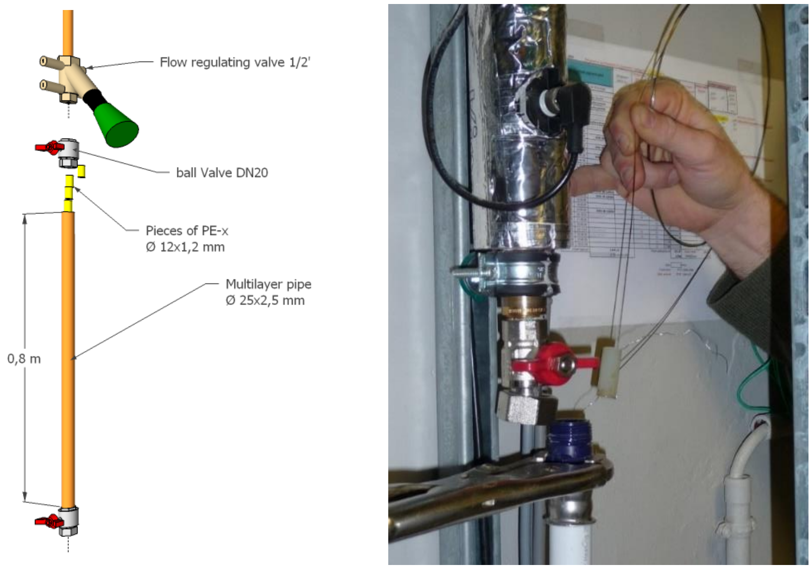


Figure 4 – (Left) Schematic view of the pipe section with rings for the biofilm monitoring. (Right) Extraction of a ring piece in PE-x.

Water samples can also be taken from the two draw-off pipes (fig.1) which are equipped with temperatures probes and regulation valves (fig.5 right). The consumption profiles are applied to these draw-offs with electro valves controlled by electronical timers. The outlets of these electro valves are connected to a closed discharge reservoir avoiding the spread of aerosols in the lab (fig 5 left and center).

Figure 5 - views of the 'kitchen' draw-off (on the left); the 'shower' draw-off (center) and their equipments : temperature probe; electro valve and regulating valve at the reservoir connections (on the right).

2.2 DHW consumption profiles.

According to the tank capacity (200 l), a realistic tap schedule based on the DHW demand of a 4 person- family was established. The tap schedule is given in the table 1.

Table 1 - Consumption profile

Tap schedule		DHW Flow-rate	Tap duration	Tapped DHW volume
Start hour	Type of draw-off	l /min	s	liters
06:59	purge of the shower pipe	6.5	**10**	**1.083**
07:00	Shower n° 1	6.5	355	**38.5**
07:10	Shower n° 2	6.5	393	**42.6**
08:00	Shower n° 3	6.5	296	**32.1**
12:00	Kitchen faucet	5	**6**	**0.50**
12:30	Kitchen faucet	5	20	1.67
13:45	Kitchen faucet	5	30	2.50
18:15	Children's bath (40 L)	6.5	311	**33.7**
19:00	Kitchen faucet	5	6	0.50
19:15	Kitchen faucet	5	3	0.25
20:00	Kitchen faucet	5	30	2.50
	Total tapped daily DHW Volume :			**155,79 l**

According to the temperature setting point of the tank (45°C), the DHW flowrate of the 'shower' draw-off was set on 6,5 l/min (corresponding to a shower with a flowrate of 8 l/min on mixed water at 38°C). The DHW flowrate of the 'kitchen' is calibrated on 5 l /min. The total daily DHW volume consumed is about 156 l/day : ~ 148 l via the 'shower' and ~7,9 l via the kitchen . The first draw-off of the day on the 'shower' (at 6:59) and on the kitchen (at 12:00) gives us the water samples for the analyses of the concentration in *Legionella sp* in the two draw-off pipes (where no circulation occurs during thermal disinfection, *except* when we wanted specifically to test the influence of a disinfection by letting the water flow through it during the thermal disinfection - weeks n° 10 and 11 - see later).

3 Heat shock experiments

As the Belgian Superior Health Council recommends concentrations of *Legionella pneumophila* (in the sanitary water), beneath 1000 cfu/l in high level risk installations, applying thermal shock disinfection of the circulation loop aims to eradicate or stabilise the *Legionella* contamination below this value. A common practice to reduce *Legionella* levels in a sanitary installation is heating up the water in the storage tank to reach 60 °C in the circulation loop for 30 minutes.

In the experimental set-up, the temperature of the boiler was set to 45°C and regulated by the temperature probe placed in the middle of the tank height, while the temperature in the circulation loop remained between 46.8°C (max. on depart) and 42,8°C (min. on return). For a thermal shock, the regulation is then switched to another regulation and when the new set point of a thermal shock is reached, a timer is activated for a chosen time duration. At the end of this period, the regulation is then automatically switched to the usual regulation of the tank.
For the thermal disinfection (thermal shock, during the night), the heating of the tank was modified so that a temperature of 63°C was reached at the outlet of the tank and so that 60°C was obtained at the end of the recirculation pipe. Water samples were taken before and a few hours after (early in the morning) the thermal shock. *Legionella spp.* concentrations were measured, both in the water and in the biofilm on the PEx-rings. All the temperatures as well as the circulation flowrate were monitored every second.

In the first shock disinfection, the temperature rise was maintained during 30 minutes. As the *Legionella* concentration remained present in a unacceptable concentration (>1000 cfu/l) a few hours after the shock, different likelihood sources of *Legionella* (re-) contamination of the test facility, like contamination of the water samples by the biofilm present in the sampling taps or re-contamination of the circulation loop water by *Legionella* bacteria from the 2 draw-off pipes were also investigated.
In order to standardise the sampling protocol, different parameters were studied as a preliminary disinfection of the sampling taps and sampling at different flow rates. Some adaptations were progressively made in the test facility and in the initial thermal disinfection protocol in order to succeed the disinfection in the test facility at 60°C. Different durations (30 min, 1 hour, 2 hour), homogenisation of the water temperature in the tank by activating of a short-loop re-circulation on the tank and different thermal disinfection frequencies were tested (see table 2).

Table 2 - Tested thermal disinfection.

weeks	T production (tank)	T heating (thermal shock)	Heating duration	Frequency	Number of thermal shocks
1 and 2	45 °C	60 °C	Warming up + 30 min	1x / week	2 shocks
3 and 4	45 °C	60 °C	Warming up + 1h	1x / week	2 shocks
5	45 °C	60 °C	Warming up + 30 min	1x / week with extra circulation on tank	1 shock
6 and 7	45 °C	60 °C	Warming up + 1 h	1x / week with extra circulation on tank	2 shocks
8 and 9	45 °C	60 °C	Warming up + 1 h	1x / week with extra circulation on tank. + 30 minutes thermal disinfection of the sampling taps	2 shocks
10	45 °C	60 °C	Warming up +4 x 30 min (for taps disinfection)	1x / week with extra circulation on tank. + 4 x 30 minutes thermal disinfection for each of the sampling taps and draw-off pipes (in the ‘circulation’ order)	1 shock
11	45 °C	60 °C	Warming up +30 min (for tank) + 4 x 30 min (for taps disinfection)	1x / week with extra circulation on tank. + 4 x 30 minutes thermal disinfection for each of the sampling taps and draw-off pipes (in the circulation order)	1 shock
14-18	45 °C	60 °C	1 h	2x / week with extra circulation on tank	9 shocks
19	45 °C	60 °C	1 h	Daily (7x /week) with extra circulation on tank	7 shocks

Besides the above indicated study on the test rig, temperature experiments were also conducted on water suspensions of *Legionella* in laboratory conditions (in parallel): they were exposed to different thermal shocks profiles (60°C, 65°C, 70°C during 5 min, 15 min, 30 min, 60 min and 120 min) in order to indicate which combination (temperature/time) could lead to success. 2 ml suspensions were transferred into glass tubes, sealed with a knot and placed into a water bath; with 3 replica for each duration.

4 Results

4.1 Sampling protocol

It is very important to standardise the sampling methodology in order to obtain reliable results of *Legionella* analysis. However, no significant difference has been observed between sampling at a flow rate of 0.5 l/min or at 2 l/min. The sampling flowrate of 2 l/min is maintained.

In order to avoid every possible contamination in the water samples coming from the flow regulation valves, a chemical disinfection of the valve has been conducted before sampling since week 8. The trapped water volume (~5 ml) between the ball valve and the regulation valve has been analysed for *Legionella* and presented a very low concentration of *Legionella* bacteria (< 1 bacteria/ml). This contamination will not affect the measured *Legionella* concentrations in the water from the circulation loop.

4.2 Thermal inactivation of *Legionella pneumophila* in laboratory conditions

In laboratory conditions, a sole thermal treatment on a homogeneous stock solution of *Legionella pneumophila* strains from the culture vessel was carried out at 60°C, 65°C and 70°C. No (cultivable) *Legionella pneumpohila* bacteria survived the thermal shock at 65°C or 70°C. The concentration of cultivable *Legionella pneumpohila* dropped from 100.000 cfu/l to beneath the detection limit (< 100 cfu/l) even after 5 minutes. However, several laboratory results indicate a *Legionella pneumophila* resistance up to 60 minutes at 60°C (reduction to 250 cfu/l after 60 minutes for cultivable bacteria).

4.3 Heat shock treatment in the test facility

A heat treatment of the circulation loop once a week (up to 1 hour at 60°C, even with recirculation over the tank) but without disinfection of the draw-off lines seemed to reduce the *Legionella* concentration temporary (in the loop), but the concentration never dropped under 1000 cfu/l. At weeks 8 and 9, the thermal disinfection (30 min, 60°C) of the sampling valves, positioned on the circulation loop, was included in the protocol.

As high concentrations of *Legionella* were reached at the draw-off pipes, at week 10, a thermal disinfection of the each tap point (30 min, 60°C) was also performed. However, the *Legionella* concentration dropped only from ~1.6 10^5cfu/l to ~ 1.1 10^3 cfu/l (2 log reduction) after 30 minutes (tap point at the 7th floor). The lower concentration was observed temporary at the tap point.

At week 11, to optimise the disinfection process, a homogeneous warm up of the tank during 30 minutes at 60°C before starting the thermal shock of the tap points was included in the disinfection protocol. During the disinfection of the tap point at the 7th floor, *Legionella* concentrations dropped from 7.8 10^4 cfu/l to 50 cfu/l (30 min after a continuous water draw-off of 30 min) but 24 hours after the disinfection, the *Legionella* concentration rised to 500 cfu/l and unfortunately, after 2 weeks the initial concentration of *Legionella* bacteria was reached again.
For 5 weeks, a thermal disinfection program of 1 hour at 60°C started two times a week in the circulation loop (to obtain 60 °C at the end of the recirculation pipe, the temperature in the storage tank stays above 60°C for 2 hours). Afterwards, the frequency was raised to a daily thermal disinfection of the circulation loop, for 1 hour at 60°C. However, the *Legionella* concentration in the circulation loop remains above 1000 cfu/l.

4.4 Biofilm monitoring

After several thermal shocks (12 x), a ring piece was collected from the recirculation pipe and analysed for the presence of *Legionella* bacteria and ATP. The results from the ATP measurements shows that the bacterial flora on the ring was not affected by the different heat shocks (average of 4.9 10^5 mean cell counts). Thermal shocks on a weekly frequency show a progressive decrease of the *Legionella* concentration on the rings from 3.3 10^6 to beneath 2.5 10^3 (average reduction of 3.3 log), but after a period of 15 days without any thermal shock *Legionella* bacteria recovered to the initial concentration in the biofilm.

5 Conclusions

By applying a thermal shock at 60°C only on the contaminated water tank and the circulation loop on a regular base, the treatment of the test facility with thermal shocks at 60°C (for 0,5 ; 1 ; 2 hours) does not lead to the eradication neither to a low (<1000 cfu/l) concentrations of *Legionella* bacteria in the loop.
Without thermal treatment of the draw-off lines the concentration of *Legionella* (in these lines) is not affected and remains on a high contamination level, which could be a source of an early recontamination of the loop. We observed that the *Legionella* concentration in the draw-off pipes raised already 30 minutes after the disinfection.

However, applying a thermal treatment to the whole test facility at 60°C (for 1 hour) does not lead to the eradication neither to a low (<1000 cfu/l) concentrations of *Legionella* bacteria. The tests performed in laboratory conditions (heat shock at 60°C up to 1 hour) on a homogeneous solution of *Legionella* bacteria in water confirm the results obtained in the test facility.

Because these results show that eradication of *Legionella spp* from the water and the biofilm, (or even stabilising the concentration beneath 1000 cfu/l) seems to be difficult to achieve and remedial action might only lead to a temporarily and limited reduction of the *Legionella* concentrations, it seems that in a contaminated DHW installation with a permanent production temperature of 45°C a regular (even daily) thermal shock at 60°C is not appropriate as a curative treatment in hot water facilities.

As the laboratory tests are promising at 65°C and 70°C, different combinations (production temperature, thermal shock temperature, duration and frequency) will be studied in the full scale test facility.

Sampling at higher flowrate (> 2 l/min) seems also to be interesting to be able to evaluate if there is a possibility of releasing biofilm during the sampling.

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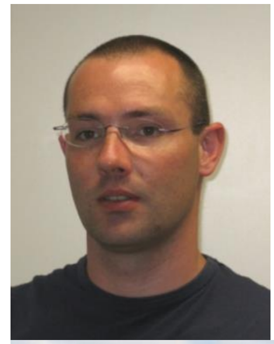
7 Presentation of Authors

Karla Dinne is biochemical engineer and is laboratory head in the laboratory of microbiology and health of the Belgian Building Research Institute (BBRI).

Olivier Gerin is bioengineer and researcher in the laboratory of water technologies of the Belgian Building Research Institute (BBRI).



Bart Bleys is bioengineer and head of the laboratory water technologies of the Belgian Building Research Institute (BBRI).

Karel De Cuyper is actually coordinator at the research directorate of the Belgian Building Research Institute (BBRI).
Before he was, for more than 30 years, in charge of research, development and standardization actions in the field of water supply and drainage of buildings.

A6 - Energy saving assessment by domestic hot water supply system

M.C. Lee
MCJL@nutc.edu.tw, National Taichung University of Science and Technology, Department of Interior Design, 129, Sec.3, Sanmin Road, Taichung , 404, Taiwan

Abstract

The domestic hot water usually consumes much energy and causes carbon dioxide emission in the water supply system. Most domestic hot water demands during the shower period in Taiwan because of hot and humid climate. The energy consumption of the hot water supply system can be divided into three partitions, which are heater efficiency in heating part, piping exothermic in transmission part and separately consumption in the usage part. Energy consumption in heating part almost equals heat loss in transmission part and usage consumption. This study investigated the current conditions in these three partitions, such as the usage part in shower behavior and water demand via users, and analyzed the impact factors to suggest the solution for water saving. It also found the unsuitable temperature of hot water remained inner transmission pipes to waste water before showering. The performance in different resource of heater was also the point of the energy consumption. Based on the investigation results, energy saving assessment equations were developed by this study. The solutions were also submitted to reduce the energy and water consumption for Eco-Life.

Keywords

Domestic hot water demand, investigation, energy and water saving, energy saving assessment equation

1 Introduction

The hot water usually consumes much energy and carbon dioxide emission in the water supply system. Most hot water demands during the shower period in the residential building in Taiwan because of hot and humid climate. The energy consumption of the hot water system can be divided into three partitions, which are heating conversion efficiency in heating part, exothermic hot water in transmission part and separately consumption in the usage part. Energy consumption in heating part almost equals heat loss in transmission part and usage consumption without considering heating conservation efficiency, as shown in Fig. 1.

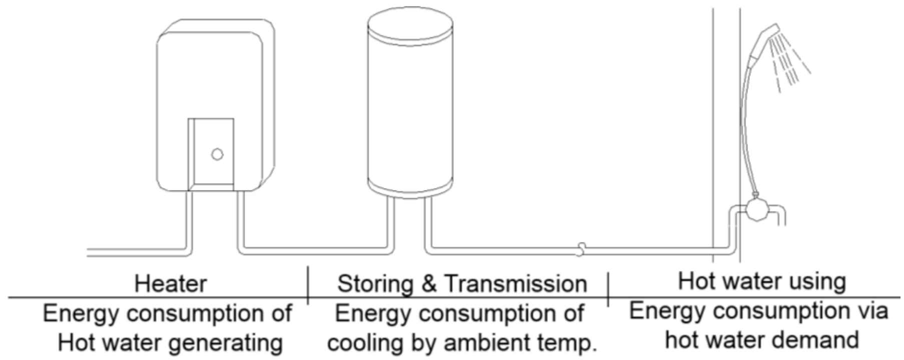


Fig. 1 Energy consumption in different partitions of hot water supply system

This study investigated the current conditions in these three partitions. The first investigation remains about the unsuitable temperature of hot water inner transmission pipes to flow out before showering. Central hot water piping systems are used in large lodging buildings (e.g. hotels, dormitories, etc...) for comfort and convenience, as shown in Fig.2. However, the water temperature drops due to the travel distance and ambient air temperature through the transmission pipes. Large amounts of energy are required for continuous heating and circulation. To evaluate energy consumption and hot water temperature drop in piping, Lee et al.[1] [2] [3] utilized simplified empirical equations and figured out the hot water temperature drop from 60℃ to 40℃ inner 13A stainless pipe is around 10 minutes, as shown in Fig.3.

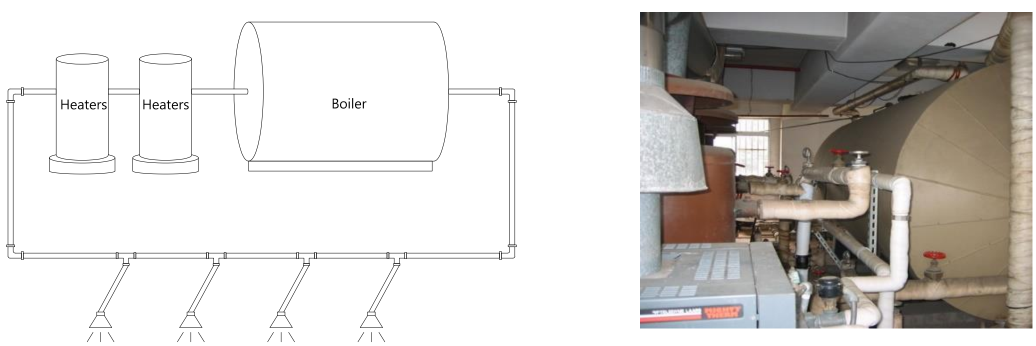


Fig. 2 Typical central circulated hot water system

The previous studies only discussed with the individual hot water non-circulated piping system temperature drop and energy consumption. Morooka and Ichikawa al. [4] provided the flow velocity and waiting time of hot water is shown in Fig.4. Lee [5] submitted an individual circulated hot water supply system to reduce the water demand of piping system

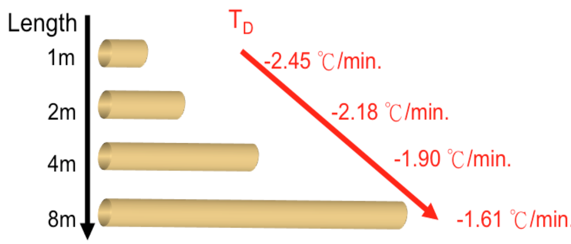


Fig. 3 Hot water temp. dropping time in different length stainless pipe (13A) [3]

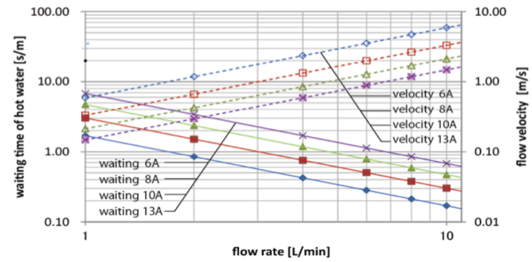


Fig. 4 Flow velocity and waiting time of hot water [4]

The second investigation focuses on shower behavior and water demand via users, and analyzed the impact factors to suggest the solution for water saving. For providing comfort shower, water temperature, flow rate, water pressure and shower period are the main impacts of shower water demand. Most results in energy consumption of hot water usage were presented in previous researches. Murakawa and Takata [6] [7] figured out the different hot water demand in different places and behavior. Mae and Kamada [8] mentioned the energy consumption of hot water demand. Cheng and Lee [9] also investigated the hot water demand in the residential building. But there are few articles discussed about the clean performance and comfort sensation related to water saving. This study focuses on hot water saving via shower periods in residential building in Taiwan, to discuss with using behavior, clean performance and comfort sensation by users for analyzing the water demand and water saving improvement.

The third investigation is related to the heating performance and energy consumption of the heater. The heating system with different heating resource and procedure consumes different quantity of energy and carbon dioxide emission. This study focused on general heating resource such as gas and electric, not in heat pump, and solar heater.

Numerous studies proposed various conservation methods such as the Building Energy Conservation Regulations in Japan (Association of Building Environment Energy Conservation [10]), which focused on energy consumption of the hot water supply system and included heat loss due to circulation. Kamada et al.[11] and Sakaue et al.[12] proposed a standard hot water temperature of a supply system based on energy conservation in Japan. Balaras et al.[13] determined that the variation in pipe heat loss was caused by variations in energy consumption. Jaćimovic et al.[14] proposed that the heat loss from heated objects is a linear function of the outdoor temperature. And Morida [15] presented heat loss calculation equations for distribution pipes. Toyosada [16] figured out the economic benefit of a carbon tax via water saving, Cheng focused on the interrelationship between water use and energy conservation and proposed an evaluation model of CO_2 emission for a water saving strategy [17]. This study discussed with the whole system energy consumption, and also organized the solution to evaluate energy reducing efficiency.

2 Transmission Part

Most residential buildings utilize a central hot water supply system because of the varying usage time periods, and to save energy. However, the problem with this type of system is once usage (circulating) stops, the hot water remaining in the pipes cools due to the ambient air around the piping. Therefore, before use, users need to wait for the undesirable cool water to flow out of the system before the desired hot water starts flowing out of the system. This process may waste a lot of water, depending on the length of the piping system. The ideal solution to this problem is to reheat the undesirable cool water inside the piping system by the use of an individual hot water circulated piping system. This study discusses water saving and energy consumption in the individual hot water circulated piping system.

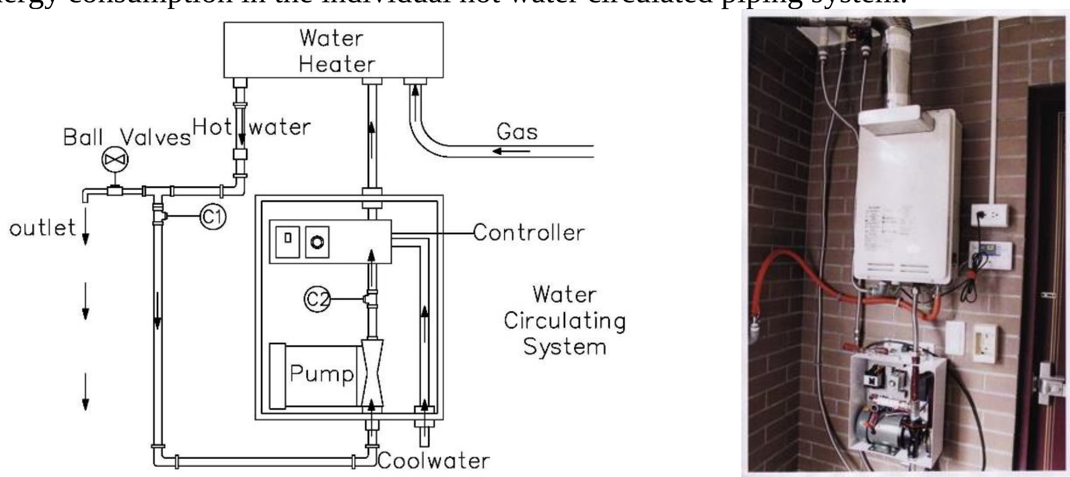


Fig. 5 Intelligent hot water circulator design concept

One circulated water pipe with a check valve (C1) setup before ball valves (faucets) to connect to transmission pipe for recycling and reheating the temperature dropped into hot water in the intelligent hot water circulation system, as shown in Fig.5. The water flows out from the circulator into the heater (gas, electrical, solar, etc.) or hot water tank to heat the recycled water or urban water. The intelligent hot water circulator recycles the temperature dropped water to save water inner transmission pipe and it also provides comfortable hot water washing and saves much energy compared with the central circulated hot water system. Based on investigation of hot water pipe lengths in Taiwan [9], the average length is around 6.5m (the shortest is 0.5m, the longest is 20m) in the residential buildings (apartments and houses). The controller for the circulator can be set by timer and remote panel to reduce the amount of electrical wiring.

An experiment was held to measure water recycling amounts and energy consumption. The experiment adopts the popular heater type in Taiwan (80%) [9], gas heater with 52.3kW heat and controllers, to heat and reheat water, and also adopts the pipe material and length referred by Cheng and Lee [3], stainless steel pipe with insulator, up to 20 meters in length. The optimal hot water circulated time should be under 1 minute to reheat the water to the suitable temperature for comfort and energy conservation. The efficiency of the pump and heater are also considered for the design. In this experiment, air temperature, water temperature, flow velocity, pressure, circulator energy consumption (including electronic control and pumping), heater, and gas consumption were measured in various pipe lengths (1m, 2m, 4m, 8m, 16m, and 20m), as shown in Fig.6. When the heated water temperature reaches the stable flowing temperature of 54℃ (heater set on 55℃), the water demand, electric consumption, and gas consumption can be compared between the circulation system and the non-circulation system.

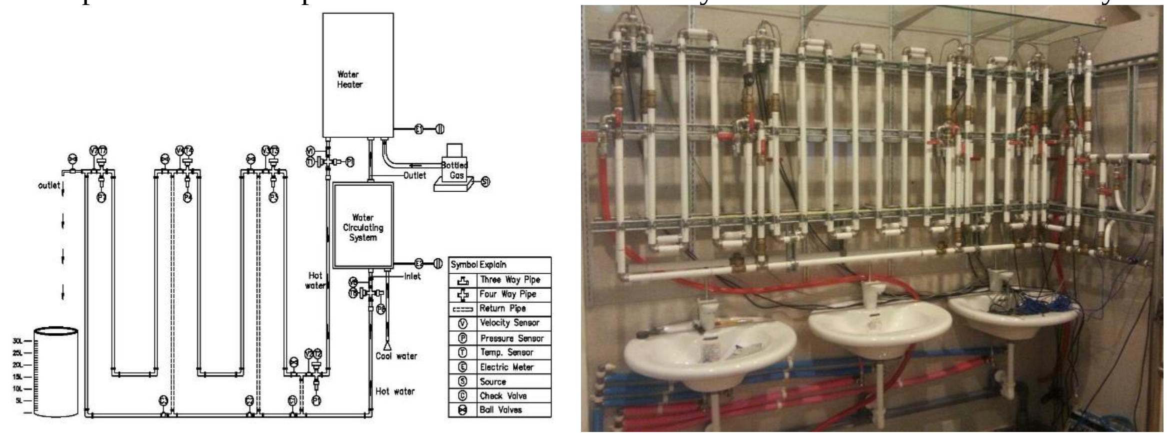


Fig. 6 The construction of a professional circulation system

The results of the experiment focus on the temperature variations and water demand between the heater outlet and faucet inlet in the non-circulated piping system. The water demand estimation is organized as (1) and (2). Based on the results of the experiment, the water demand and energy consumption in the non-circulated piping system is listed in Table 1, the other results in the circulated piping system is listed in Table 2.

$$Q_{1i} = \left(t_n \times v_n\right)_i \quad (1)$$

$$Q_{2i} = Q_{1i} - \left(A_p \times L_p\right)_i \quad (2)$$

Table 1 Water demand and energy consumption in the non-circulated piping system

Pipe length	Period time	Wasted water (Q_2)	Heated water (Q_1)	Gas consumption (S_{ni})	Heater power
m	*sec.*	*l*	*l*	*g*	*Wh*
1	20	3.4	3.5	9.1	1.8
2	25	3.6	3.8	11.2	2.2
4	35	5.8	6.3	15.3	3.1
8	50	7.7	8.8	21.4	5.8
16	80	12.3	14.5	34.0	7.1
20	90	14.3	17.0	39.8	8.0

Table 2 Energy consumption in the circulated piping system

Pipe length	Circulation period time	Gas consumption (S_{ci})	Heater power $(E_H)_{ci}$	Circulator power $(E_R)_{ci}$	Total power
m	*sec.*	*g*	*Wh*	*Wh*	*Wh*
1	13.0	8.8	1.2	1.3	2.5
2	15.0	10.2	1.3	1.5	2.8
4	20.0	11.9	1.8	2.0	3.8
8	30.0	16.6	2.7	3.0	5.7
16	55.0	25.8	4.9	5.5	10.4
20	60.0	31.0	5.3	6.0	11.3

According to Cheng [18] figures out that "1m^3 domestic water consumes about 1kWh equivalent power". The non-circulated piping system can waste large amounts of water depending on pipe length as cool water needs to be discharged from the pipes before the desirable water temperature flowing out. The volume of wasted water is measured and converted to electric equivalent power, then added to the heater power consumption, the results show the total energy consumption of the non-circulated piping system is 50% higher than the energy consumption of the circulated piping system in Fig. 7. The circulated piping system not only saves water, but also saves the energy within the system.

The energy of transmission in piping system (E_P) is related to heated water (Q_1), wasted water (Q_2) with equivalent power coefficient in water (θ_W), fuel weight in non-circulated piping system (S_{ni}) with equivalent power coefficient in heating source (θ_S), and energy consumption of the heater n non-circulated piping system $(E_H)_{ni}$. The solution of transmission energy lost was submitted individual circulated device, the transmission of energy in circulated piping system (E_P') is related to the original energy of transmission of energy in piping system (E_P), and piping transmission energy saving considering by E_{PWS} (power saving without wasted water (Piping water saving), fuel weight in circulated piping system (S_{ci}) with equivalent power coefficient in heating source (θ_S), and energy consumption of the heater $(E_H)_{ci}$ and circulated device $(E_R)_{ci}$ in circulated piping system). The evaluated equation organized as (3) and (4).

$$E_P = (Q_{1i} - Q_{2i}) \times \theta_W + (E_H)_{ni} + S_{ni} \times \theta_S \qquad \text{kWh} \qquad (3)$$

$$E_{PWS} = (Q_{1i} - Q_{2i}) \times \theta_W + (E_H + E_R)_{ci} + S_{ci} \times \theta_S \qquad \text{kWh} \qquad (4)$$

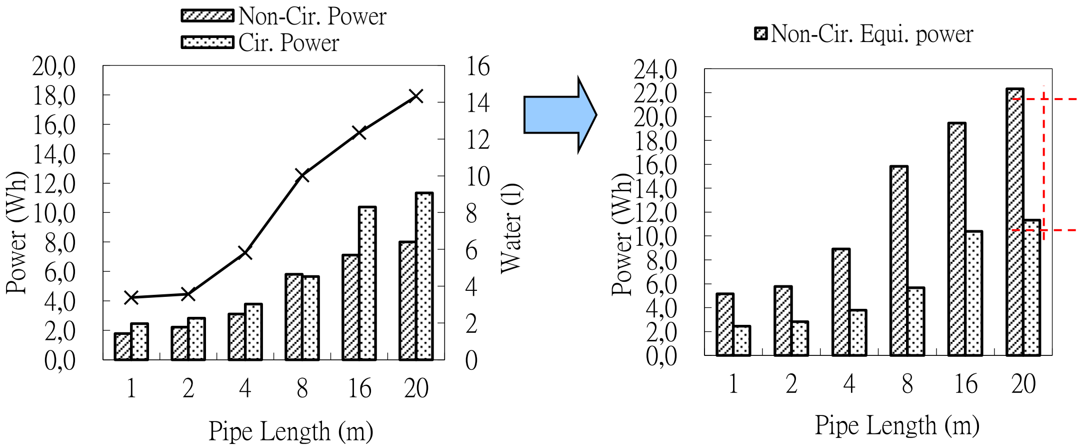


Fig. 7 Wasted water converted into equivalent power to compare with the total power consumption between the non-circulated and circulated piping system

3 Shower behavior and water demand (Usage Part)

To understand the shower comfort in water temperature, flow rate, water pressure and shower period are the main impacts of shower water demand. This study invited about 40 households to participate to this investigation with different showerheads in Eco shower (ES) and Investigated shower (IS) to compare with the shower comfort of subjects in the same water supply pressure in each sample. The investigation was divided into field survey for physical parameters and questionnaire for user sensation, as shown in Fig. 8.

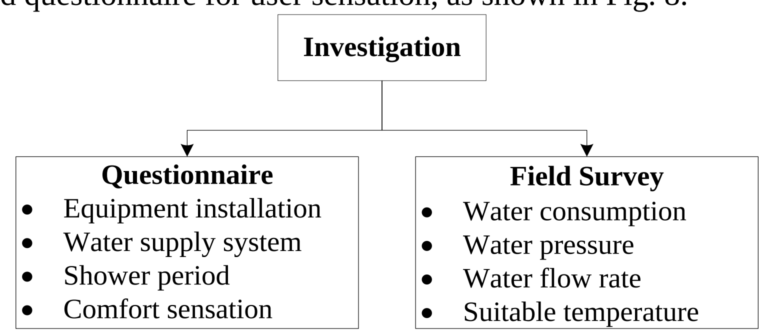


Fig. 8 Two phases of observation in investigation

The field survey are adopted the pressure meter, flow meter, thermometer and timer to measure the water pressure, flow rate, suitable water temperature and shower period. Set up a set of measurement as shown in Fig. 9. The device must set up as high as the faucet to reduce the mistake from height difference pressure and flow rate. The questionnaire for investigation is to ask the showering sensation of user, it divided into three parts, as listed as Table 3.

Table 3 Questionnaire of field survey in current hot water system

Part. 1 The water supply conditions in the residential building

1. What was the type of your dwelling?
2. How many floors does your residence have?
3. Which floor do you live?
4. What kinds of water supply system does your house have?

Part. 2 Shower comfort sensation of subjects

5. How well does the water flow "Soft Sensation" compared with your previous showerhead?
6. How well does the water flow "Dense Sensation" compared with your previous showerhead?
7. How well does the water flow "Concentrated Sensation" compared with your previous showerhead?

Part. 3 Measuring in water supply pressure, flow rate, temperature, and periods.

Measuring values / Shower Head type	Water pressure (MPa)	Flow rate (l/min)	Temperature (℃)	Shower periods (Sec.)
NS				
IS				
ES				

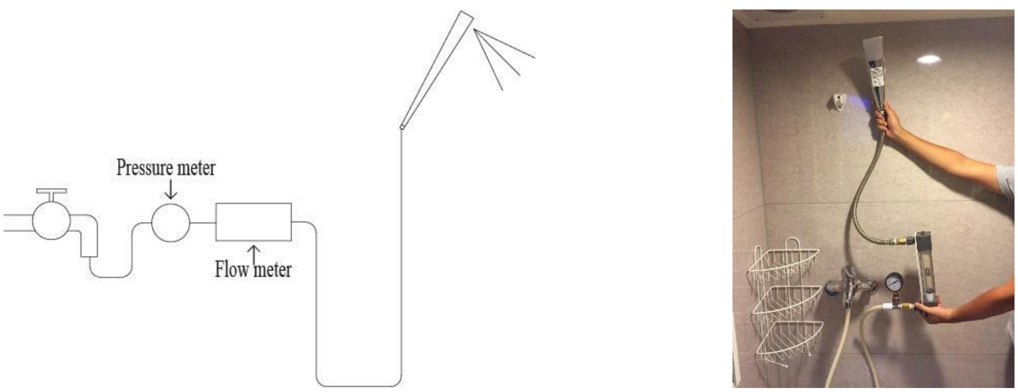


Fig. 9 - Measure device schematic and field survey installation

Based on the investigated results, the water pressure is significantly different between Taipei (many apartments with pressure water system) and Taichung (many houses with gravity pressure water). The comfort sensation votes of users by using ES are shown as Fig. 10, the results show the feeling of users in high water supply pressure area is much acceptable concentrated feeling than the feeling of the users in low water supply pressure area. Because users in Taipei are long-term staying in high water pressure, users have already accustomed by strong pressed feeling, other feelings are similar with dense feeling and soft feeling in different pressure conditions.

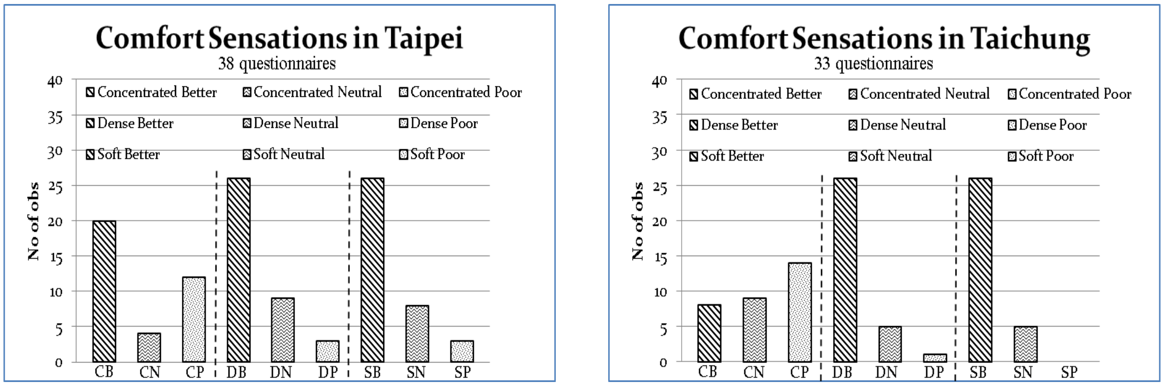


Fig. 10 The Comfort Sensation in Taipei and Taichung

Compare with the shower period and water consumption between ES and IS, the average of shower period in ES is longer than it in IS in Taichung, but it is opposite in Taipei. The reason is related to the water supply pressure and comfort sensation with Eco showerhead (ES). When the water pressure is large, the users feel comfortable with the concentrated sensation in high water supply pressure areas, they do not spend much time to take a shower, as shown in Fig. 11. The figure 11 presents the average shower period is around 300 sec. but the average water flow rate in ES is only 70% with it in IS. It means the water saving rate *"REWS"* of showerhead is about 0.7 when ES is adopted.

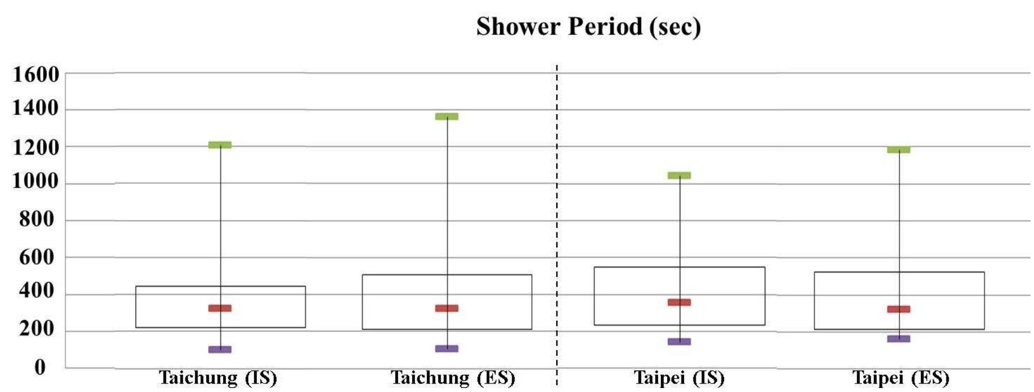


Fig. 11 Shower period in ES and IS in different water supply pressure areas

The hot water demand (Q_i) is calculated with water flow rate and showering period in Eq.5. The energy consumption of water using is related with water demand, density, specific heat, and temperature difference, (hot water heating energy and water supply energy θ_W (kWh/m^3) as shown in Eq. 6. The temperature of cold water is referred with Lee's evaluated equations in Eq.7 [2].

$$Q_i = v_i \times t_i \quad (5)$$

$$E_U = Q_i \times \rho \times s \times [(T_{ave} - T_C) + 1] \times \theta_W \quad (6)$$

$$T_C = 0.93 \times T_a + 1.78 \quad (7)$$

The water saving is related to the shower comfort analysis via water pressure and flow rate. Unsuitable water pressure and flow rate may cause an uncomfortable shower sensation and water consumption while long shower period and strong or tender water flowing. Setup critical values of water pressure and flow rate via shower comfort sensations could be saved the water in different showerheads. The investigated water flow rate is also organized as shown in Fig.12. The average water flow rate is 8.6 l/min in Japan and 9.9 l/min in Taiwan, the water demand over the average value is defined as wasted water [19]. Save 9% water demand from 9.9 l/min to 9 l/min by accumulated percentage of comfort water flow rate, saving 19% from 9.9 l/min to 8 l/min, and saving 29% from 9.9 l/min to 7 l/min in Taiwan. Referenced the water saving percentage to define 3 levels in water saving via flow rate. The flow rate in lower saving level is between 8.5 to 10.0 l/min, the second level is during 7.0-8.5 l/min, the top saving level is under 7.0 l/min.

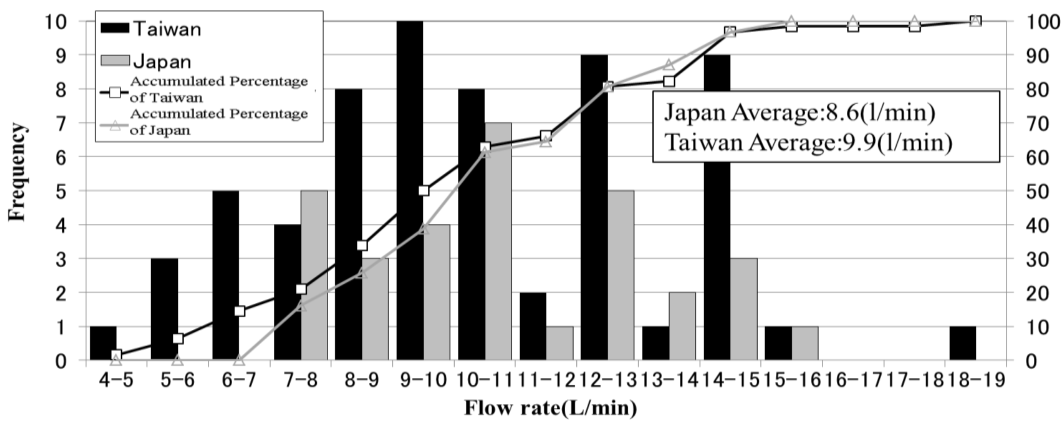


Fig. 12 The accumulated percentage of comfort water flow rate in Taiwan and Japan

4 Heating Part

The energy consumption of heating part almost equals the energy consumption of transmission part and using part. But the different performance of heater caused the energy consumption more or less. The performance is related with coefficient of performance (*COP*) of the heater. The past heater was supported by gas, oil or electric, mostly in gas and electric in the residential building. For considering the conditions of hot water supply, the hot water supply system usually divides into two types in central and individual system. Central hot water supply system is used in large lodging buildings (e.g. hotels, dormitories, etc.) with boiler and circulated piping system for comfort and convenience. Individual system normally installed with a single small heater into independent house, flat or apartment with non-circulated piping system.

The *COP* of heaters is improving in these years for energy consideration, such as heat pump between 2 to 6, gas heater over 0.95 (0.8 in the past), electric heater over 0.8 (0.6 in the past). The renewable heater also developed without much energy consumption, such as solar heater, ground heat source heater. This study investigated with current installed heaters and evaluated with the energy consumption of each person while showing with 45l in 39℃ (the water temperature of heater outlet is set in 55℃ for deducing Legionella bacteria, cold water is set as 23℃).

5 Energy reducing evaluation

Based on the energy consumption in heating part (EH) almost equals heat loss in transmission part (EP) and usage consumption (EU) without considering heating conservation efficiency. The evaluation of whole hot water supply system can be organized as follow, it should be also considered with heating conservation efficiency in COP, piping transmission energy saving considering by EPWS（Piping water saving）, shower head water saving rate REWS（Rate of Equipment in Water Saving, less or equal than 1.0） for real condition. The evaluation equations of energy consumption and energy conservation (EH') by water saving could be submitted as follow. The energy reducing efficiency could be submitted as E_E to evaluate the improving method of water saving or energy saving, the E_E should be under 1.0 (lower is much better than higher). If E_E is higher than 1.0, it means the improving method should be revised.

$$E_H = (E_P + E_U)/COP \quad \text{kWh} \quad (8)$$

$$E_H' = (E_P' + E_U')/COP \quad \text{kWh} \quad (9)$$

$$E_P' = E_P - E_{PWS} \quad \text{kWh} \quad (10)$$

$$E_U' = E_U \times REWS \quad \text{kWh} \quad (11)$$

$$E_E = E_H'/E_H \quad - \quad (12)$$

One example from our investigation in original and improving condition of energy consumption in whole hot water system in Taiwan is checked by these assessment equations. The transmission pipe belongs 13A stainless pipe in 8m long with non-circulated and circulated piping system, 45l mixed hot water temperature is set around 39℃ (hot water in 55℃ and clod water in 23℃), the water saving showerhead is around 70% than original showerhead. The results are presented in the estimation of the energy reducing efficiency by the evaluation concepts as shown in Table 4. The energy reducing efficiency (E_E) is estimated at 0.475, it means the **energy saving 52.5%** after submitting the solution to rise up the *COP* of the heater, to adopt the individual circulated piping system, and to change the water saving showerhead.

Table 4 Energy reduces efficiency of hot water saving solution

Original energy consumption in hot water supply system (E_H)		Improving the condition of energy consumption in the hot water supply system (E_H')	
COP = 0.8 Old LPG heater		*COP* = 0.95 New LPG heater	
E_P 0.30 kWh	E_U 0.77 kWh	E_P' 0.07 kWh	E_U' 0.54 kWh
$\boldsymbol{E_E}$ **= 0.475**			

6 Conclusion

This study investigated with whole energy consumption of hot water supply system, and also submitted some energy and water saving solutions in different parts (heating part, transmission part and using part) for Eco-Life. Based on the energy consumption in each partition to submit the assessment equations for checking the efficiency of energy reducing. As the investigation and summited solution, the energy reducing efficiency (E_E) was estimated at 0.475, the energy saving 52.5% after rising up the COP of the heater, individual circulated piping system, and change the water saving showerhead. If the heater changes in renewable energy, the energy reducing efficiency would be higher.

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8 Acknowledgment

The authors would like to thank the Ministry of Science and Technology of Taiwan, for financially supporting this research under Project Contract No. MOST 103-2221-E-025 -005 and MOST 104-2221-E-025 -012, and also thank TOTO LTD to collaborate with this research.

9 Presentation of Author

Meng-Chieh, Jeffrey Lee is a PhD in Architecture and an Associate Professor at National Taichung University of Science and Technology, Department of Interior Design. His major is water plumbing system, sanitary equipment safety and new technology development, interior environmental control and energy saving.

A7 - Quantitative Evaluation Method of Resource and Energy Conservation in a Water Supply and Drainage System

Hiroyuki Kose (1), Tamiko Nakano (2) and Toyohiro Nishikawa (3)
1. hkose@toyo.jp
2. t-naka@suac.ac.jp
3. t-nskw@cc.kogakuin.ac.jp
(1) Professor, Department of Information Sciences and Arts, Faculty of Information Sciences and Arts, Toyo University, Japan
(2) Associate Professor, Department of Design, Faculty of Design, Shizuoka University of Art and Culture, Japan
(3) Professor, Department of Urban Design and Planning, School of Architecture, Kogakuin University, Japan

Abstract

This paper is the activity report organized as subcommittee of Architectural Institute of Japan (AIJ). The mechanism to estimate overall about resource and energy conservation in a building have been made from the time when United Nations Framework Convention on Climate Change is proclaimed in 1994 and the Kyoto Protocol is adopted in 1997. And the middle target reduced 26.0 % in fiscal year 2030 by the ratio in fiscal year 2013 is set by the Paris agreement settled on in COP21, 2015 at present [1]. Moreover "ZEB road map" aiming at achieving ZEB (net zero energy building) for an average of new public buildings by 2020 and for an average of new buildings by 2030 was published by Japanese Government in 2015 [2]. Energy conservation-ization in the water supply and drainage system is a pressing problem introduction of high-efficient hot-water supply. However, the contribution is small more than the other elements for the element about the water supply and drainage system and the water environment in Japan. For example, it's estimated as individual effort, but behavior such as water conservation fittings, rainwater use system and drainage reuse system aren't estimated at the inside through infrastructure from water intake to effluent treatment, and it isn't done clearly how effective its effect is to society and the environment. So, the evaluation and indication method in a quantitative way is developed that how much each effort of the resource and energy conservation about a water supply and drainage system and water environment will be in this paper. By the former activity of this sub-committee, collection of evaluation methods of resource and energy conservation, case collection of resource and energy conservation

architectures and examination of a structure of evaluation were cleared. The current state of study and future's task will be reported in this paper.

Keywords

Water conservation, energy conservation, simple evaluation system,

1 Introduction

In the plumbing system field of Japan, water conservation and energy saving about water are performed each element of water supply, hot water supply and plumbing fixtures and t and the study which includes the whole isn't enough. For example, even if reduction in washing quantity of water of the plumbing fixtures is developed, the thing can't be reflected about laying of the pipes and a design of equipment.
When it's possible to know how much water resource saving of the amount and energy saving are planned for as the whole when water conservation and energy saving were formed out of equipment, an incentive to introduction will function and be promotion of the spread. When it's possible to make the simple tool the way of calculation tends to understand, it'll be promotion to consideration to water environment by the level of the architect and the client and I can think it can also be utilized as educational consideration.
So, the evaluation and indication method in a quantitative way is developed that how much each effort of the resource and energy conservation about a water supply and drainage system and water environment will be in this paper. Moreover, this paper is the activity report organized as subcommittee of Architectural Institute of Japan (AIJ).

2 Methods

First, it's surveyed the evaluation of water supply and drainage system about environmental performance evaluation tool CASBEE [3] developed in Japan, similar tool LEED v4 BD+C [4] in the United States and building energy simulation tool the BEST Program [5] developed in Japan. The evaluation factor of Net Zero Water Building Strategies [6] settled on by American Department of Energy is checked.
The basic unit for these water resources and the energy (here, the carbon dioxide amount of emission) is set as a process to the source of water supply, water supply, hot water supply, drainage and water processing while referring to a document about these evaluation technique and basic unit. And the worksheet which calculates water resources the energy consumption in a building are made.
At the end, water resources and the energy consumption are calculated as a test using this worksheet. A change in the consumption of the water resources and the energy by introduction of water conservation equipment, water conservation behavior, introduction of renewable energy in hot water supply and introduction of non-potable water use is considered.

3 Evaluation Tools of Water Resources and Energy

3.1 CASBEE

CASBEE (Comprehensive Assessment System for Built Environment Efficiency) is developed in Japan and is the environmental in building total performance evaluation system which is widely used. Evaluation is formed out of BEE (Built Environment Efficiency) = Q (Quality) / L (Load) in CASBEE It'll be high evaluation so that building environmental performance is high and that building environmental load will be low.
It's explained about the item about the field related to the water supply and drainage system. There are preservation and creation of the renewal necessary time of the air conditioning and the water supply and drainage laying of the pipes, the reliability of the water supply and drainage, the renewal performance of a pipe for water supply and drainage, and creature of the biotic environment on the outside environment (biotope) about Q (building environmental performance). The energy saving and high efficiency-ization of hot water equipment and high efficiency operation, the rainwater use and non-portable water use which use efficiently and contributes to reduction in water supply consumption as water resource conservation and rainwater outflow restraint as consideration the area environment are incorporated about L (building environmental load). But these items are a partial one, and relationship of infrastructure and each item isn't considered.

3.2 The BEST Program

The BEST Program is able to do the simulation which coupled all equipment in a building. And it is able to simulate in detail using a weather data and the load pattern with the feature. In the water supply and drainage system, there are three programs: water supply, hot water supply and rainwater use. A simulation is possible by the condition of the default simply, and when customizing the condition, an in-depth simulation is possible. But it's difficult to grasp resource and energy conservation in water supply and drainage system.

3.3 LEED

Then a water relation system takes up LEED v4 BD+C (renewed on July 1, 2015) as integrated process first. It's written clearly to contribute to load reduction in water and sewage by reduction in the inside or outside demand of water and the grade of the supplier's provision of non-drinking water here. Outflow restraint of rainwater by maintenance of green infrastructure is written clearly in storm water management of SS credit in a site.
More use of water conservation equipment in the indoor water consumption reduction, measurement of a water meter and reduction in watering in the reduction by which it's the watering amount whether it's unnecessary and which are watering in the outdoor water consumption reduction in efficient use of water (WE) are written clearly.
But, point system is taken for LEED, and it isn't certain how much effect these restraints bring specifically.

3.4 Net Zero Water Building

In the “Net Zero Water Building Strategy”, to verify that the building is operating at net zero, annual water use data for each water flow is collected.
- Potable water use
- Non-potable water use (from freshwater sources)
- Alternative water use
- Treated wastewater on-site returned to original water source
- Storm water infiltrated to the original water source through green infrastructure.

When there is a destination of sewage and a branch at a Japanese city, underground penetration is prohibited. But for the underground penetration system to be used, when there were no destinations, I decided to make the model who can calculate based on this concept by this study.

4. Program for Water Resources and Energy Evaluation

4.1 Purpose

For the purpose of development of the program is that a building designer and a client can put in the water and energy conservation can consider each other, when, even a learner, for example a college student can use easily. And it was considered in order to subdivide various water use.

4.2 Calculation Method

Water use was shared with 17 according to the use and available discharge per each once was presumed from a reference [7]. And the use number of times per day per person and number of users is inputted, and the annual use number of days is crossed and annual water consumption in each water use is calculated.
Water resources are classified into 5 stages of the water sources, water supply, water heating or cooling, water discharge or recharge and the water processing, and volume of water consumption and the energy amount (here, the amount of CO_2 emission) according to each use are totaled. The CO_2 emissions per unit in each use is being presumed based on a reference [8] - [12]. Further, the use volume of hot water was calculated as a test as 50% of volume of water consumption of each use.
The condition can change the basic unit. It'll be necessary to be setting standard value from now on.

4.3 Trial Calculation

A case is set up as a trial about housing of family number of people 3 people, 100 m^2 of roof area, 1300 mm of annual amount of rainfall and 50 % of rainwater collection rate by this research. It was analyzed by 7 cases: use only of potable water (rainwater recharge), introduction of water conservation equipment, reduction in bathtub bathing number of times, introduction of a solar heat hot water supply system, introduction of rainwater use, introduction of drainage reuse and septic tank drainage recharge by this study. Table-1 shows a default case

(Case 1) and a worksheet. Table-2 shows each case or parameters. From Figure-1 to Figure-4 show diagrams of each water system.
Figure-5 and Figure-6 show some comparisons between calculated water consumption and CO_2 emissions using some indices. The model outline is shown on the table.
This test shows that volume of water consumption is decreased at most 20 % by introduction of water conservation equipment and decrease of the bathtub bathing. I find out that amount of CO_2 emission is reduced at most 49 % by introducing a solar heat hot water system and a rainwater utilization system as well as these systems and a service.
Each reduction in water resources and energy by introduction of the system and load reduction to infrastructure become possible to estimate the various situations relatively by use of this program. The throughput of the non-potable water and the amount of consumption decrease by introduction of water conservation equipment by the test calculation which assumed detached house, and a desirable thing finds out that rainwater use is introduced.
Because the bathtub bathing is performed daily in Japan, reduction in hot water supply amount and introduction of a solar heat hot water supply system are very effective in reduction in CO_2 emission.

5 Conclusion

This study was made the fact purpose of comparing and examining a resource saving and energy saving in water environment and developing the simple program with which introduction of environment consideration equipment and a system is supported. A program using a spread sheet was developed and 7 cases were calculated as a test calculation while surveying an environment evaluation system in a building of existence.
The next can be named as future's problem.

1. Collection of the appropriate basic unit according to the building use and the scale and consideration of its validity (based on the primary energy)
2. Consideration of groundwater use in the water source
3. Consideration of an energy consumption of a pump in a watering system in the building
4. Consideration of a cooling tower make-up water in a building for business use
5. The information collection to raise a generality and renewal of a program

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7 Presentation of Author

Hiroyuki Kose is the Professor at Toyo University, Faculty of Information sciences and arts from 2009. Special fields of study are plumbing engineering, water environment, reproduction of the agricultural and forestry industries by collaboration of citizens and an organization and community design for regional vitalization.

Table-1 Worksheet of Default Case (Case 1)

Water

Item	Element
Water Source	City Potable Water
	Rainwater+Gray Water
Water supply	Potable Water
	Non-Potable Water
Water Heating & Cooling	Hot Water Supply
	Cold Water Supply
	Regional Heat Supply
Water Discharge or Recharge	Black Water
	Gray Water
	Recharge Water
Water Treatment	Sewage System
	Septic System
	Water Treatment

Buildings

Item	Element
Type	House
Person(s)	3
Roof Area [m^2]	100
Rainwater [mm/year]	1300

CO_2 Emission

Energy	CO_2 Emission [kg-CO_2/m^3]
Potable Water	0.251
Non-Potable Water	0.063
Hot Water Supply	4.8
Sewage System	0.439
Septic System	1
Water Treatment	0.6

Household

Persons	Water Consumption [m^3/year]
1	98.4
2	190.8
3	244.8
4	291.6
5	342

Others

Hot Water Use Ratio	0.5
Rate of Water collection	0.5

No.	Water Use	Unit of Water Consumption [L/times]	Times [times/day]	Person(s) or Times	Number of Days Used	Annual Water Consumption [m^3/year]	Percentage of Water Consumption	Water Source	Water Supply	Water Heating or Cooling	Water Discharge or Recharge	Water Treatment	Unit of CO_2 Emission from Water Supply [kg-CO_2/m^3]	Unit of CO_2 Emission from Water Heating or Cooling [kg-CO_2/m^3]	Unit of CO_2 Emission from Water Treatment [kg-CO_2/m^3]	CO_2 Emission from Water Supply [kg-CO_2/year]	CO_2 Emission from Water Heating of Cooling [kg-CO_2/year]	CO_2 Emission from Water Treatment [kg-CO_2/year]	Annual CO_2 Emission [kg-CO_2/year]	Percentage of CO_2 Emission
1	Kitchen Cooking & Washing	13	3	3	365	43	17%	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	0.25	4.80	0.44	10.79	103.20	18.88	133	23%
2	Hand & Face Washing	1.5	7	3	365	11	4%	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	0.25	4.80	0.44	2.76	26.40	4.83	34	6%
3	Bathtub	200	1	1	365	73	29%	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	0.25	4.80	0.44	18.32	175.20	32.05	226	39%
4	Bathroom Shower	35	1	3	365	38	15%	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	0.25	4.80	0.44	9.54	91.20	16.68	117	20%
5	Bidet	0.2	3	3	365	1	0%	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System	0.25	4.80	0.44	0.25	2.40	0.44	3	1%
6	Washing Machine	40	1	3	300	36	14%	City Potable Water	Potable Water		Black Water	Sewage System	0.25	0.00	0.44	9.04	0.00	15.80	25	4%
7	Dishwasher												0.00	0.00	0.00	0.00	0.00	0.00	0	0%
8	Humidifying	1	1	1	100	0	0%	City Potable Water	Potable Water				0.25	0.00	0.00	0.00	0.00	0.00	0	0%
9	Evaporative Cooling												0.00	0.00	0.00	0.00	0.00	0.00	0	0%
10	Steam Heating												0.00	0.00	0.00	0.00	0.00	0.00	0	0%
11	Cleaning	5	1	3	180	3	1%	City Potable Water	Potable Water		Black Water	Sewage System	0.25	0.00	0.44	0.75	0.00	1.32	2	0%
12	Plumbing Fixtures	9	5	3	365	49	19%	City Potable Water	Potable Water		Black Water	Sewage System	0.25	0.00	0.44	12.30	0.00	21.51	34	6%
13	Fire Fighting												0.00	0.00	0.00	0.00	0.00	0.00	0	0%
14	Thawing												0.00	0.00	0.00	0.00	0.00	0.00	0	0%
15	Vehicle Washing												0.00	0.00	0.00	0.00	0.00	0.00	0	0%
16	Irrigation	20	1	1	100	2	1%	City Potable Water	Potable Water				0.25	0.00	0.00	0.50	0.00	0.00	1	0%
17	Landscape												0.00	0.00	0.00	0.00	0.00	0.00	0	0%
18	Overflow of Gray Water					0	0					Sewage System			-0.15	0.00	0.00	0.00	0	0%
19	Rainwater	130000				65	0	Rainwater			Recharge Water		65							
		Rainwater Fall				Rainwater Recharge	Rainwater Use						Rainwater Catchment							

1	City Potable Water	Potable Water	Hot Water Supply	Black Water	Sewage System
2	Rainwater +Gray Water	Non-Potable Water	Cold Water Supply	Gray Water	Septic System
3	Rainwater		Regional Heat Supply	Recharge Water	Water Treatment

Water Consumption								
Total [m^3/year]	256	1	256	256	166	254	254
Total [L/day,person]	234	2	0	0	0	0	0
		3	65		0	65	0
		Total	321	256	166	319	254
		Rate	25%		65%	99%	99%
			Zero Water Building		Water Heating or Cooling	Rate of Water Discharge	Rate of Water Treatment

[kg-CO2/year]		Water Supply	Water Heating or Cooling	Water Treatment	Total	Rate
CO_2 Emission	from Infrastructures	64	0	112	176	31%
	From a Building	0	398	0	398	69%
	Total	64	398	112	574	
	Rate	11%	69%	19%		

Table-2 Parameters of Each Case

Case	Wter Source	Water Supply	Water Discharge or Recharge	Water Treatment	Rainwater	Water Conservation Equipment	Water Heating or Cooling	Unit of Water Consumption [L/times] of Bathroom Shower	Unit of Water Consumption [L/times] of Plumbing Fixtures	Number of Days Used of Bathtub	Unit of CO_2 Emission from Water Heating or Cooling [kg-CO_2/m^3]
Case 1	City Potable Water	Potable Water	Black Water	Sewage System	Recharge Water	None	Heat Pump Water Heater	35	9	365	4.8
Case 2	City Potable Water	Potable Water	Black Water	Sewage System	Recharge Water	Bathroom Shower and Plumbing Fixtures	Heat Pump Water Heater	25	6	365	4.8
Case 3	City Potable Water	Potable Water	Black Water	Sewage System	Recharge Water	Bathroom Shower and Plumbing Fixtures Reduce of Days Used Bathtub	Heat Pump Water Heater	25	6	250	4.8
Case 4	City Potable Water	Potable Water	Black Water	Sewage System	Recharge Water	Bathroom Shower and Plumbing Fixtures Reduce of Days Used Bathtub	Heat Pump Water Heater + Solar Water Heater	25	6	250	2.4
Case 5	City Potable Water	Potable Water	Black Water	Sewage System	Recharge Water	Bathroom Shower and Plumbing Fixtures Reduce of Days Used Bathtub	Heat Pump Water Heater + Solar Water Heater	25	6	250	2.4
	Rainwater	Non-Potable Water									
Case 6	City Potable Water	Potable Water	Black Water	Sewage System	Recharge Water	Bathroom Shower and Plumbing Fixtures Reduce of Days Used Bathtub	Heat Pump Water Heater + Solar Water Heater	25	6	250	2.4
	Rainwater+Glaywater	Non-Potable Water	Gray Water	Water Treatment							
Case 7	City Potable Water	Potable Water	Recharge Water	Septic System		Bathroom Shower and Plumbing Fixtures Reduce of Days Used Bathtub	Heat Pump Water Heater + Solar Water Heater	25	6	250	2.4
	Rainwater+Glaywater	Non-Potable Water	Gray Water	Water Treatment	Recharge Water						

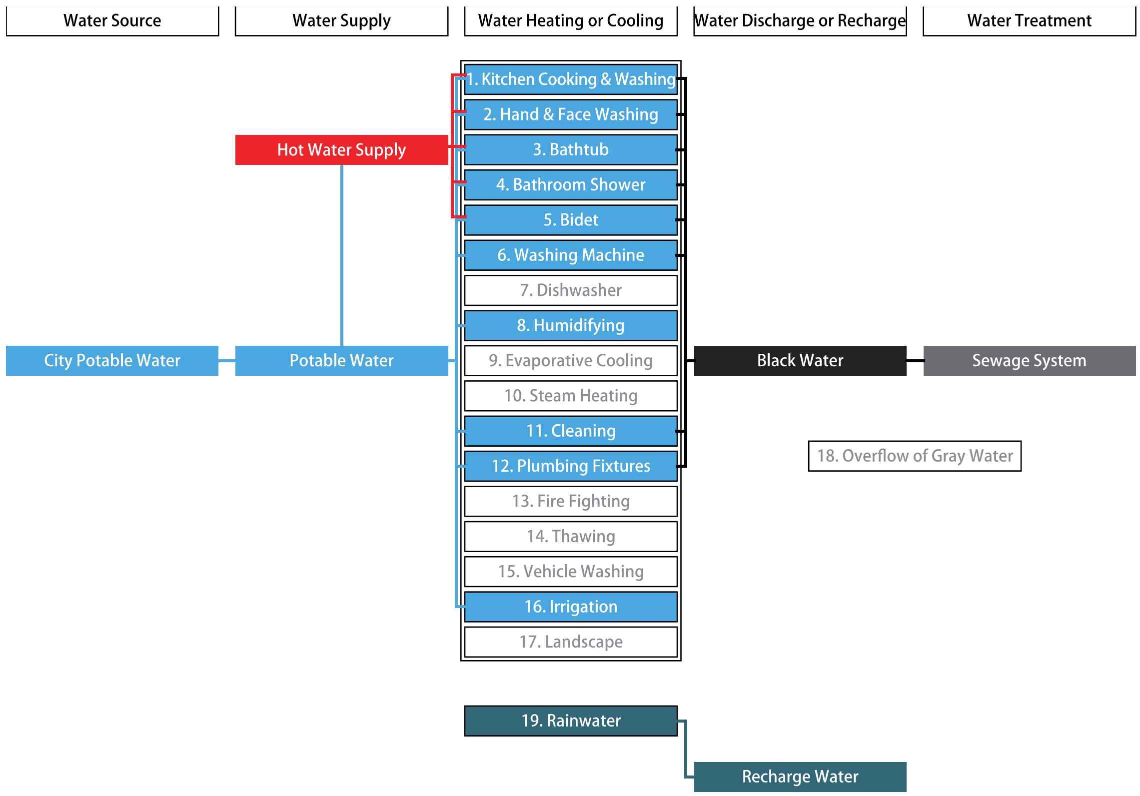

Figure-1 Diagram of Water System in Case 1,2,3,4 (Default Case)

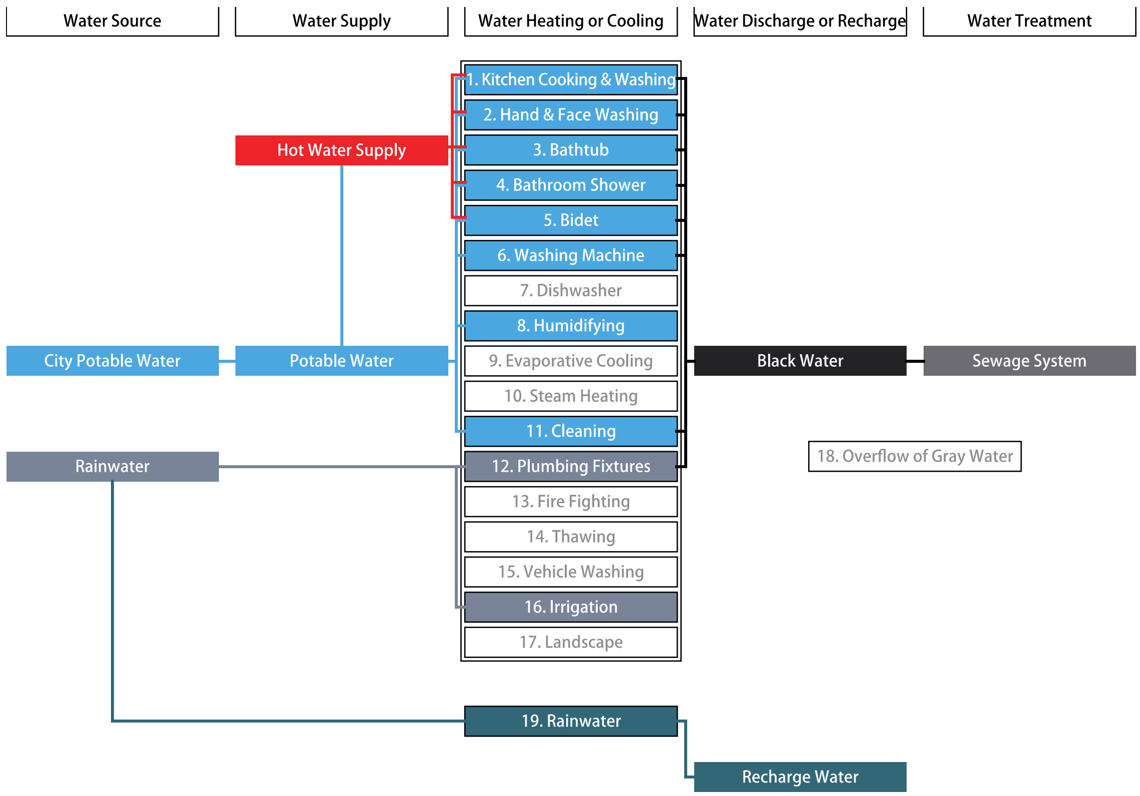

Figure-2 Diagram of Water System in Case 5 (Introduction of Rainwater Use System)

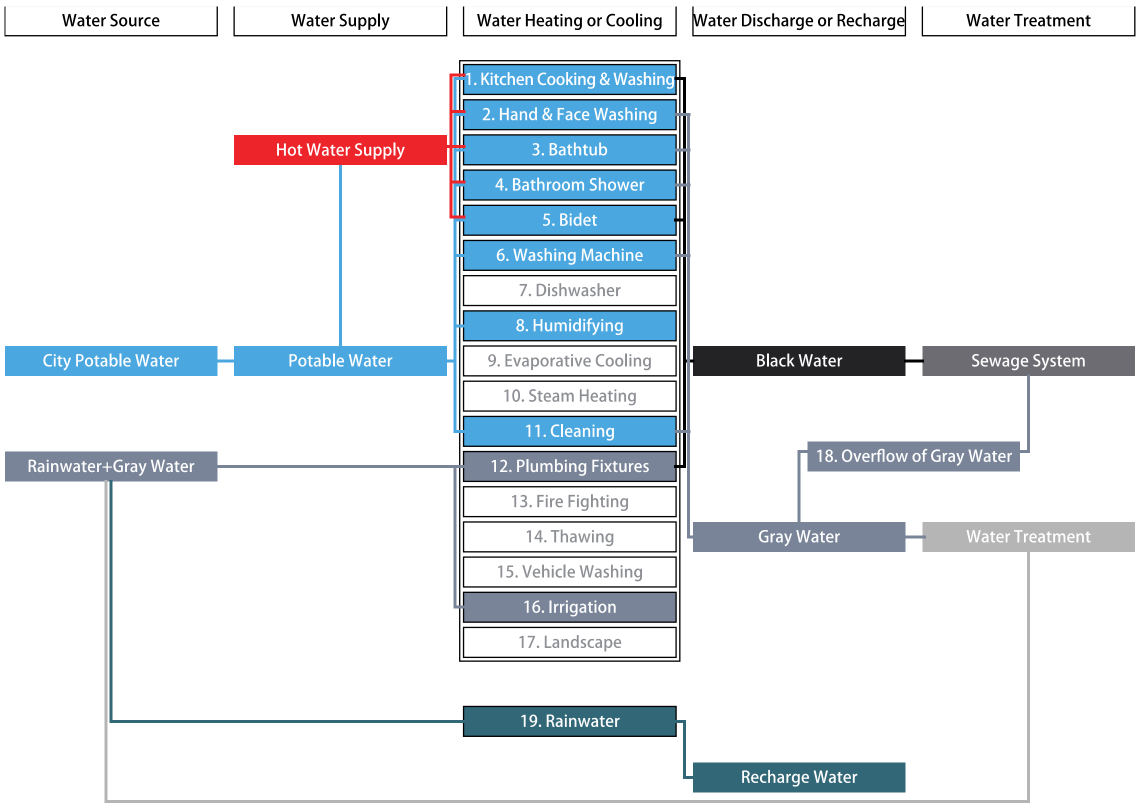

Figure-3 Diagram of Water System in Case 6 (Introduction of Gray Water Use System)

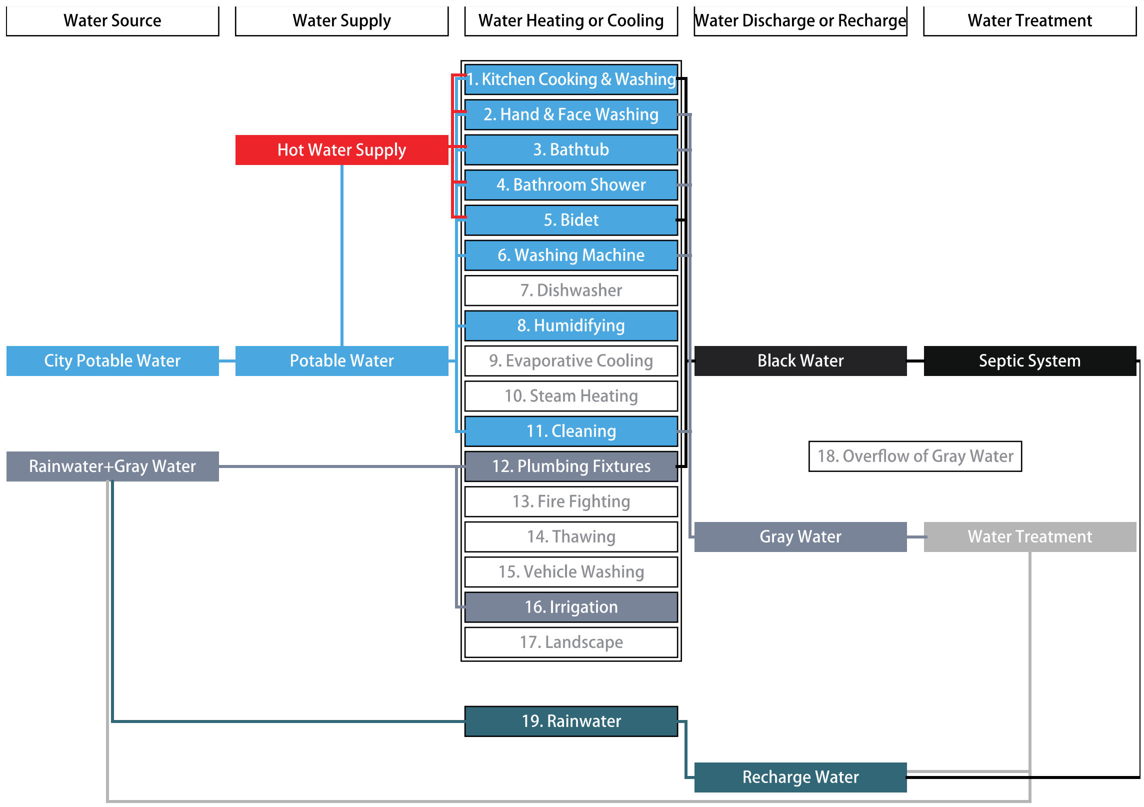

Figure-4 Diagram of Water system in Case 7
(Introduction of Septic Tank Drainage Recharge)

Figure-5 Results of Test Calculation
(1. Rate of Non-Potable Water, 2. Water Balance of Non-Potable Water, 3. CO2 Emission from Infrastructures or a Building, 4. Net Zero Water Index)

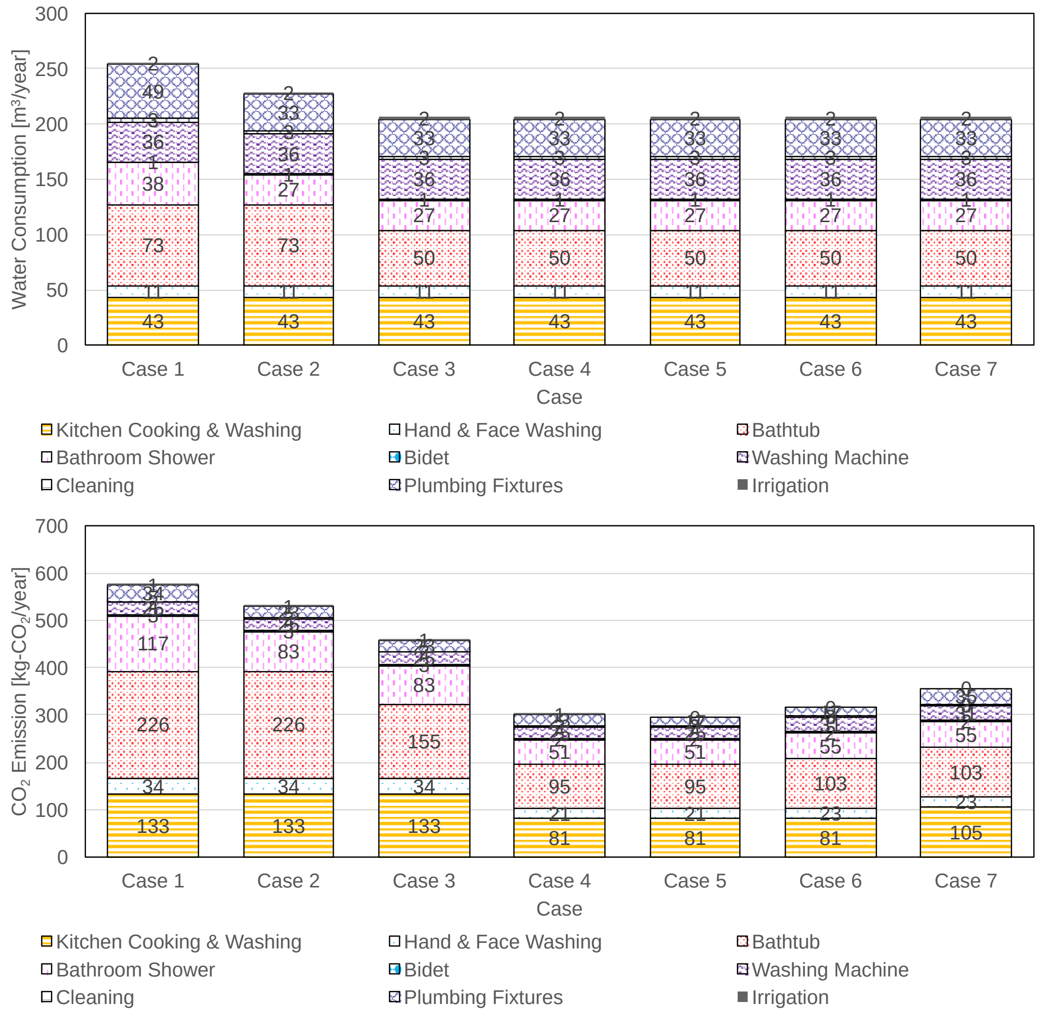

Figure-6 Results of Test Calculation
(5. Total Water Consumption and CO_2 Emission for Each Case)

A8 - Role of pipe materials in enhanced microbial growth of total microflora and opportunistic pathogens

Paul W.J.J. van der Wielen (1, 2), Ludmila Bereschenko (3) & Kimberly Learbuch (4)

1. paul.van.der.wielen@kwrwater.nl
(1) Principle Scientist, KWR Watercycle Research Institute, Netherlands; (2) Laboratory of Microbiology, Wageningen University, Netherlands; (3) Postdoc Researcher, Netherlands; (4) PhD student, KWR Watercycle Research Institute, Netherlands.

Abstract

Introduction and aims: Pipe materials can contain growth-promoting compounds and enhance microbial growth in drinking water distribution and premises plumbing systems. The aim of this study is to determine the influence of pipe materials on total microbial growth and the growth of *L. pneumophila*, *M. kansasii*, *P. aeruginosa* and A. *fumigatus*. **Method**: Microbial growth on the materials was determined for 34 weeks in the biomass production potential (BPP)-test according to NEN-EN16421:2014. Growth of opportunistic pathogens was determined by adding them at day 0 or 126 and follow their growth using selective culturing or qPCR. **Results and conclusion**: Copper reduced *L. pneumophila* growth compared to the negative control (glass), whereas PVC-C did not enhance growth. In contrast, *L. pneumophila* growth was enhanced tenfold by PE-based materials and 1000-fold by PVC-P. A distinct correlation (R^2=0.81) was observed between *L. pneumophila* and biofilm concentration, indicating an (in)direct relationship between biofilm and *L. pneumophila*. For *M. kansasii*, it was also observed that PE-based materials enhanced growth. Growth of *P. aeruginosa* was only increased with materials that enhance microbial growth substantially (PVC-P and EPDM), whereas all materials enhanced growth of *A. fumigatus* to the same extend, except PVC-P which resulted in a ten-fold increase compared to the other materials. It is concluded from this study that the type of pipe material used can influence growth of certain opportunistic pathogens. Moreover, to prevent *L. pneumophila* growth in water systems, the use of PE-based materials in distribution and premises plumbing systems should yet be restricted as much as possible.

Keywords

Pipe materials; enhanced microbial growth; *Legionella pneumophila*; opportunistic pathogens.

1 Introduction

Growth of microorganisms in the distribution system and/or premises plumbing system for drinking water can cause problems, due to growth of opportunistic pathogens (e.g. *Legionella pneumophila*, certain nontuberculous mycobacterial species, *Pseudomonas aeruginosa*, *Aspergillus fumigatus*) (Edberg et al. 1996, Falkinham et al. 2001, Lawrence et al. 1999, van der Wielen and van der Kooij 2013). In addition, growth in the drinking water ecosystem can also cause aesthetic problems (e.g. taste and odour complaints, growth of invertebrate animals visible to the human eye) or technical problems (e.g. microbial induced corrosion)(van der Kooij and van der Wielen 2014). Consequently, drinking water companies limit the microbial growth in their distribution system. In most parts of the world this is done by adding a disinfectant residual to the distributed drinking water. However, some European countries (e.g. Denmark, Switzerland, parts of Germany and the Netherlands) limit microbial growth by limiting the concentration of biodegradable compounds in drinking water and as a result, distribute the drinking water without a disinfectant residual.

Biodegradable compounds for microorganisms in the drinking water ecosystem can come from the drinking water, since treatment will not remove all biodegradable compounds, but these compounds can also be released from certain pipe materials, especially plasticized materials such as polyethylene (PE), polypropylene (PP), polybutylene (PB) or soft polyvinylchloride (PVC-P) (Hambsch et al. 2014). Drinking water companies, therefore, restrict the use of these materials in the drinking water distribution system. In premises plumbing systems, however, PE-materials are increasingly used (ten koste van) copper. Although it has already been shown that certain plasticized materials enhance microbial growth when in contact with drinking water, it remains unknown whether pipe materials also enhance growth of opportunistic pathogens. Therefore, the objective of this study is to determine the influence of pipe materials on the total microbial growth and the growth of *L. pneumophila*, *Mycobacterium kansasii*, *P. aeruginosa* and A. *fumigatus.*

2 Materials and Methods

The enhanced microbial growth on different materials was tested using the standardized biomass production potential (BPP) test as described in NEN-EN16421:2014. To study the enhanced growth of *L. pneumophila*, glass, copper, PVC-C, PE-Xb, PE-Xc, PE-100, PE-80 and PVC-P were incubated for 16 weeks in the BPP test, after which *L. pneumophila* was added to the materials. Subsequently, water and materials were sampled after another 8, 12 and 16 weeks of incubation in the BPP-test. Biofilm and water were tested for ATP, as measure for total bacterial activity, according to NEN-EN 16421:2014. In addition, colony counts of *L. pneumophila* were determined using the culture method on buffered charcoal yeast extract (BCYE) agar with antibiotics and the plates were incubated at 37°C for 7 days (ISO standard 11731-2). Typical colonies were counted and subsequently confirmed using BCYE agar without the antibiotic cysteine. The enhanced growth of *M. kansasii, P. aeruginosa* and *A. fumigatus* was studied under similar conditions for glass, copper, stainless steel (SS), PVC-C, PE-Xa, PE-Xc, PE-100, PE-40, EPDM and PVC-P, except that these organisms were added directly to the materials (t=0) or, for some materials, after the BPP-test already run for 126 days. Colony counts of *P. aeruginosa* were determined on *Pseudomonas* agar base supplemented with CN agar (ISO standard 16266). *M. kansasii* and *A. fumigatus* were enumerated using previously described qPCR protocols (van der Wielen et al. 2014).

3 Results and Discussion

3.1 *Legionella pneumophila*

The biomass production potential of the different materials used to test enhanced growth of L. pneumophila are shown in Table 1. Glass showed a BPP of 132 ± 11 pg ATP cm^{-2}, and since glass is an inert material, this enhanced growth observed on glass is caused by the biodegradable compounds present in the water. Copper and PVC-C showed similar BPP values as glass, indicating that these material do not release microbial biodegradable compounds as well. In contrast, the BPP-values of the PE pipe materials (PE-Xb, PE-Xc and PE-100) were 6.0 to 16.7 higher than for glass, demonstrating that these materials release compounds that are degraded by microorganisms in the biofilm and water. The highest BPP values were observed for PVC-P (113 times higher than glass), which is probably caused by the biodegradability of the softeners used in PVC-P. The observed BPP values for the different materials are comparable to previously published BPP values for pipe materials (Hambsch et al. 2014).

Table 1 The biomass production potential in pg ATP cm^{-2} for the different materials tested for enhanced growth of *L. pneumophila*

	BPP (pg ATP cm^{-2})	
Material	**Average**	**St.dev**
Glass	132	11
Copper	112	26
PVC-C	185	45
PE-Xb	880	208
PE-Xc	794	69
PE-100	2,204	207
PVC-P	14,885	3,300

Legionella numbers in the biofilm of the different materials differed considerably (Table 2). Copper reduced *L. pneumophila* growth compared to the inert material glass, whereas PVC-C did not enhance growth. In contrast, *L. pneumophila* growth was enhanced 1.6 to 5.8 by PE-based materials and 475-fold by PVC-P. A distinct linear correlation (R^2=0.81) was observed between log transformed *L. pneumophila* numbers and log transformed ATP concentration in the biofilm, indicating an (in)direct relationship between biofilm and *L. pneumophila*. The observed bacteriostatic/bactericidal effect of copper is probably caused by the release of copper ions onto the pipe surface (van der Kooij et al. 2005). However, it was observed that this protective effect of copper was only temporarily and that when sufficient corrosion products have accumulated on the surface, *Legionella* numbers increased to same numbers as observed for the negative control (stainless steel)(van der Kooij et al. 2005). Moreover, the results from our study indicates that the use of new PE-materials or PVC-P in distribution system and premises plumbing system can pose a risk for growth of *L. pneumophila*, whereas this risk is absent or lower when new copper or PVC-C is used. Next to pipe materials, other environmental conditions (e.g. drinking water quality, temperature, hydraulics) also impact growth of *L. pneumophila* in the drinking water environment (Van der Kooij 2014). Currently, control of *L. pneumophila* growth in the premises plumbing systems in the Netherlands is mainly based on producing high quality drinking water at the production plant, keep drinking water in cold water system below 25°C, keep drinking water in warm water systems above 60°C and prevent dead-ends in the premises plumbing systems. Considering the effect of pipe materials on growth of *L. pneumophila*, it can be advisable to also restrict use of pipe materials that enhance growth of *L. pneumophila* in the premises plumbing system.

Table 2 Average numbers of *L. pneumophila* in the biofilm (cfu cm^{-2}) determined after 8, 12, 16 weeks after *L. pneumophila* was inoculated in BPP test with different pipe materials

	L. pneumophila **(cfu cm^{-2})**	
Material	**Average**	**St.dev**
Glass	3.1×10^3	3.7×10^3
Copper	2.5×10^1	1.4×10^1
PVC-C	1.4×10^3	7.2×10^2
PE-Xb	1.1×10^4	6.3×10^2
PE-Xc	5.1×10^3	2.1×10^3
PE-100	1.8×10^4	8.1×10^3
PVC-P	1.5×10^6	1.2×10^5

3.1 *P. aeruginosa*, *A. fumigatus* and *M. kansasii*

When *P. aeruginosa* was inoculated together with a natural microflora into the BPP test at day 0, then EPDM and PVC-P enhanced the growth of this microorganism to levels of 2.2×10^3 to 1.7×10^5 cfu cm^{-2}. All other materials did not enhance growth of this organism. The *P. aeruginosa* numbers on EPDM and PVC-P peaked within the first ten days after they were inoculated. Subsequently, numbers decreased to relatively low numbers (<50 cfu cm^{-2}) after 70 days of incubation. Moreover, when *P. aeruginosa* was added to PVC-P after 126 days in the BPP test, meaning that the natural microflora has formed a biofilm on the material for 126 days, enhanced numbers of *P. aeruginosa* were not observed. These results indicate that *P. aeruginosa* is an initial colonizer when new EPDM or PVC-P material comes into contact with drinking water, but that when time proceed the organism loses the competition with other naturally occurring microorganisms. Overall, the tested pipe materials does not seem to increase risk of P. aeruginosa growth in the distribution system and/or premises plumbing systems.

Table 2 Geometric mean of *P. aeruginosa* in the biofilm (cfu cm^{-2}) determined after 8, 12 and 16 weeks after *P. aerugionsa* was inoculated on day 0 (Direct) or after 126 days in the BPP test with different pipe materials

	Inoculation	
Material	**Direct**	**After 126 days**
Glass	0.4	1.3
Copper	< 0.1	ND[a]
SS	0.3	ND
PVC-C	1.6	2.0
PE-Xa	0.9	ND
PE-Xc	0.2	ND
PE-100	0.3	2.0
PE-40	0.3	1.6
EPDM	2.2×10^{3}	ND
PVC-P	1.7×10^{5}	0.9

[a] ND: not determined

Growth of *A. fumigatus* was enhanced for all materials when *A. fumigatus* was inoculated on day 0 in the BPP test (Table 3). The lowest geometric mean of *A. fumigatus* in the biofilm was observed for glass (1.8×10^{3} gene copies cm^{-2}) and the highest geometric mean for PVC-P (2.2×10^{5} gene copies cm^{-2}). The other materials showed slightly higher geometric means than was observed for glass. The materials also enhanced growth of *A. fumigatus* when the organism was inoculated in the BPP test after 126 days, but surprisingly the numbers were higher on most materials than when *A. fumigatus* was inoculated on day 0 (Table 3). It remains unclear what the cause is for this difference, but, due to the nutritional versatility of *A. fumigatus* (Rhodes 2006), it might be that a more mature biofilm contains higher concentrations and more diverse extracellular polymeric substances (EPS) that could serve as growth substrate for *A. fumigatus*. An exception to the higher *A. fumigatus* numbers inoculated on day 126 versus day 0 is PVC-P, where the geometric mean of *A. fumigatus* inoculated on day 0 was 28.6 times higher than the geometric mean of *A. fumigatus* inoculated on day 126. This indicates that other unknown conditions affect growth of *A. fumigatus* in the biofilm on pipe materials in contact with drinking water as well. Overall, the results show that most tested pipe materials slightly enhance growth of *A. fumigatus* compared to an inert material as glass, but that these tested pipe materials do not differ in the level to which they enhance growth of *A. fumigatus*.

Table 3 Geometric mean of *A. fumigatus* in the biofilm (gene copies cm^{-2}) determined after 8, 12 and 16 weeks after *A. fumigatus* was inoculated on day 0 (Direct) or after 126 days in the BPP test with different pipe materials

	Inoculation	
Material	**Direct**	**After 126 days**
Glass	1.8×10^3	7.4×10^4
Copper	5.2×10^3	ND
SS	3.5×10^3	ND
PVC-C	5.1×10^3	1.2×10^5
PE-Xa	5.4×10^3	ND
PE-Xc	3.4×10^3	ND
PE-100	4.7×10^3	1.5×10^5
PE-40	2.6×10^3	1.4×10^5
EPDM	3.7×10^3	ND
PVC-P	2.2×10^5	7.7×10^3

[a] ND: not determined

The growth of *M. kansasii* on pipe materials in contact with drinking water was only studied for inoculation after 126 days in the BPP test, after it was observed that *M. avium* was unable to grow in the biofilm on materials when the organism was inoculated at day 0 in the BPP test (results not shown). The geometric mean of *M. kansasii* in the biofilm on the inert material glass was 613 gene copies cm^{-2} (Table 4), indicating that nutrients present in drinking water can result in growth of *M. kansasii* in the biofilm on glass surface. The geometric mean of *M. kansasii* in the biofilm on PVC-C was comparable to glass, indicating that PVC-C did not enhance growth of *M. kansasii*. Compared to *M. kansasii* growth on the inert material glass, PE-40, PE-80 and PE-100 enhanced growth of *M. kansasii* 1.2, 2.9 and 1.6 times, respectively. Furthermore, growth of *M. kansasii* on PVC-P was reduced compared to glass (Table 4), despite the observation that PVC-P had the highest BPP values, showing that PVC-P leaks relatively high concentrations of biodegradable compounds. It could be that *M. kansasii* is well-adapted to oligotrophic environments, which could make the organism less competitive in environments with relatively high nutrient concentrations such as PVC-P in contact with drinking water. Overall, it can be concluded that the tested PE pipe materials pose a risk that *M. kansasii* numbers slightly increase in the drinking water environment.

Table 4 Geometric mean of *M. kansasii* in the biofilm (gene copies cm^{-2}) determined after 8, 12 and 16 weeks after *M. kansasii* was inoculated after 126 days in the BPP test with different pipe materials

Material	***M. kansasii*** **(gene copies cm^{-2})**
Glass	613
PVC-C	600
PE-40	735
PE-80	1774
PE-100	1004
PVC-P	114

[a] ND: not determined

No clear linear correlations were observed between log transformed *P. aeruginosa*, *M. kansasii*, *A. fumigatus* and log transformed ATP concentration in the biofilm, which indicates that, as opposed to *L. pneumophila*, the biofilm concentration is not a pivotal parameter that (in)directly determines growth of these opportunistic pathogens in the drinking water environment.

4 Conclusions

- The tested polyethylene based pipe materials and PVC-P can enhance growth of *L. pneumophila* in the distribution system and/or premises plumbing system when other conditions are favourable for growth of *L. pneumophila*;
- The tested pipe materials do not seem to increase risk for growth of *P. aeruginosa* in the drinking distribution system and/or premises plumbing system;
- Most pipe materials tested can slightly enhance growth of *A. fumigatus* compared to an inert material as glass in the drinking water distribution system and/or premises plumbing system, but most of these pipe materials do not differ in the level to which growth of *A. fumigatus* is enhanced;
- The tested polyethylene based pipe materials can enhance growth of *M. kansasii* in the distribution system and/or premises plumbing system when other conditions are favourable for growth of *M. kansasii*;
- Based on the precautionary principle, the use of polyethylene type materials, EPDM and PVC-P in the distribution system and premises plumbing systems should be restricted as much as possible.

Acknowledgments

This work was financed by the joint research program (BTO) of the Dutch drinking water companies. In addition, we thank several manufacturers for supplying the different pipe materials.

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6 Presentation of presenting Author

Paul van der Wielen is a senior researcher in the water microbiology section of KWR Watercycle Research Institute and is also stationed as guest researcher at the Laboratory of Microbiology department of the Wageningen University. He has almost twenty years of experience on research in microbial ecology, and at KWR/WUR he focuses on biological stability of drinking water, growth of opportunistic pathogenic microorganisms in water, (micro)biological processes in drinking water treatment, enhanced microbial growth by materials and microbial ecology in drinking water. He has conducted both research and consultant studies in (inter)national projects. Paul studied Microbial Ecology at the university of Groningen, before receiving his PhD at the University of Utrecht. After receiving his PhD, he worked for 3½ years at the University of Groningen, before joining KWR in 2004. Keywords in his specialisation are: biological stability and regrowth, *Legionella*, fungi, opportunistic pathogenic microorganisms, nitrification, methane oxidation, microbial ecology and water quality monitoring.

Session B Water saving and sustainable use

B1 - The prediction method of supply water temperature for energy simulation of hot water supply system

Shizuo Iwamoto(1), Ayano Dempoya(2), Kyosuke Sakaue(3)
1. iwamotos@jindai.jp
2. dempoya@kanagawa-u.ac.jp
3. sakaue@isc.meiji.ac.jp
(1) Professor, Dept. of Architecture, Faculty of Engineering, Kanagawa University, Japan
(2) Assistant Professor, Dept. of Architecture, Faculty of Engineering, Kanagawa University, Japan
(3) Professor, Dept. of Architecture, School of Science and Technology, Meiji University, Japan

Abstract

Introduction and aims: The energy consumption for hot water supply system is large in buildings such as dwellings, hotels and hospitals. It is sometimes up to 30 percent of the entire building energy consumption. Energy consumption in the hot water supply system is very important on energy saving in the buildings and consists on energy to make hot water from cold water and heat loss due to piping and in heat sources. Heat loss in heat sources is calculated from efficiency of heat sources. Efficiency of boilers is not so much affected by the supply water temperature. But that of other heat source system is sometimes affected by supply water temperature. Therefore, supply water temperature is one of the important input conditions to evaluate and predict the energy consumption. In a small building such as detached houses city-pressure water supply system is employed and water supply temperature is equal to city water temperature. Break tank is used in general and supply water temperature will be equal to the tank water temperature that is different from city water temperature. Therefore, this study focused on supply water temperature in a building.
Method: This paper will describe the followings.
(1) The calculation method of city water temperature from river water temperature as water sources from our published paper.
(2) The calculation method of the break tank water temperature from our published paper.
(3) The calculation method of supply water temperature combined (1) and (2).
(4) The results of case study with a business hotel on energy consumption for hot water supply system by simulation used supply water temperature by (3).
Results and conclusion: The above case study shows details of energy consumption for hot water supply system by supply water temperatures.

Keywords

Hot water supply system; energy saving; city water temperature; tank water temperature.

1 Introduction

The energy consumption for hot water supply system is large in buildings such as dwellings, hotels and hospitals. It is sometimes up to 30 percent of the entire building energy consumption. Energy consumption in the hot water supply system is very important on energy saving in the buildings and consists on energy to make hot water from cold water and heat loss due to piping and in heat sources. Heat loss in heat sources is calculated from efficiency of heat sources. Efficiency of boilers is not so much affected by the supply water temperature. But that of other heat source system is sometimes affected by supply water temperature. Therefore, supply water temperature is one of the important input conditions to evaluate and predict the energy consumption. In a small building such as detached houses city-pressure water supply system is employed and water supply temperature is equal to city water temperature. Break tank is used in general and supply water temperature will be equal to the tank water temperature that is different from city water temperature. Therefore, this study focused on supply water temperature in a building [1)].

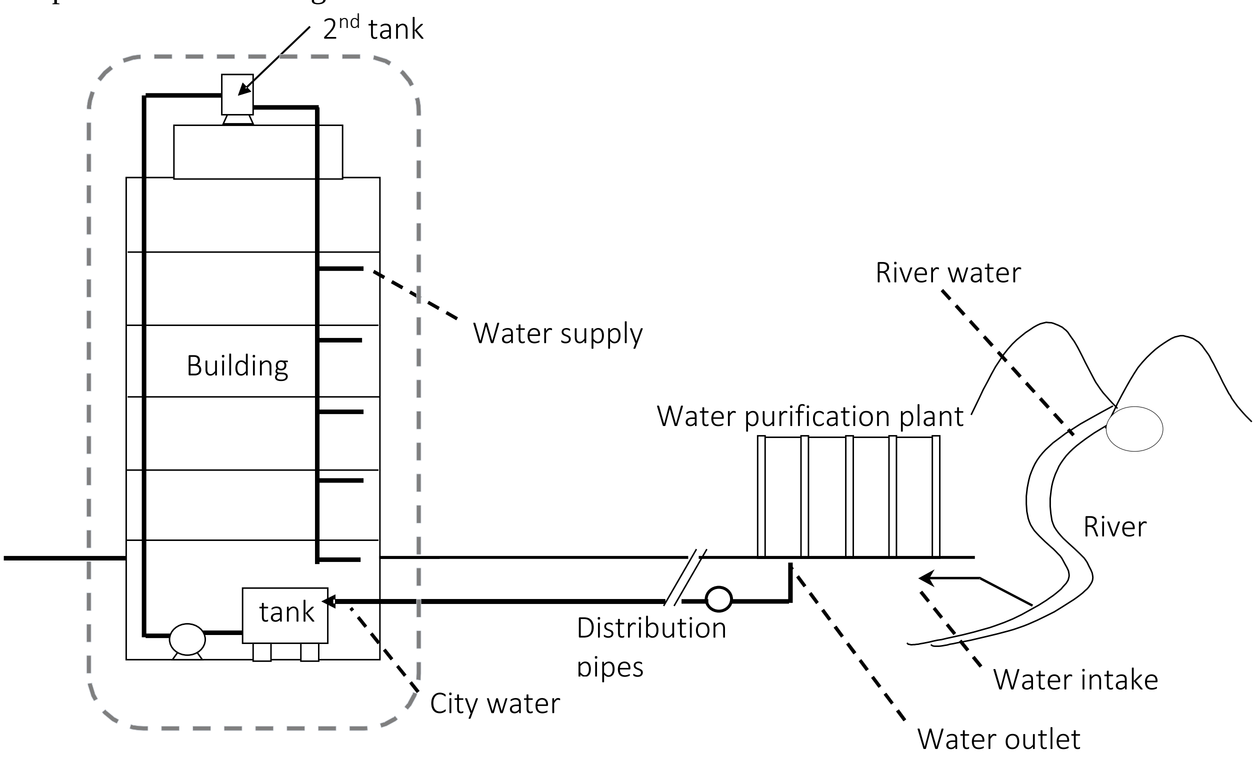


Fig.1 The summary of city water system and water supply system in the building in Japan

Fig.1 shows the summary of the city water system and water supply system for building services in Japan. River water is taken to the water purification plant. City water is made and distributed form the plant to buildings. The supply water temperature is equal to the city water temperature in a small building such as a detached house. It is equal to tank water temperature in general. But both water temperatures are not measured usually. Thus, this study is aimed to provide a generic calculation method of supply water temperature and this paper describes as follows;

(1) The calculation method of city water temperature from river water temperature as water sources from Iwamoto et al.[2)]

(2) The calculation method of the break tank water temperature from Iwamoto et al.[3)]

(3) The calculation method of supply water temperature combined (1) and (2).

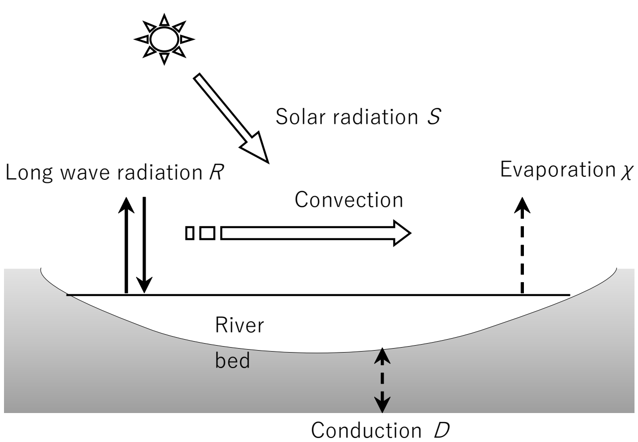
(4) The results of case study with a business hotel on energy consumption for hot water supply system by simulation[4)] used supply water temperature by (3).

2 Calculation method

2.1 City water temperature

The calculation method of city water temperature is described here. City water temperature is determined using river water temperature as water sources and affected by the purification process. In this study, city water temperature is set to outlet water temperature in purification plant.

2.1.1 River water temperature



$$
\left.\begin{aligned}
S &= (1 - ref_W) S^{\downarrow} \\
C &= c_p \rho C_H U_M (T_M - T_{MW}) \\
R &= \varepsilon L^{\downarrow} - \varepsilon \sigma (T_{MW} + 273)^4 \\
\chi &= i \rho C_H U_M (q_{SAT}(T_{MW}) - q)
\end{aligned}\right\} \quad (1)
$$

$S^{\downarrow}$: overall horizontal solar radiation[W/m^2], ref_W :albedo of water (=0.06), c_p: specific heat of air =1.00 kJ/(kg K)), ρ : air density (=1.2 kg/m^3), $C_H U_M$: convective heat coefficient (=0.001+0.00566（$U^{0.8}/X^{0.2}$）[m/s]）, U : air velocity [m/s], X: length on wind blow (=30 m), ε : emissivy of water (=0.96), $L^{\downarrow}$: atmospheric radiation, σ : Stefan-Bolzmann Constant =5.67X10^{-8} W/(m^2 K$^{4)}$), T_M : daily average air temperature [°C], T_{MW} : river water temperature [°C], i: heat of water vaporization (=2.45X10^6 J/kg), $q_{SAT}(T)$: saturated specific humidity of air at air temperature T °C [kg/kg], q: specific humidity of air [kg/kg]

Fig.2 Heat balance of river water

At first, river water temperature is calculated. This calculation method is by Kondo[5)] and validated by Iwamoto et al.[2)] This section describes the summary of the calculation method.

Fig.2 shows the summary of heat balance of river water. Solar radiation S, convection C and Evaporation χ are determined from formulas (1). Then the equilibrium water temperature is determined from formula (2).

$$T^* = T_M + \frac{S + \varepsilon L^{\downarrow} - \varepsilon\sigma(T_M + 273)^4 - \chi}{\mu} \quad (2)$$

where,

$$\mu = 4\varepsilon\sigma T_M{}^3 + c_p\rho C_H U_M + i\rho C_H U_M \Delta$$

$$\Delta = \frac{6.1078(2500 - 2.4T_M)}{0.4615(T_M + 273)^2} \times 10^{\frac{7.5T_M}{237.3+T_M}} \times \frac{0.622p}{(p - 0.378e_{SAT})^2}$$

p : atmospheric pressure [hPa]

e_{SAT} : saturated water vapor pressure [hPa]

The river water temperature T_{WM} at intake of purification plant is determined from formula (3). Where, T_o is the water temperature at the source of river, d_w is average river depth and τ is elapsed time from the source of river to purification plant. T_o is obtained as the average of underground temperatures of depth 0.1m and 1.5m.

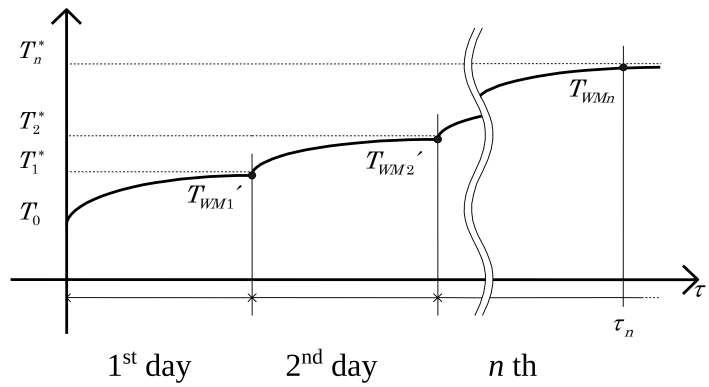
$$T_{WM} = T_0 + (T^* - T_0)\left[1 - \exp\left(-\frac{\tau}{\tau_0}\right)\right] \quad (3)$$

$$\tau_0 = \frac{c_W \rho_W d_W}{\mu \times 3600}$$

c_W : specific heat of water (=4.186 kJ/(kg･K))

ρ_W : water density (=1,000 kg/m^3)

Iwamoto et al.[2)] calculated river water temperature using formula (3) with h varied by 0.5m from 0.5 to 5.0 m and τ varied by an hour from 1 to 200 hours. The result was determined using the annual average water temperature. When τ is over 24 hours, the equilibrium water temperature of the next day is used and T_o and T* are replaced in formula (3) shown as Fig.3 and formula (4) [4)].



$$T_{WM1} \ldots - T_0) \left[\ldots \left(\tau_{01} \right) \right]$$

$$T_{WM2} = T_{WM1}´ + \left(T_2^* - T_{WM1}´\right)\left[1 - \exp\left(-\frac{\tau - 86400}{\tau_{02}}\right)\right]$$

$$T_{WMn} = T_{WM(n-1)}´ + \left(T_n^* - T_{WM(n-1)}´\right)\left[1 - \exp\left\{-\frac{\tau_n - 86400(n-1)}{\tau_{0n}}\right\}\right] \quad (4)$$

Fig.3 The summary of calculation method of river water temperature

2.1.2 City water temperature

There are various impacts on water temperature in purification process. The measurement results by Bureau of Waterworks, Tokyo Metropolitan Government shows that the temperature difference between intake and outlet water temperatures in purification plant is about 0.5 – 1.0 °C and Iwamoto et al.[2)] uses the formula (5). Then the city water temperature is set to T_{OUT}.

$T_{OUT} = T_{IN} + d_0\left(\nu \times 10^6\right)$ (5) d_0 : coefficient (=0.5), ν : kinematic viscosity coefficient of water [m^2/s]

2.2 Water temperature in buildings

Fig.4 shows the summary of the calculation method of tank water temperature.
Step 1 calculate the water volumes for supply and use every hour
Step 2 calculate the initial temperature of the tank water (arrow a in Fig.4)
Step 3 calculate the temperature of tank water with overall heat transfer from/to the ambient environment (arrow b in Fig.4)
According to Iwamoto et al.[3)], the difference between measurement and calculation results averaged for 7 days (18th - 24th Nov. 2000) is about 0.20 °C in the break tank and 0.13 °C in the 2nd tank.

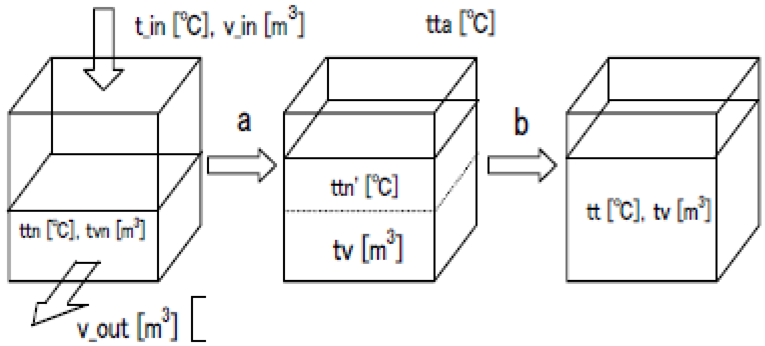


Fig.4 The summary of calculation method of tank temperature

Where,
t_in:inlet water temperature [°C]
v_in;inlet water volume [m^2]
ttn:tank water temperature at the previous step [°C]
tvn;tank water volume at the previous step [m^3]
v_out;used water volume [m^2]
tta;ambient air temperature aroung the tank [°C]
ttn'; tank water temperature after the previous step [°C]
tv;tank water volume at the present step [m^2]
tt;tank water temperature at the present step [°C]

This result shows the required conditions to calculate temperature of tank water.
(1) Water volume of use and supply
(2) Water temperature of supply
(3) Ambeint air temperature around water tank
(4) control condition of tank water volume

3 Case study on the business hotel

Table 1 The summary of the hotel setting

The business hotel has	7 stories and basement With 96 rooms
The number of quests	150
Daily use volume of water	57,500 L/day
Daily use volume of hot water	29,775 L/day
The capacity of gas boiler	116 kW X 2
The efficiency of gas boiler	0.78
Circulation pump	0.25 kW
Circulation pump for boilers	0.75 kW2
Storage tank volume	4.5 m^3
Storage tank insulation	Rock wool 75 mm
Break tank volume	28 m^3

3.1 The summary of hotel

In this study, a business hotel is employed for case study of primary energy consumption. Table 1 shows the summary of the hotel. It has a central hot water supply system and booster pump water supply system.

3.2 The usage of water

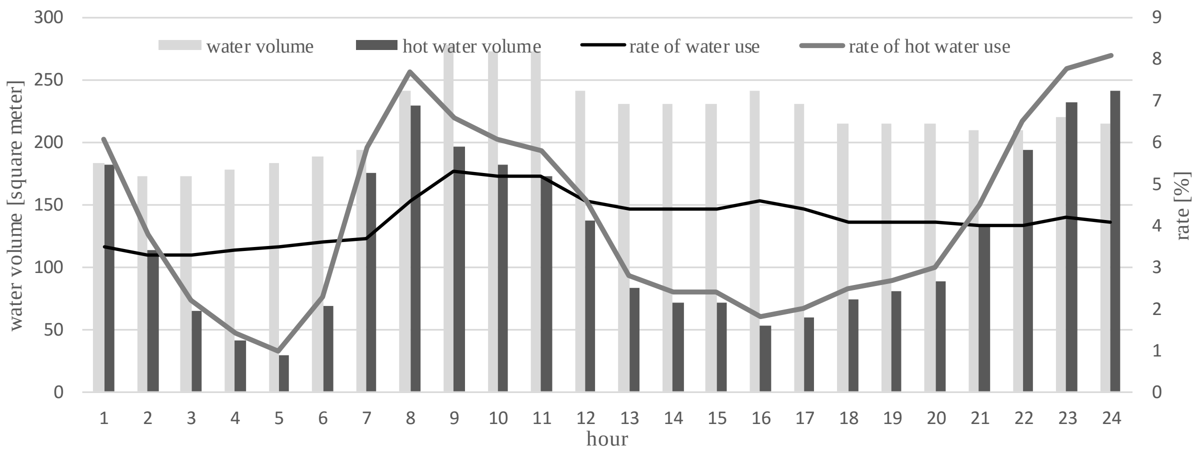


Fig.5 The schedule of water and hot water usage

Fig.5 shows the time schedule of hot water and water volume per an hour. The rate of usage for daily water volume is also showed in Fig.5. There is no consideration on the daily variation of water volume and water volume per a day is constant.

3.3 Calculation result of the water temperatures

Fig.6 shows the result of water temperatures by measurement in Misono purification plant and by calculation in Misono purification plant and break tank in 2003.

The measurement was conducted in Misono purification plant in Bureau of Waterworks, Tokyo Metropolitan Government. This measurement result was conducted by the staff visually on week day. It is set to be used interpolation in water temperatures on Saturday and Sunday.

The meteorological data in 2003 for formulas (1) and (2) is obtained from website[6)]. The air temperature around the break tank is set to the average of air temperatures of outside and air-conditioned guest room.

The annual average of temperature difference between measurement and calculation is 0.760 °C. This shows a good agreement between measurement and calculation.

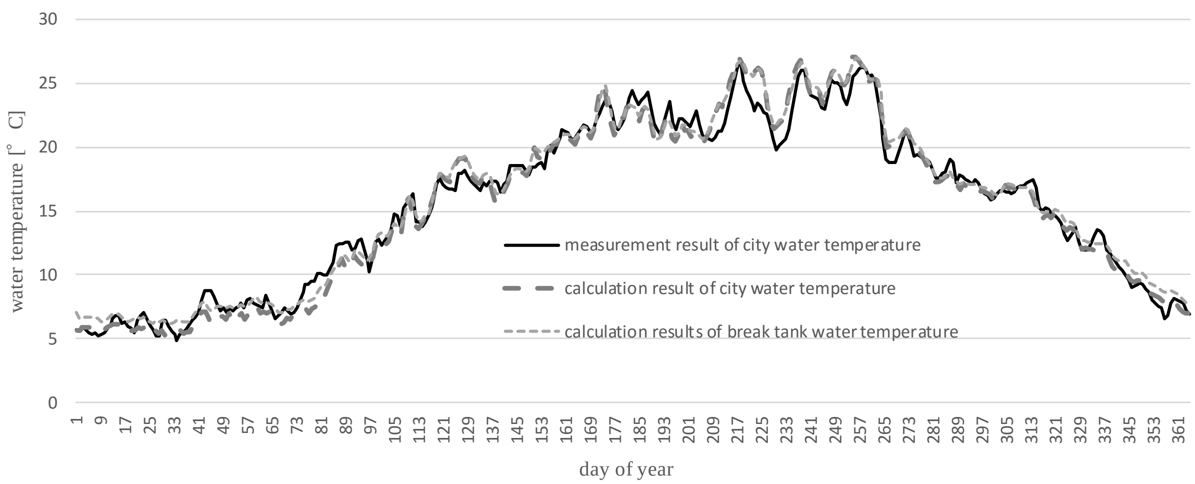


Fig.6 The results of water temperatures

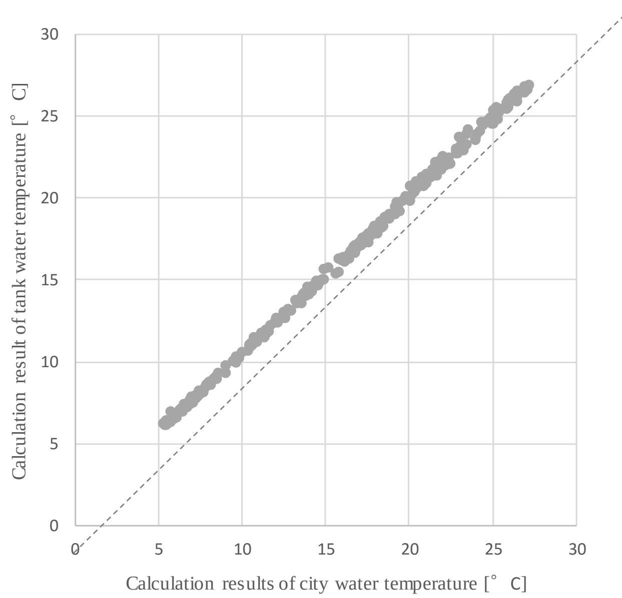


Fig.7 The results of temperatures of city water and the break tank water

Fig.7 shows calculation results of temperature between city water and tank water. The annual average of temperature difference between city water and tank water is 0.725 °C. In summer, there is little difference between city and tank water temperature but the difference is up to 1.5 °C in winter.

3.4 Calculation results of primary energy consumption

Table 2 shows the results of primary energy consumption of 3 cases obtained by CEC/HW method[4)]. The water temperature of case-1 is set by original method on CEC/HW and that of case-2 is city water temperature based on the above method (2.1) for MISONO water

purification plant in 2003. That of case-3 is the break tank water temperature calculated by the above method (2.2) using case-2 city water temperature.
Compared with case-1, hot water supply load is 1.4% larger and total primary energy consumption is 1.2% larger in case-2. The calculation results of ase-1 and case-3 are similar in this case study.

Table 2 The calculation results of annual primary energy consumption by CEC/HW [4)]

Item	CEC/HW[*)]	City water (%)	Tank water (%)
Hot water supply load	1,242	1,260 (101.4)	1,241 (99.9)
Heat loss due to dead end piping	21.2	21.4 (100.9)	21.2 (100)
Heat loss from circulation pipe	156.2	←	←
Heat loss from heat source side pipe	29.7	←	←
Heat loss from hot water storage tank	10.2	←	←
Consumption energy of circulation pumps	42.5	42.8 (100.7)	42.4 (99.8)
Total primary energy consumption	1,913	1,936 (101.2)	1,912 (99.9)

4 Conclusion

This paper shows;
(1) the calculation method of temperature of city water and break tank water from the references[2),3)].
(2) the calculation results of case study in a business hotel. Water temperature difference between city water and tank water is small such as a hotel where water is often used all day but the difference is up to 1.5 °C in winter
We plan to measure the tank water temperature in long term more than a year and try to show the validity of the calculation method by comparing the measurement and calculation results.

Acknowledgments

A part of this study is supported by JSPS KAKENHI Grant Number JP17K06682.

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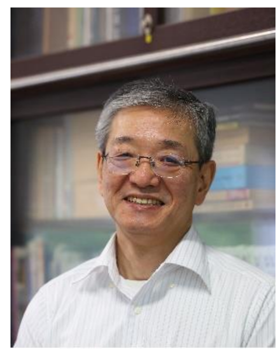
6. Japan Meteorological Agency (http://www.jma.go.jp/jma/indexe.html) Weather observation data search (Japanese only)

6 Presentation of Authors

Shizuo Iwamoto is the presenter of this study and the professor in the department of architecture, faculty of Engineering at Kanagawa University. He has a doctor of engineering from Meiji University. He is interested in built environment and building services such as air conditioning and hot water supply system.



Ayano Dempoya is the co-author of this study and the assistant professor in the department of architecture, faculty of Engineering at Kanagawa University. She has a doctor of clothing environment from Bunka Gakuen University. Her main interest is the evaluation of thermal comfort considering clothes and built environment.

Kyosuke Sakaue is the co-author of this study and the professor in the department of architecture, faculty of Engineering at Meiji University. He has a doctor of engineering from Meiji University. He is interested in building services such as plumbing system.

B2 - Decision support model for water heaters based on stochastic water demand modelling

See A0-Keynote-10 Using a stochastic demand model to design cold and hot water installations inside buildings

B3 - The potential of a new drainage system with special resin fittings for multiple water-saving toilet units in commercial buildings

Masayuki Otsuka (1), Norihiro Hongo (2), Yuki Kuga (3), Ryota Sugimoto (4)

1. dmotsuka@kanto-gakuin.ac.jp
2. hongou@yamagata-cit.ac.jp
3. m17J3006@kanto-gakuin.ac.jp
4. sugimoto-r@nihonsekkei.co.jp

(1) Prof. Dr.Eng., Department of Architecture and Environmental Design,
College of Architecture and Environmental Design, Kanto Gakuin University, Japan
(2)Assoc. Prof. M. Eng., Architecture Environment System Engineering, Yamagata College of Institute of Technology, Japan
(3) Graduate Student, Graduate School of Engineering, Kanto Gakuin University, Japan
(4) M. Eng., NIHON SEKKEI, INC., Japan

Abstract

In Japan, the currently used drainage stack systems for business-related office buildings, which comprise multiple toilet units connected thereto, are equipped with a vent stack and a loop vent pipe. Meanwhile, recently, JIS Standard (JIS A 5207-2014) water-saving type II toilets using 6.5L or less flush water have been widely promoted. These toilets discharge water into the drainage stack system at a lower flow rate than conventional type toilets that use more than 8.5L flush water. Therefore, the water-saving type toilets are thought to have less influence on the drainage capacity than the conventional type toilets.

With this background, in the study, an easy-to-construct, lightweight drainage system with special resin fittings was firstly developed as an alternative to the high-capacity drainage system with special cast-iron fittings, which has long been used for high-rise and super high-rise apartment and hotel buildings. Next, the drainage system with special resin fittings was combined with multiple water-saving toilet units to propose a new type of drainage system with special fittings as an alternative to the conventional loop vent type system. The study also reports the results of examining the influence of the proposed drainage system on the drainage capacity.

Keywords

Drainage system, drainage performance, special resin fittings, multiply water-saving toilet units

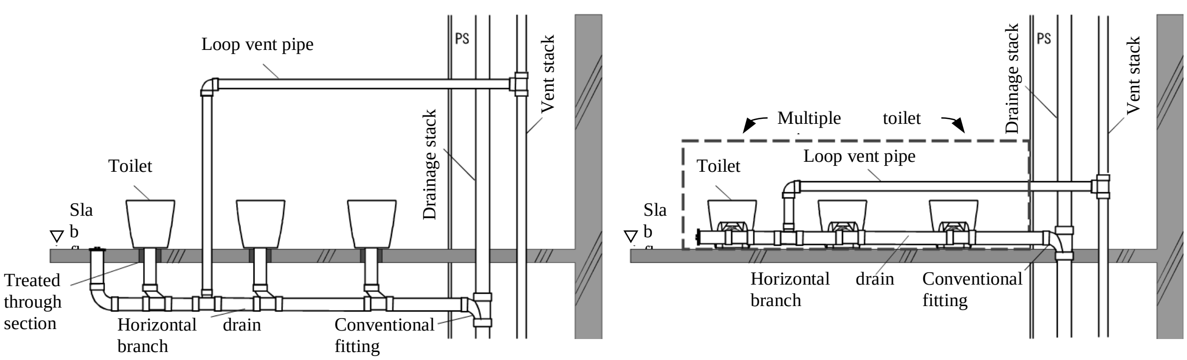
1. Background and objectives

Recently in Japan, when installing multiple water-saving toilet units in newly built office buildings, multiple toilet units which are plumb able above floor slabs are more commonly installed than the under-floor type (conventional type) from the viewpoint of (1) the workability and compatibility of drainpipes and (2) ensuring waterproofing by connecting drainpipes to the horizontal drain branch without having to penetrate floor slabs (see Fig. 1 and Photo 1). The amount of water for flushing each toilet was 13L in the 1970s, but it was gradually reduced, and nowadays, many toilets use 6.5L or less flush water and are widely available (see Fig. 2). Meanwhile, drainage stack systems for business-related buildings are largely of a loop vent type equipped with a loop vent pipe and a drainage stack. However, as reported at the 39th International Symposium CIB W062 2013 (Nagano, Japan) [1], the reduced amount of flush water means less influence on the drainage capacity of drainage stack systems. In response, the study examined a high-capacity conventional drainage system with special fittings for high-rise and super high-rise apartment and hotel buildings for applicability to highly marketable 10-storey high-rise business buildings (see Fig. 3). The study then examined the possibility of removing the vent stack and loop vent pipe from the system. This report clarifies the following points.

(1) Proposal and overview of a drainage system with special resin fittings compatible with multiple water-saving toilet units in business-related buildings

(2) Understanding of the drainage loads generated by multiple water-saving toilet units

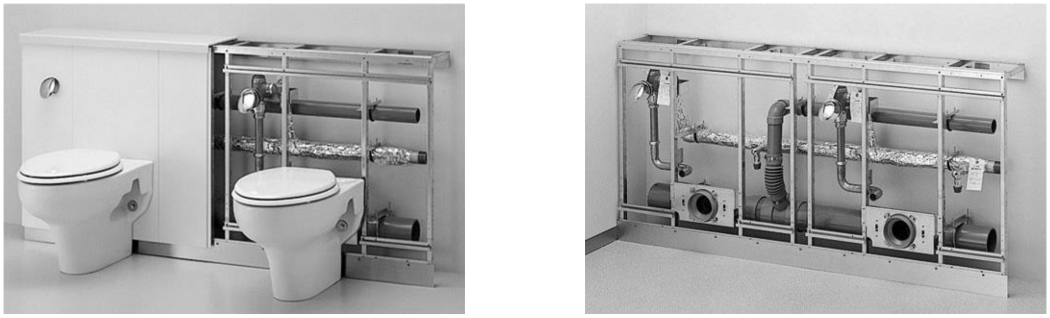
(3) Understanding of the influence of drainage loads on the drainage capacity of a drainage stack system and the verification of the effectiveness of the proposed system



(1) Under-slab-floor plumbing (with conventionally arranged toilet units)

(2) Above-slab-floor plumbing (with sequentially arranged toilet units)

Fig. 1 Comparison between two different horizontal drain branch arrangements with multiple toilets



(1) Multiple toilet units (2) Plumbing

Photo 1 Plumbing of multiple toilet units

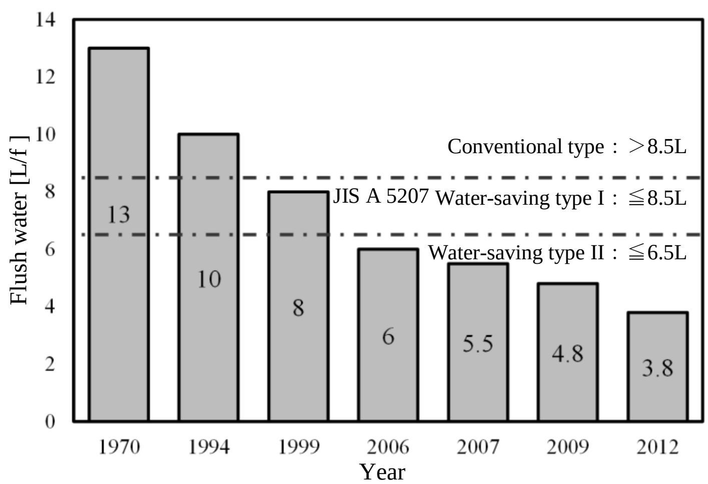
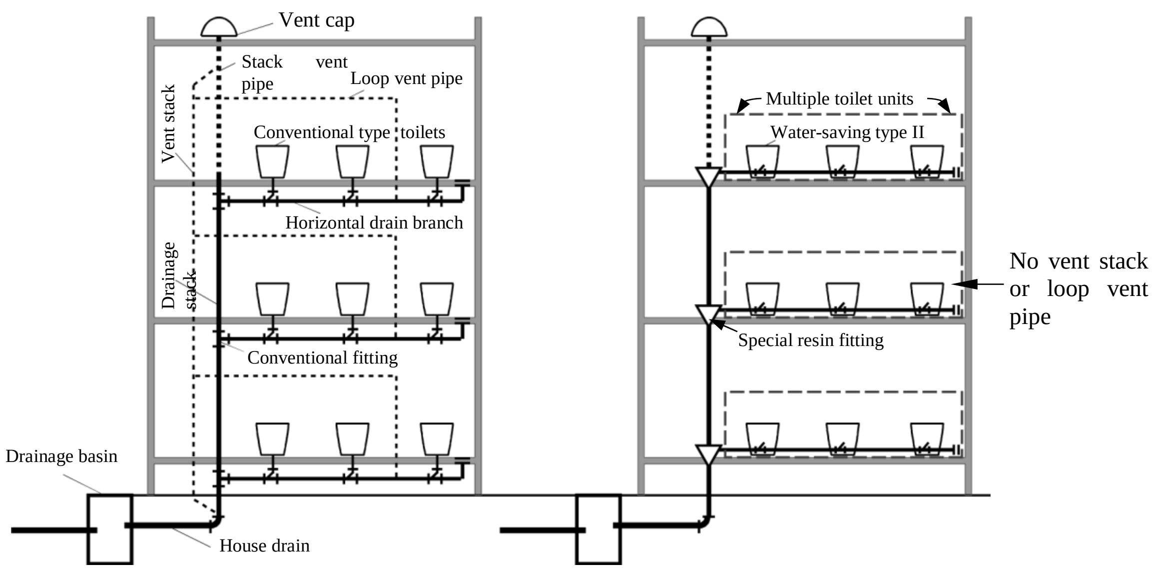


Fig. 2 Transition of water-saving trends with toilets



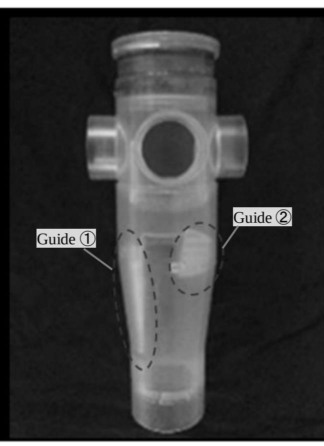
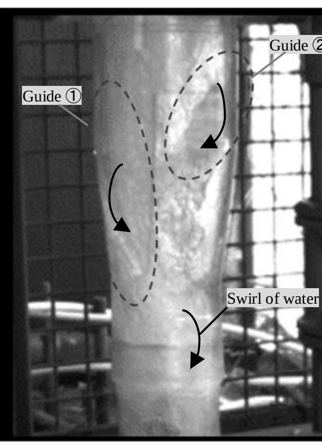
(1) Conventional drainage system (loop vent system) **(2) Special fitting drainage system (for multiple water-saving toilet units)**

Fig. 3 Conventional drainage system and special fitting drainage system for multiple water-saving toilet units

2. Proposal and overview of a drainage system with special resin fittings compatible with multiple water-saving toilet units in business-related buildings

The overview of the proposed drainage system with special resin fittings is as follows. Table 1 shows a conventional, cast-iron type special fitting and a resin type special fitting as well as showing the state of wastewater flowing down the resin fitting in a swirling fashion. Fig. 4 shows the relationship between the drainage load flow rate and the average velocity in the stack vent pipe (in-pipe flow velocity index), and according to the diagram, with the JIS-DT fitting (hereinafter referred to as the conventional fitting), the average velocity increases as the drainage load flow rate increases, while with the special resin fitting, the average velocity hardly increases after the drainage load flow rate reaches 3.0L/s, and even when the drainage load flow rate is 6.5L/s, the average velocity is still 2.4m/s. That is, the average velocity is 60% less when the special resin fitting is used than when the convention fitting is used, demonstrating that the special resin fitting has a good flow velocity reducing effect. Fig. 5 shows two distributions of in-pipe pressure values (average value Pave, maximum value Pmax and minimum value Pmin) which were obtained from experiments carried out according to the Testing Methods of Flow Capacity for Drainage System in Apartment Houses specified by SHASE-S218, using two different drainage load flow rates; 2.5L/s and 6.5L/s. The graphs show that the variation of in-pipe pressure is reduced significantly by using the special fitting. Based on Fig. 5, the relationship between the drainage load flow rate and the in-pipe pressure values (maximum value Pmax and minimum value Pmin) is translated into a graph of Fig. 6. With reference to the reference value (±400Pa) specified by SHASE-S218, the drainage capacity is 2.0L/s when the convention fitting is used, while the drainage capacity is 6.5L/s when the special fitting is used, indicating a 3.25 times increase. Moreover, the special fitting comprises a fire resistant resin, which expands to close the pipeline in the event of a fire, thus, preventing flames and smoke from entering the drainage system to minimise the spread of fire (Fig. 7). Therefore, PVC pipes can be used for the stack and the horizontal drain branch in a fireproof section, which is within 1m from the fitting section. In addition, PVC pipes have good sound insulation, thus, minimising the noise of wastewater flowing through the pipes.

Table 1 Special fittings

<table>
<tr><th>Cast-iron fitting</th><th>Resin fitting</th><th>The flow of water when drained</th></tr>
<tr><td></td><td>
</td><td>
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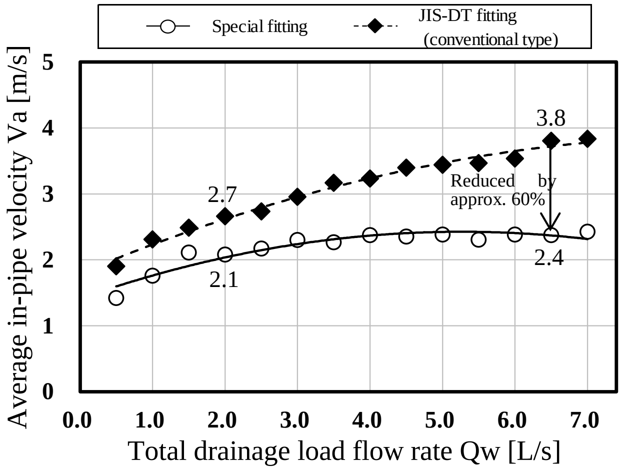
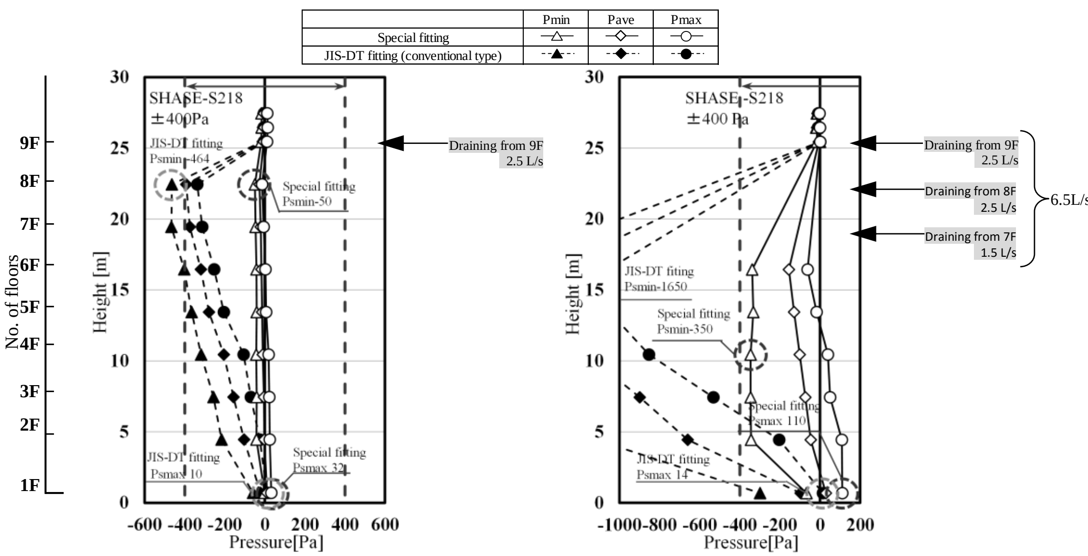


Fig. 4 Total constant flow drainage load flow rate Qw and average in-pipe velocity Va



(1) 2.5[L/s] per drainage **(2) 6.5[L/s] per drainage**

Fig. 5 Distributions of pressure by applied constant flow drainage loads

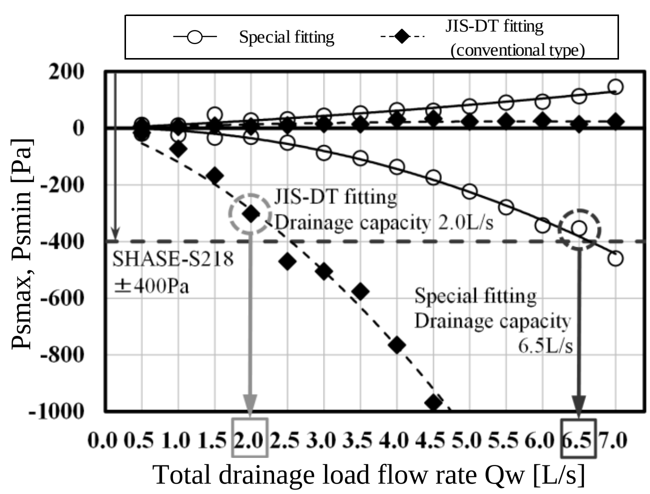


Fig. 6 Total drainage load flow rate Qw in relation to maximum system value Psmax and minimum system value Psmin

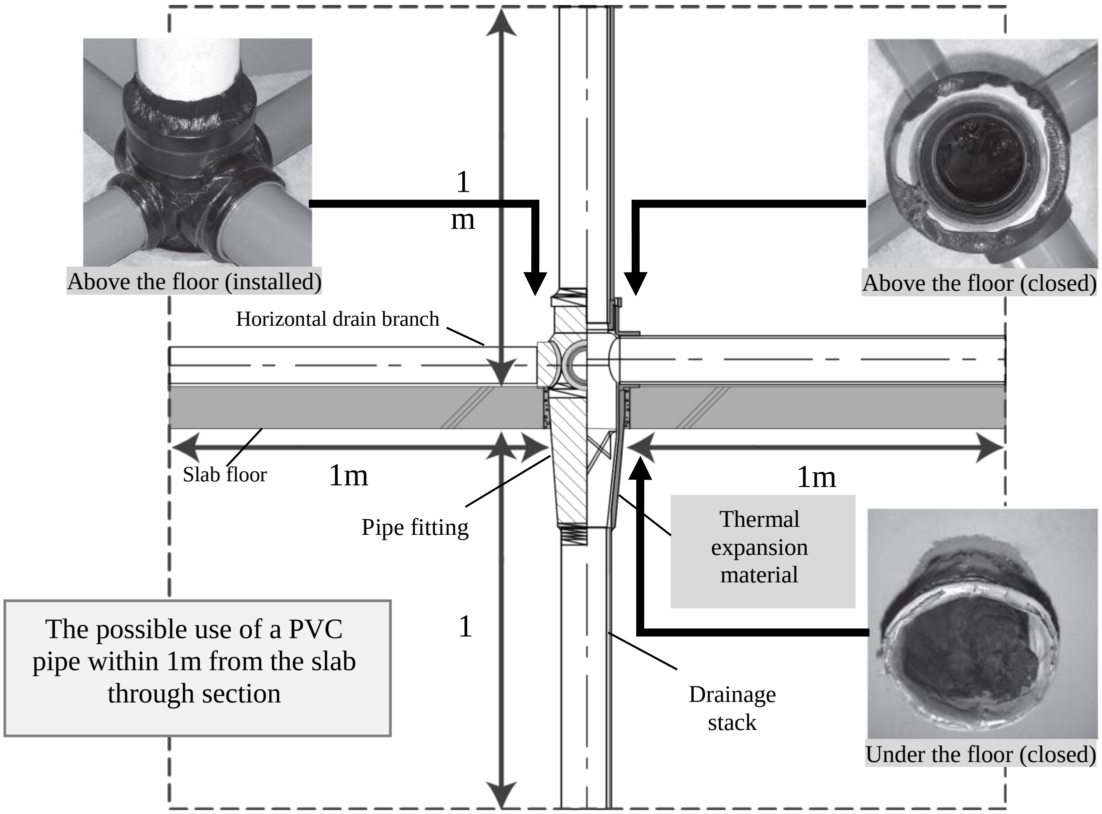


Fig. 7 Fire resistance of the special fitting

3. Understanding of the drainage loads generated by multiple water-saving toilet units

In accordance with SHASE-S220 Testing Methods of Discharge Characteristics for Plumbing Fixtures, the testing apparatus shown in Fig. 8 was used for measuring the discharge characteristics of the experimental water-saving toilets. The measured values are listed in Table 2 and are plotted on the graph of Fig. 9. When three toilets were flushed simultaneously (flushing pattern No. 7), the average drainage flow rate, qd´, was measured to be 1.35L/s, and the maximum drainage flow rate, qmax, was measured to be 2.55L/s, which is considered roughly the same as the drainage load flow rate of 2.5L/s measured in one horizontal drain branch according to SHASE-S218. Therefore, although the drainage capacity testing methods specified by SHASE-S218 are essentially intended for 'apartment houses', it is considered that the testing methods can be applied to 'business-related buildings'. The previous study[4)] proposed a similar system for apartment housing. This study makes use of the knowledge acquired in the previous study to discuss the applicability of the hybrid system for offices.

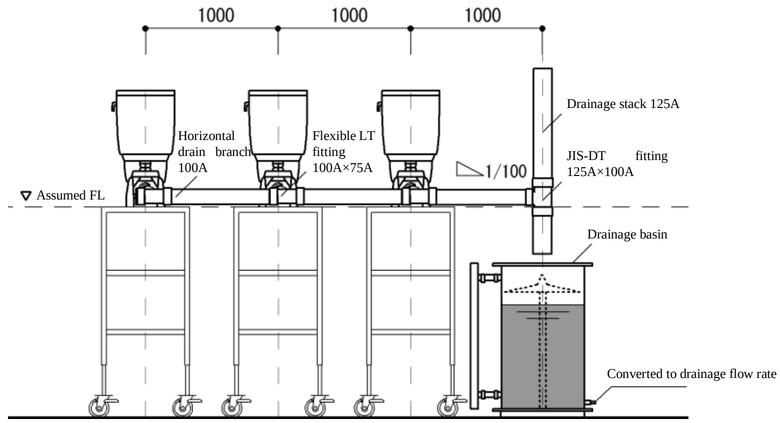


Fig. 8 Fixture discharge characteristics testing apparatus (SHASE-S220)

Table 2 Discharge characteristics of experimental water-saving toilets

Flushing pattern	Flushing point			Amount of flushed water	Average drainage time	Average drainage flow rate	Max. drainage flow rate
	①	②	③	w[L]	td′[s]	qd′[L/s]	qmax[L/s]
No.1	●			6.0	6.0	0.60	0.99
No.2		●		6.0	8.2	0.44	0.93
No.3			●	6.0	9.6	0.38	0.94
No.4	●	●		12.1	7.2	1.01	1.76
No.5	●		●	12.0	6.7	1.07	1.87
No.6		●	●	12.1	8.0	0.90	1.83
No.7	●	●	●	18.0	8.0	1.35	2.55

※Single flush (horizontal drain branch length 1m) w: 6.0L/s td’: 4.0s qd’: 0.91L/s qmax: 1.19L/s

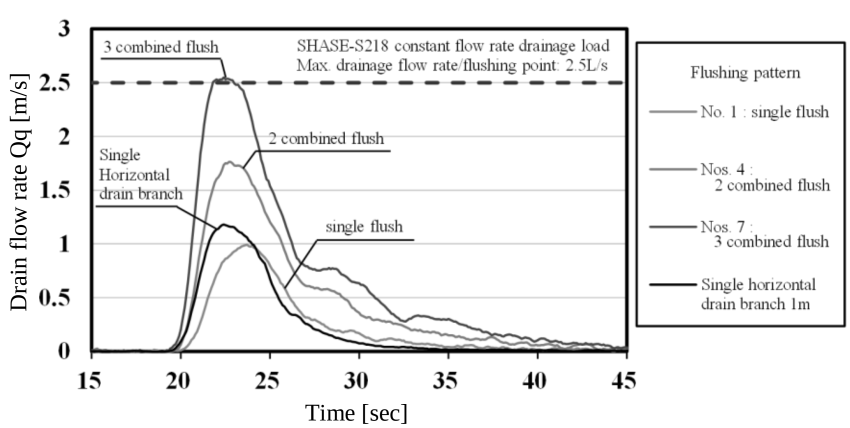


Fig. 9 Flow rates of water drained from experimental multiple water-saving toilets

4. Understanding of the influence of drainage loads on the drainage capacity of a drainage stack system and the verification of the effectiveness of the proposed system

(1) Discussion on the in-pipe pressure distributions

Experimental horizontal drain branch systems comprising multiple water-saving toilet units (see Fig. 11) connected thereto were connected to the experimental drainage stack system of the nine-storey tower (see Photo 2 and Fig. 10**)**, respectively on the 8th and 7th floors. Fixture drainage load tests were then carried out, using the drainage load patterns in Table 3. Fig. 12(1) shows the distribution of pressure generated by applying drainage load pattern No. 7 (combined flushing of three toilet units from the 8th floor ($\Sigma qd' = 2.7L/s$)), and Fig. 12(2) shows the distribution of pressure generated by applying No. 12 (combined flushing of six toilet units from the 8th and 7th floor ($\Sigma qd' = 5.4L/s$)). According to the graphs, in the case of No.7, Pmin exceeds the reference value of ±400Pa when the conventional fitting is used; approximately -480Pa on the 6th floor, whereas Pmin does not change greatly on the 6th to 2nd floor when the special fitting is used; approximately -25Pa on each floor, which is approximately 5% less than when the conventional fitting is used. In the case of No.12, Pmin is approximately -900Pa on the 6th floor when the conventional fitting is used, while Pmin is approximately -85Pa when the special fitting is sued, which is approximately 20% less than when the conventional fitting is used.

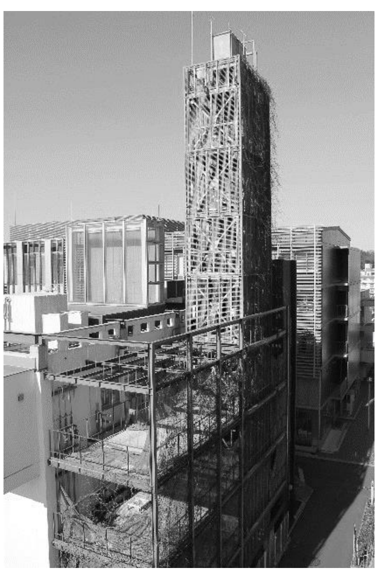


Photo 2 Experimental tower (Kanto Gakuin University)

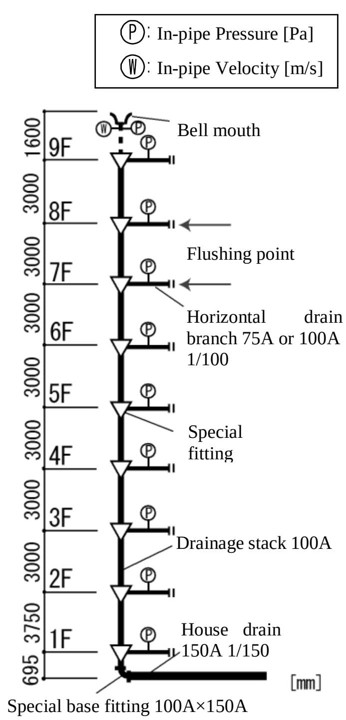
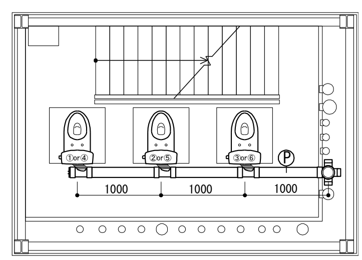
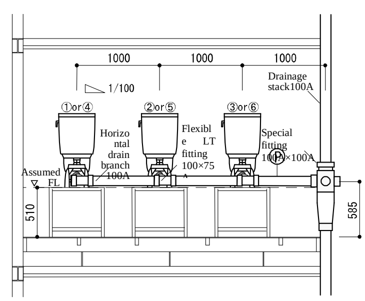


Fig. 10 Experimental drainage stack system



(1) 8F and 7F - plane view

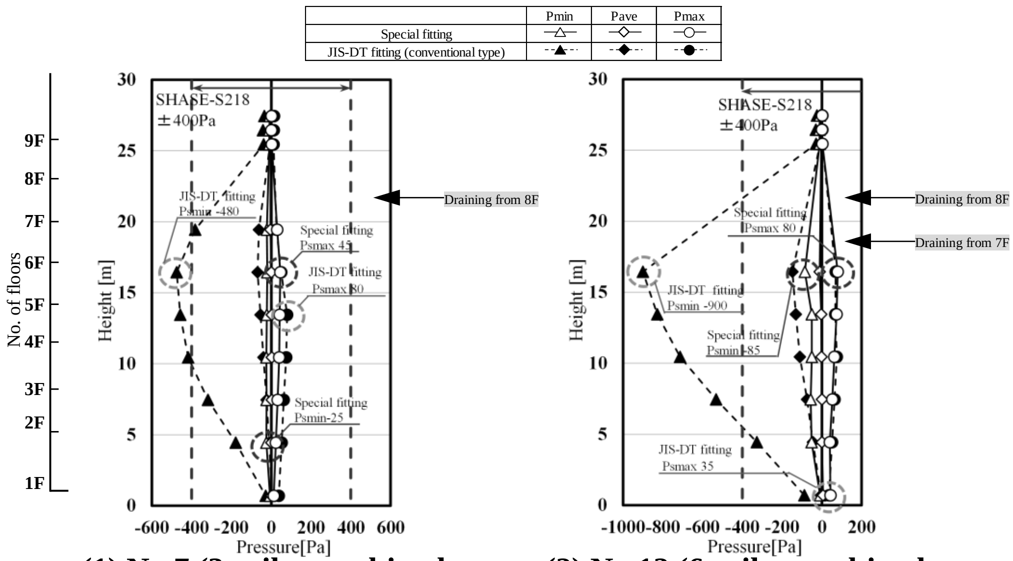


(2) 8F and 7F - elevation view

Fig. 11 Experimental horizontal drain branch system (installed on 8F and 7F)

Table 3 Drainage load patterns

Drainage load pattern			No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12
Flushing point	Multiple toilets on 8F	①	●			●	●		●	●	●	●	●	●
		②		●		●		●	●		●	●	●	●
		③			●		●	●	●			●	●	●
	Multiple toilets on 7F	④								●	●	●	●	●
		⑤									●		●	●
		⑥												●
Total average drainage load flow rate		Σqd'[L/s]	0.9	0.9	0.9	1.8	1.8	1.8	2.7	1.8	3.6	3.6	4.5	5.4



(1) No.7 (3-toilet combined flushΣqd′＝2.7L/s)

(2) No.12 (6-toilet combined flushΣqd′＝5.4L/s)

Fig. 12 Distribution of pressure by applied drainage loads

(2) Discussion on the drainage capacity

Fig. 13 shows the total average drainage load flow rate, Σqd′, in relation to the maximum system value, Psmax, and the minimum system value, Psmin. In the case of using the conventional fitting, when three toilets were flushed together, Σqd′ was measured to be 2.7L/s and exceeded the reference value of SHASE-S218, whereas in the case of using the special fitting, even when as many as six toilets were flushed together, Σqd′ was measured to be 5.4L/s and exceeded the reference value by a mere 20% or so. This demonstrates that the use of the special fitting is effective in securing an adequate drainage capacity to manage multiple water-saving toilet units installed in high-rise business-related buildings with approximately 10 floors.

Fig. 14 shows the trap seal loss, ⊿h, of the trap, which was disposed immediately underneath the draining floor, in relation to the total constant flow rate drainage load flow rate, ΣQw, specified by SHASE-S218 and the total average fixture drainage flow rate, Σqd′. The trap seal loss values were measured when five fixture drainage loads were applied one by one without topping up the trap seal water. As a result, compared to the constant flow load, the fixture drainage load caused approximately 40% trap seal loss, which is considered to be a small influence on the trap. Therefore, with reference to the variation of in-pipe pressure and the trap seal loss as indices, it is right to say that the proposed drainage system has an adequate drainage capacity.

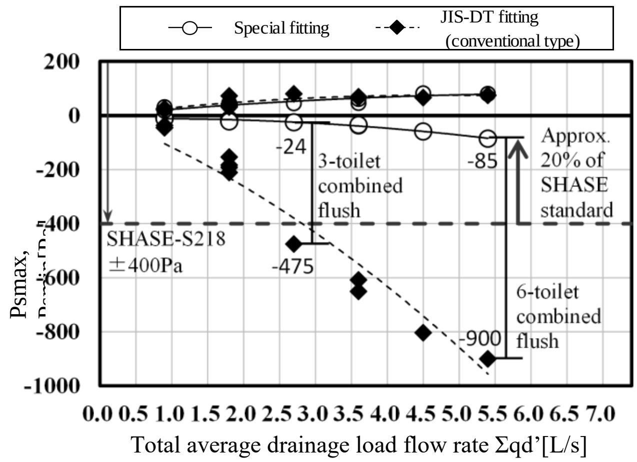


Fig. 13 Total average drainage load flow rate Σqd' in relation to maximum system value Psmax and minimum system value Psmin

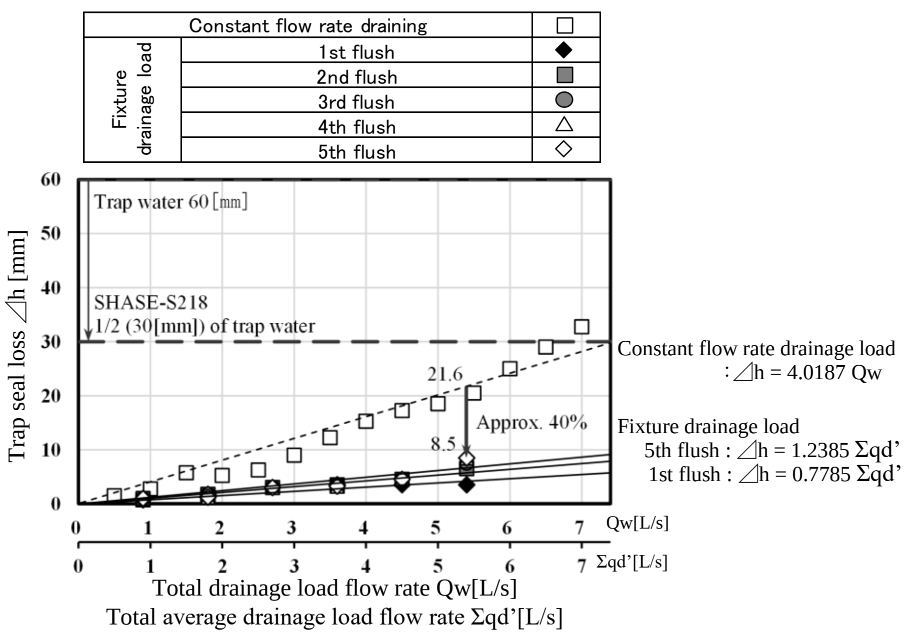


Fig. 14 Trap seal loss ⊿h in relation to drainage load flow rates

5. Conclusion

A drainage system with special resin fittings was proposed for multiple water-saving toilet units that are installed in business-related buildings, and drainage capacity experiments were carried out on an experimental drainage system. Consequently, the following knowledge has been acquired.

(1) Subsequent to the tests according to SHASE-S218, it has been confirmed that the use of special fittings ensures a drainage capacity approximately 2.5 times larger than when conventional fittings are used. The increased drainage capacity is considered related to a factor such as the reduced flow velocity in the pipe.

(2) Regarding flow rates of drainage loads flowing from the horizontal drain branch with approximately three toilet units connected thereto down into the drainage stack, the maximum drainage load flow rate is approximately 2.5L/s, and the average fixture drainage flow rate is less than 1.5L/s. SHASE-S218 specifies the maximum drainage load flow rate from the first floor to be 2.5L/s, and the measured drainage load flow rates are within the range of SHASE-S218. Therefore, SHASE-S218 is applicable to drainage systems for business-related buildings.

(3) With reference to the reference value specified by SHASE-S218; the variation of in-pipe pressure (within ±400Pa) and the trap seal loss (seal water depth: less than 1/2), it has been confirmed that the proposed drainage system is applicable to high-rise business-related buildings.

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7. Presentations of Authors

Masayuki Otsuka is a professor at Department of Architecture and Environmental Design, Kanto Gakuin University. He is a member of AIJ (Architecture Institute of Japan) and SHASE(the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His latest interest is the development of a hybrid drainage system that uses both force feed type and gravity type drainage methods compatible with commercial building conversions.

Norihiro Hongo is an associate professor at Department of Architectural Environment System Engineering, Yamagata College of Industry and Technology. He has a Master of Engineering degree. He is a member of AIJ (the Architectural Institute of Japan) and SHASE (the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan).

Yuki Kuga is a master's degree student at the Otsuka Laboratory, Kanto Gakuin University. He is a member of AIJ (the Architecture Institute of Japan) and SHASE (the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His latest interests is to acquire knowledge about effects of special resin fittings on drainage performance.

Ryota Sugimoto works at the Department of Environment & MEP Engineering of NIHON SEKKEI Inc. He has a Master of Engineering degree. Currently, he has been engaged in the planning and design of multistoried apartment houses and commercial buildings. He is also a member of AIJ (the Architectural Institute of Japan) and SHASE (the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan).

B4 - Water efficiency of kitchen faucets in manual dishwashing

L.S. Yee (1), L.T. Wong (2), K.W. Mui (3), Y. Zhou (4)
2. beltw@polyu.edu.hk
3. behorace@polyu.edu.hk
(1), (2), (3), (4) Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

Abstract

Washing up dishes under running tap water is a key contributor to domestic water consumption. This study investigates the water efficiency of kitchen faucets in manual dishwashing in terms of the washing height, water supply pressure and dish orientation, and thus determines the efficiency improvement potential. The results indicate that the potential water efficiency improvements for the changes in washing height, water supply pressure and faucet resistance factor are 8%, 25% and 48% respectively. Moreover, it is demonstrated that 30–40% of the water consumed in manual dishwashing can be reduced at a tilted angle of 30–60°.

Keywords

Water efficiency; water efficient taps; experiment; dishwashing.

1 Introduction

Water conservation is a global issue. Domestic water use accounts for 20-30% total water consumption in developed cities. Surveys indicated that at least a quarter of the domestic fresh water consumed is tap water [1,2]. Hence, replacing water inefficient faucets with water efficient ones is believed to be an effective way to improve domestic water use efficiency [3]. Water efficiency of dishwashing is also a concern. A study on global manual dishwashing behavior revealed that the most water-consuming manual dishwashing method among all investigated ones is washing up dishes under running tap water [4]. This study investigates the water efficiency of kitchen faucets in manual dishwashing in terms of the washing height, water supply pressure and dish orientation, and thus determines the efficiency improvement potential.

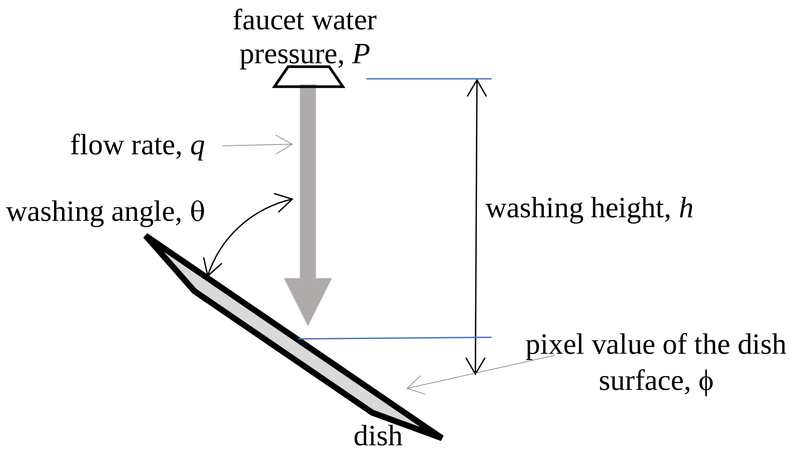
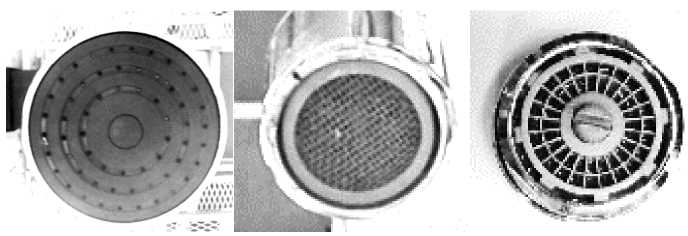


Figure 1 - Dishwashing experiment



(a) k=7.2 kPa min^{2}L^{-2} (b) k=3.2 kPa min^{2}L^{-2} (c) k=3.8 kPa min^{2}L^{-2}

Figure 2 - Sample faucets: (a) spray type; (b) column type; (c) flow restrictor

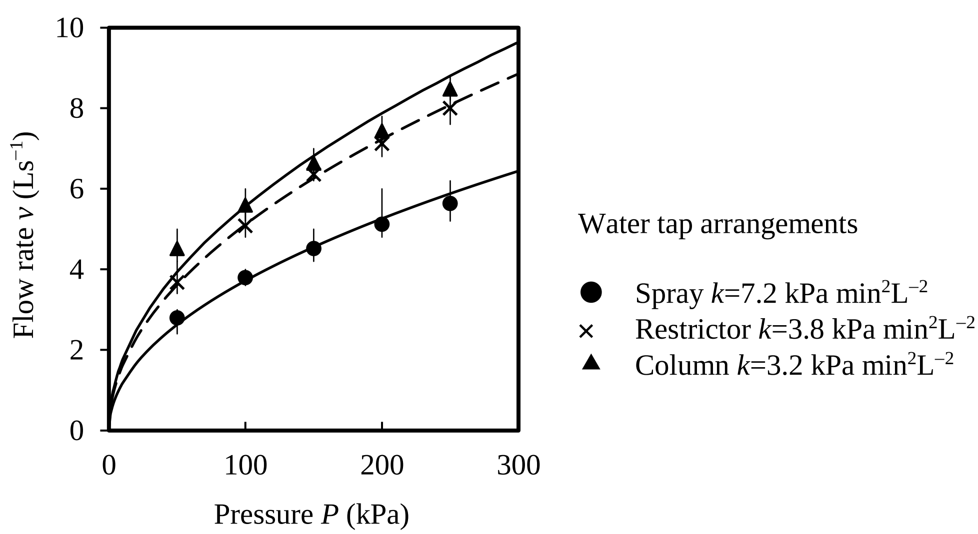


Figure 3 - Discharge characteristics of three sample faucets

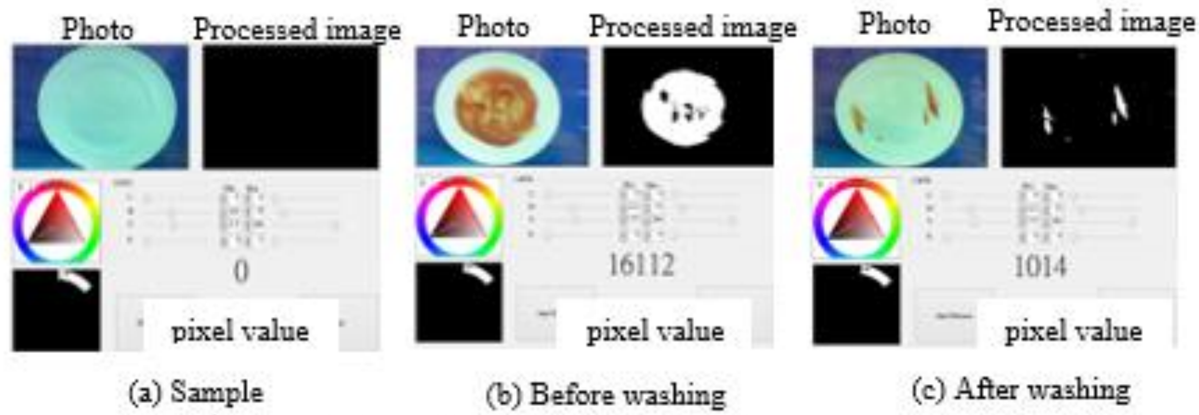


Figure 4 - Measured pixel values for a dish sample

2 Methodology

Sample dishes were purchased directly from the market. Each dish was 220mm in diameter, with a base diameter of 160mm. Water consumption V (L) for cleaning a dish is estimated by the following expression, where V_e (L) is the experimental water consumption for cleaning the dish, φ is the measured cleanliness, and ϕ_0 and ϕ_1 are the pixel values for the soiled area of the dish before and after washing respectively,

$$V = \frac{V_e}{\varphi}\ ;\ \varphi = \frac{\phi_0 - \phi_1}{\phi_0} \qquad \dots (1)$$

The experimental water consumption V_e (L) is determined by the tap flow rate v (Ls^{-1}) and tap discharge time τ (s),

$$V_e = v\tau \qquad \dots (2)$$

Dishwashing tests were conducted using the method described in a previous study [5]. In each test, a tablespoon of tomato sauce (3g) was distributed over the surface of a dish and the dish was washed under a kitchen faucet at a washing height h (m) and a washing angle θ (º) as shown in Figure 1.

Three water tap settings for dishwashing were considered in this study. Figures 2(a) and 2(b) illustrate the spray and column faucets (i.e. the first two sample faucets) used in the tests. Figure 2(c) shows a flow restrictor that was installed inside a column faucet (i.e. the third sample faucet) to reduce water supply flow rate. Figure 3 graphs the discharge characteristics of the three sample faucets (in the range of 3.2 to 7.2 kPa min^2L^{-2}; p<0.01, t-test) given by the resistance factor k (kPa min^2L^{-2}). k is expressed by Equation (3), where v (Ls^{-1}) is the discharge flow rate measured at a water supply pressure P (kPa) in the range of 50 to 250 kPa.

$$k = \frac{P}{v^2} \qquad \dots (3)$$

The pixel values ϕ were determined from images captured by a camera. Figure 4 illustrates the processed images of a dish sample, where τ=10s and the diameter of the soiled area is 160mm (i.e. the base diameter).

3 Results and discussion

Figure 5 presents the average water consumption required for cleaning a soiled dish *V* (L) from 5 washes against: (a) water supply pressure at the faucet *P*; (b) washing angle θ; (c) washing height *h* – the distance between faucet outlet and dish centre; and (d) a dimensional quantity $(Ph/k^2)^{0.3}$. Volume consumption *V* for cleaning a dish was found to be correlated with faucet water pressure ($p<0.05$, *t*-test) and with washing height at a rate of height increase of 0.0038L/mm ($p<0.05$, *t*-test). However, its correlation with faucet resistance factor *k* was insignificant at a height (p=0.09–0.27, *t*-test), and it had no significant correlation with the washing angle ($p\geq0.3$, *t*-test). As shown in Figure 5(b), variations of water consumption indicated by the consumption ratio from maximum to minimum were 1.49, 1.59 and 1.67 for restrictor, column and spray faucets respectively. A larger variation indicated that water consumption was more sensitive to the washing angle. Figure 5(b) demonstrated that 30–40% of the water consumed in manual dishwashing could be reduced at a tilted angle of 30–60°.

Excluding the washing angle, water consumption for dishwashing can be expressed by,

$$V \sim \left(P, \frac{1}{k}, h \right) \qquad \dots (4)$$

Figure 5(d) shows the water consumption given by the following expression (R=0.91, $p<0.0001$, *t*-test),

$$V = 0.194\left(Phk^{-2}\right)^{0.3} \qquad \dots (5)$$

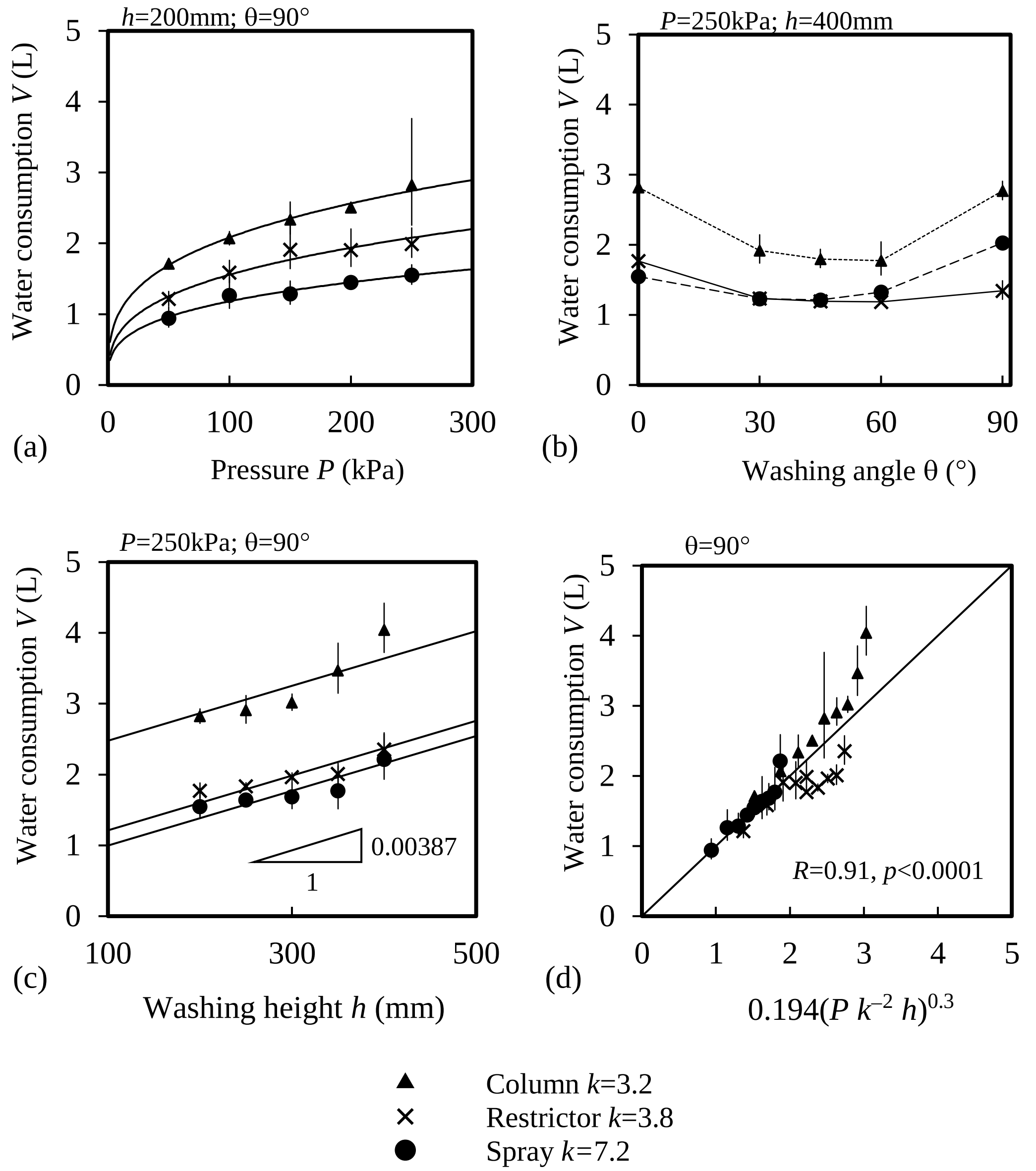


Figure 5 - Water consumption against: (a) water pressure *P* (kPa); (b) washing angle θ (°); (c) washing height *h* (mm); (d) 0.194($Pk^{-2}h$)$^{0.3}$

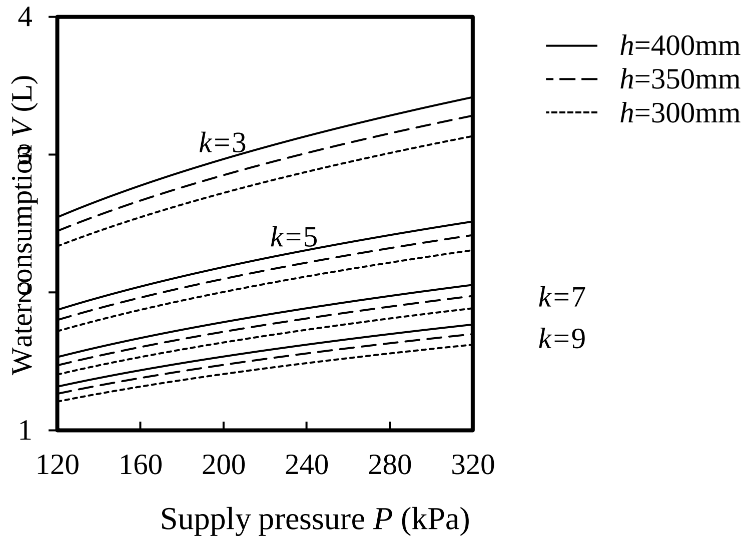


Figure 6 - Predicted water consumption for a sample dish wash

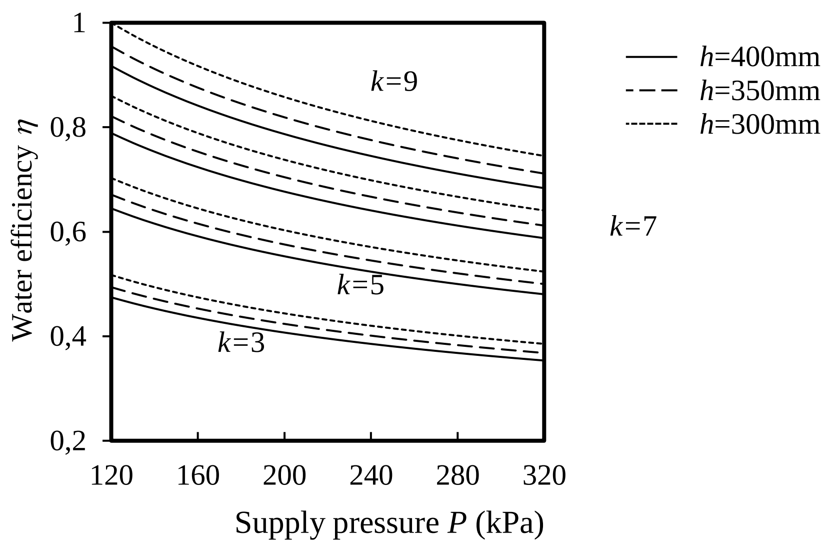


Figure 7 - Water efficiency for the sample dish wash

As graphed in Figure 6, for a sample dish wash with a pressure range P=120–320 kPa, a height range h=300–400mm, and a faucet characterized by k=3–9 kPa min^{2}L^{-2}, the range of predicted water consumption is V=1.2–3.4L using Equation (5).

Water efficiency η of the sample dish wash can be determined by the minimum water consumption required for washing the dish V_{min} divided by the amount of water actually consumed in the dish wash. The maximum water efficiency improvement η_s over the range of operating parameters is given by,

$$\eta_s = 1 - \eta = 1 - \frac{V_{\min}}{V} \quad \ldots (6)$$

Figure 7 graphs the water efficiency results for the sample dish wash. Average water efficiencies for the ranges of washing height *h* (300–400mm), water supply pressure *P* (120–320 kPa) and faucet resistance factor *k* (3–9 kPa $\text{min}^2\text{L}^{-2}$) are 0.92, 0.75 and 0.52 respectively, indicating the potential water efficiency improvements for the changes in *h*, *P* and *k* are 8%, 25% and 48% respectively. For the above three parameter ranges, the minimum water efficiency is 0.35 and the maximum water efficiency improvement is 65%.

4 Conclusion

This study investigated the water efficiency of kitchen faucets in manual dishwashing in terms of the washing height, water supply pressure and dish orientation, and thus determined the efficiency improvement potential. The results showed that the potential water efficiency improvements for the changes in washing height, water supply pressure and faucet resistance factor were 8%, 25% and 48% respectively. Moreover, it was demonstrated that 30–40% of the water consumed in manual dishwashing could be reduced at a tilted angle of 30–60°.

Acknowledgment

The work described in this paper was partially supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region (HKSAR), China (PolyU 5272/13E) and by four other grants from The Hong Kong Polytechnic University (GYBA6, GYL29, GYM64, GYBA7, GYBFN).

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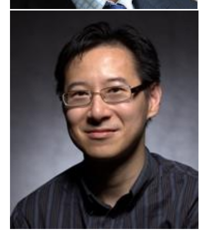
6 Presentation of Authors

Mr. L.S. Yee is an undergraduate student at the Department of Building Services Engineering, The Hong Kong Polytechnic University.

Dr. L.T. Wong is an associate professor at the Department of Building Services Engineering, The Hong Kong Polytechnic University.

Dr. K.W. Mui is an associate professor at the Department of Building Services Engineering, The Hong Kong Polytechnic University.



Mr. Y. Zhou is a PhD student at the Department of Building Services Engineering, The Hong Kong Polytechnic University.

B5 - Integration of grey water recycling with PGWS in residential building

C.L. Cheng. (1), C.H. Yeh. (2), J.J Perg. (3), H.P. Lin(4)

1. CCL@mail.ntust.edu.tw
2. D10513017@mail.ntust.edu.tw
3. af9864@cpami.gov.tw
4. M10413901@mail.ntust.edu.tw

(1) (2) (3) (4)National Taiwan University of Science and Technology, Department of Architecture, Taiwan, R.O.C.

Abstract

In high-density urban area, using the mode of reuse and on-site circulation is one of the effective strategies which can efficiently improve resource utilization. According to the prototype of purification green-wall system (PGWS), this study will discuss further more on aspects of functional and operational optimization strategies and try to combine with the concept of individual grey water streams. The result of experiment verified that PWGS with a 1/4 planting pots of the origin can also treat grey water recycled from daily shower and basin in a 4 people family efficiently. On the other hand, PGWS provide more flexible property for both source and amount of domestic grey water by modularizing the planting pot and separating the drainage streams. The convenience and individualization on its operation and maintenance are helpful for the application and promotion of the system. In view of grey water's recycle-treatment-reuse in house, modularized PGWS can not only content to the demand of individual domestic reused water, but also have the potential for supplying a large amount of recycled water for the public water use in urban area.

Keywords

green wall; grey water; reuse; constructed wetlands; domestic water consumption; on-site circulation; individual grey water streams

1 Introduction

Under the severe environment of climate change and increasingly amount of global population, water as one of the necessary conditions for human living, will definitely become an important competitive resource between countries. In high-density urban area, using the mode of reuse and on-site circulation is one of the effective strategies which can efficiently improve resource utilization. The PGWS is a new pattern of ecological engineering used for both greening and water saving. This system can not only achieve the goal for on-site circulation of water reusing inside the building, but also result many aspects of benefit for high-density urban area such as air quality improvement, heat island reduction, landscape aesthetic enhancement, reduction of water resource consumption and cost-down of sewage treatment. According to the prototype of PGWS, this study will discuss further more on aspects of functional and operational optimization strategies. On the other hand, in accordance with E.Friedler(2004),various kinds of domestic grey water result in different pollutants. Thus, if we separate different grey water drainage according to its pollutants' composition as well as import relative treatment mechanism of PGWS, more multiple and flexible reuse program of domestic grey water shall be supplied. These programs can be taken in water supply and drainage system of newly-built buildings as well as existing ones with restricted water-using space.

2 Theories and Methods

A PGWS of two planting pots connected full of 18 liters each, under a model of 9 liters per hour inflow frequency, 4 hours HRT, could be a feasible system, shown as Figure1. It can treat 216 liters of less polluted grey water continuously each day. Figure2 shows how it was combined with house. Its capability of pollutant treatment is shown in Fig.3 and Fig.4.

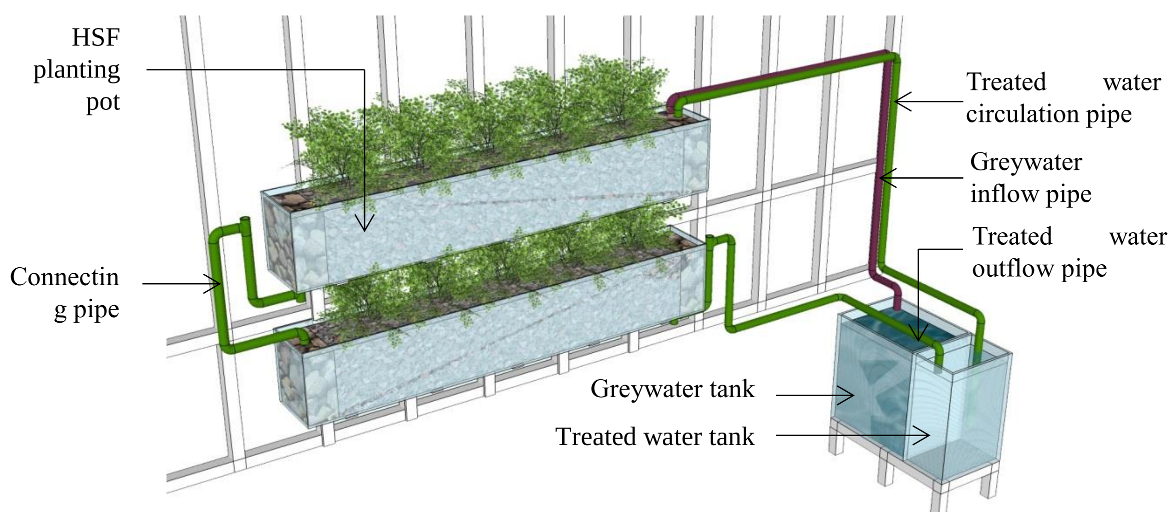


Fig.1 Purification green-wall system (PGWS)

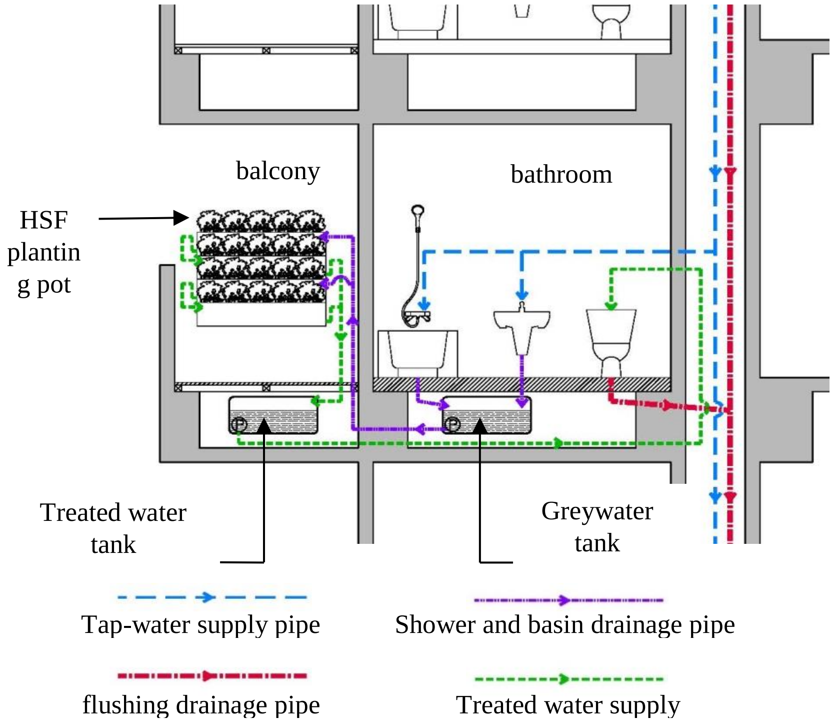


Fig.2 The water supply and drainage system of PGWS in apartment

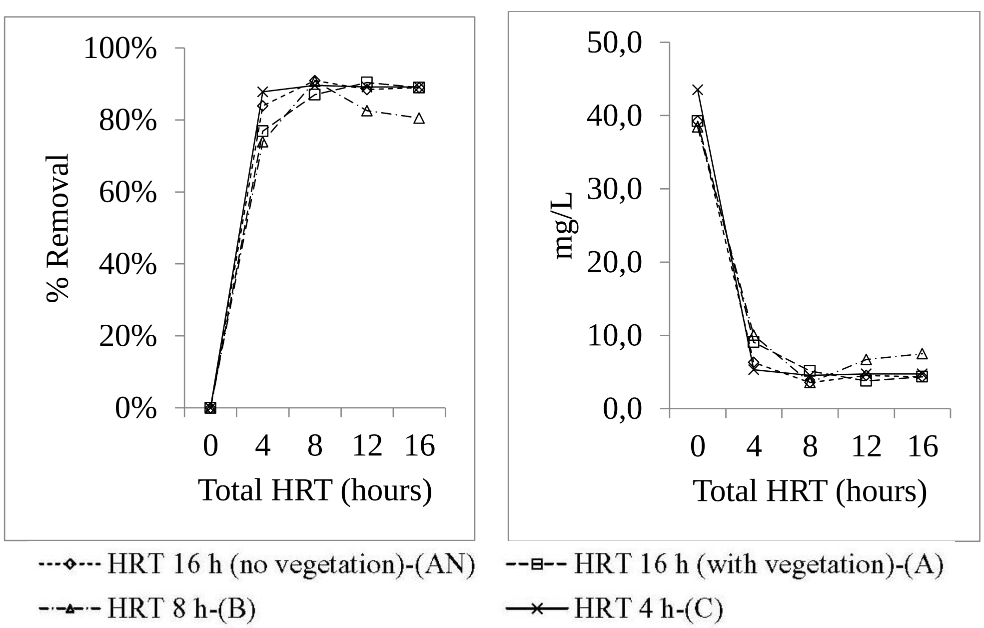


Fig.3 Variation of BOD_5, 20℃

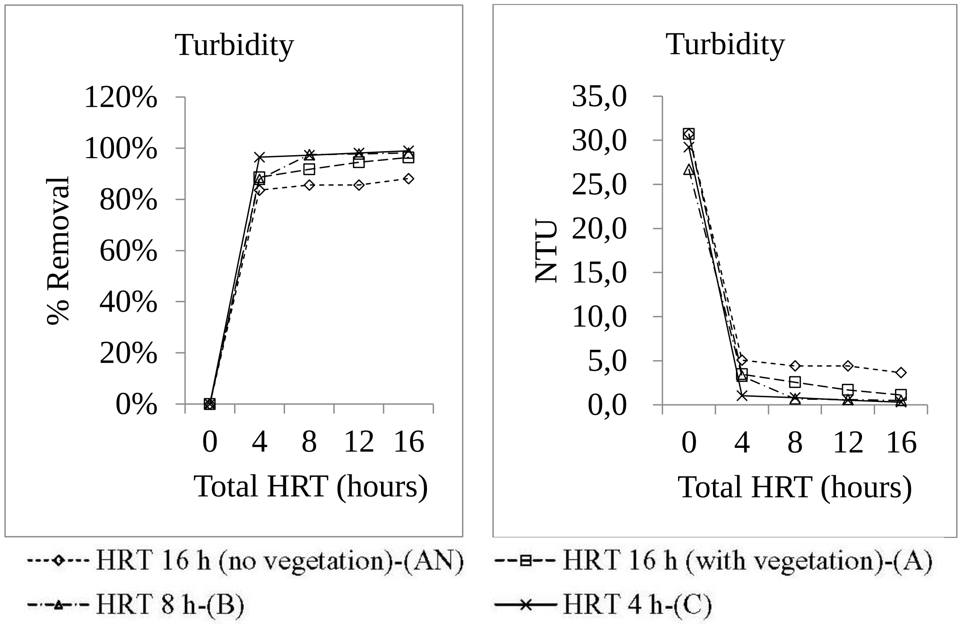


Fig.4 Variation of turbidity

According to the experimenting results, the removal efficiency of BOD_5 and turbidity both reached excellent degree at the fourth hour. Using the same equipment and testing methods, this study will observe the pollutant removal effect within 1-4 hours.

3 Experiment and results

Experiments, sampling and water quility analysis are taken in May 2017, and the results are shown as Table 1, Fig.5 and Fig.6. This experiments verified that a good effect of pollutant removal can also be held under a shorttened HRT(1 hour) of PGWS. According to the result, PWGS with a 1/4 planting pots of the origin can also treat grey water recycled from daily shower and basin in a 4 people family efficiently. Meanwhile, a better effect of pollutant removal is shown with a longer HRT. Thus, if the purpose of reuse require higher standard of water quility, the HRT should be prolonged appropriately.

Table 1 Results of lab analysis

HRT	Total Coliform (TC)		BOD_5, 20℃		Turbidity		pH
	CFU/100 mL	Removal %	mg/L	Removal %	NTU	Removal %	--
0 hr	2200000	0%	81.480	0%	96.10	0%	6.78
1 hr	250	99.99%	18.226	77.63%	23.70	75.34%	7.25
2 hr	13000	99.41%	21.042	74.18%	23.10	75.96%	7.57
3 hr	35000	98.41%	19.662	75.87%	20.50	78.67%	7.93
4 hr	40000	98.18%	12.591	84.55%	12.60	86.89%	7.80

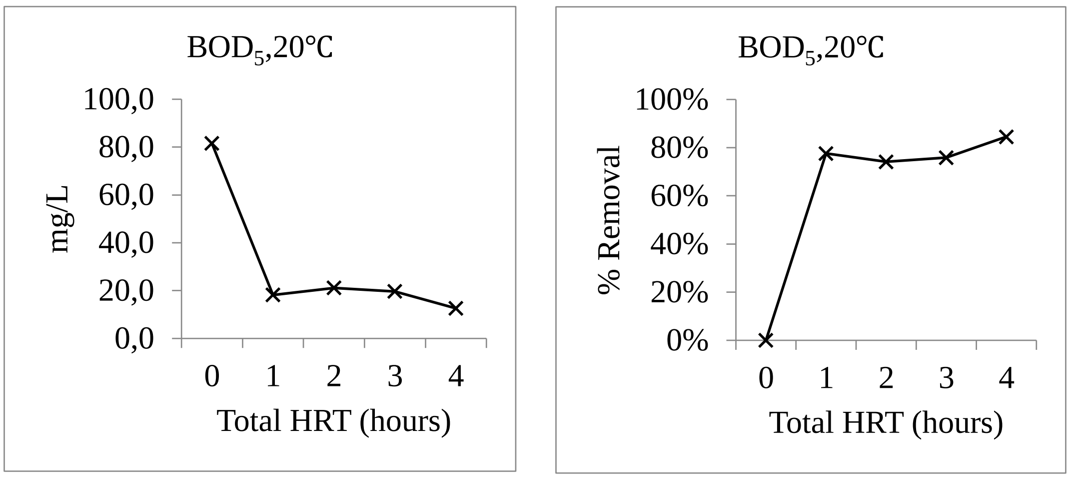


Fig.5 Variation of BOD_5, 20℃

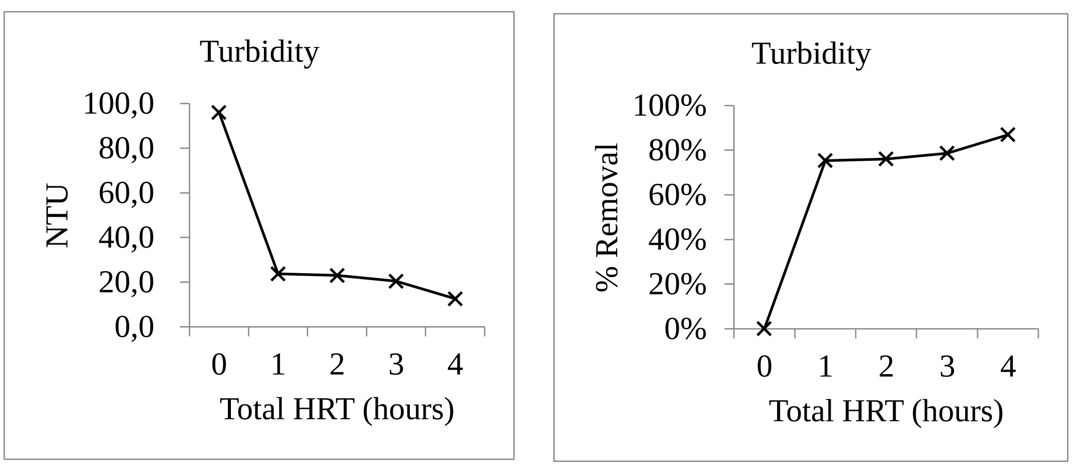


Fig.6 Variation of turbidity

4 Discussion and application

4.1 Modularized PGWS

A PGWS with single planting pot of 150 cm in length, 20 cm in width, 25 cm in height, and 20 cm height of full water level can accommodate 18 liters of water after placing substrate, shown as Fig.7. Considering the inconvenient replacement of substrate or planting as well as the total weight, the installation and placing of the pot cannot be done by a single person. Thus, in aspect of operation and maintenance, the purpose of a PGWS designed for a single family usage cannot be achieved. On the other hand, being a devise of treating individual grey water streams classified from domestic drainage, the PGWS need to have a satisfying flexibility of treatment mechanism, which is not provided in its original prototype. This study tries to add a flexible modularized system, easy for operating, into the prototype of PGWS. The installation steps are shown as below.

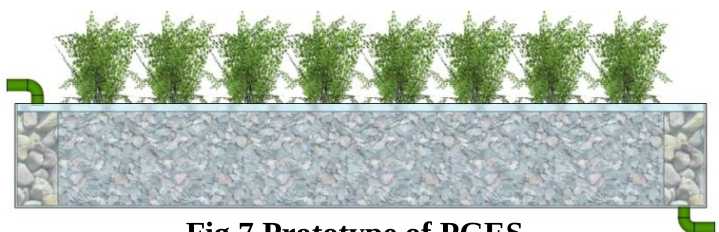


Fig.7 Prototype of PGES

1. The single planting pot is divided into 10 small units which 2 of them at both ends are in-flow and out-flow units and others are planting pot units.Each small unit are separated by permeable partition, shown as Fig. 8.

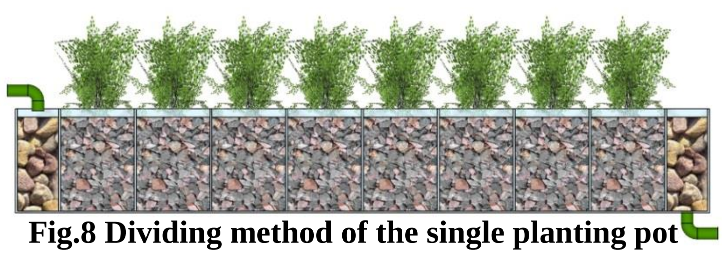


Fig.8 Dividing method of the single planting pot

2. Each small unit is a container made of non-woven fabric. By putting substrate mixed with ∮5~10mm gravel and Ceramsite into the in-flow and out-flow units, grey water is evenly distributed in the section of pot. Mixture of ∮3~5mm perlite、∮5~10mm Ceramsite and ∮5~10mm vermiculite are placed in the planting pot units as growing base material for aquatic plants.Each unit can be planted 1-2 aquatic plants, shown as Fig. 9.

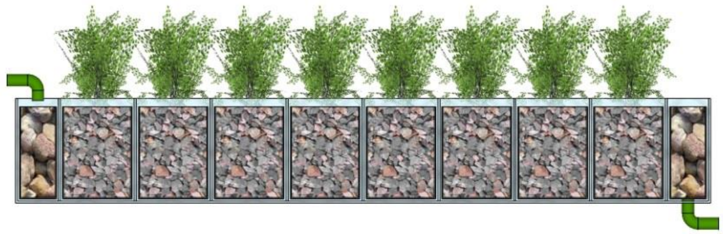


Fig.9 Small unit of the single planting pot

3. Each planting pot unit can change the sort of substrate flexibly according to the grey water source and pollutant characteristics. Plant species can be determined by user likes, shown as Fig. 10.

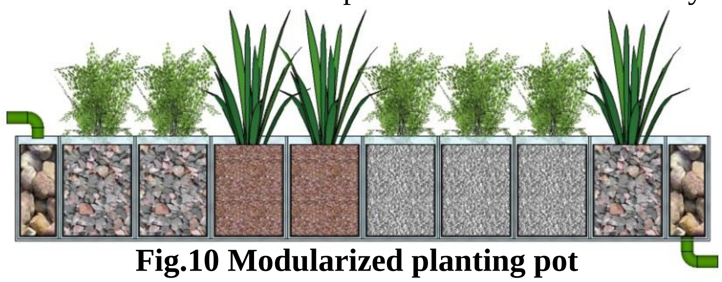


Fig.10 Modularized planting pot

4. The number of planting pot unit is adjustable according to the space and the concentration of pollutant in grey water, shown as Fig .11.

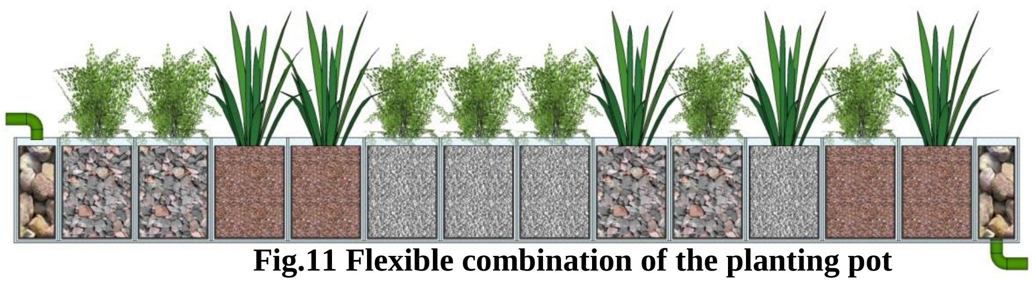


Fig.11 Flexible combination of the planting pot

Except the advantages on installation, operation, maintenance and individualization, the water treatment ability, which is the core characteristic of modularized PGWS, is provided with more flexible property for both source and amount of individual grey water streams. According to the result of experiments, modularized PGWS with only 4 planting pot units added between the in-flow and out-flow units could be a feasible devise which can supply an adequate amount of reused water for flushing in a 4 person family. Despite of space restriction on newly-built or existing buildings and different individual domestic grey water streams, the modularized PGWS is applied to all kinds of urban building as well as supplies a more convenient water reuse system of on-site circulation.

4.2 Individual grey water streams in residential building

A study of domestic grey water made by E. Friedler (2004) pointed that the pollutant characteristic of individual source is different. Thus, if we classify different grey water drainage according to its characteristic of pollutants as well as import relative treatment mechanism of PGWS, more multiple and flexible reuse program of domestic grey water shall be supplied. According to the reports from Water Resource Agency, Minister of Economic Affairs of Taiwan, the average tap-water consumption of housing is 157.8 liters per person per day, 19.12% of which is laundry, 20.47% of which is shower, 11.41% of which is basin, 21.95% of which is flushing, 14.14% of which is kitchen, and the remaining 12.93% is for other use. Water supply and drainage of traditional system is shown as Fig.12. Water supply and drainage of PGWS is shown as Fig.13. A modularized PGWS and its water supply and separating drainage system is shown as Fig.14. Treating individual domestic grey water can supply not only for the flushing and landscape irrigation which is a 32% saving of tap water supply, but also a daily production of about 57 liter per family which can replace the water consumption of street cleaning and sidewalk plant irrigation if we separate and treat all kinks of domestic grey water.

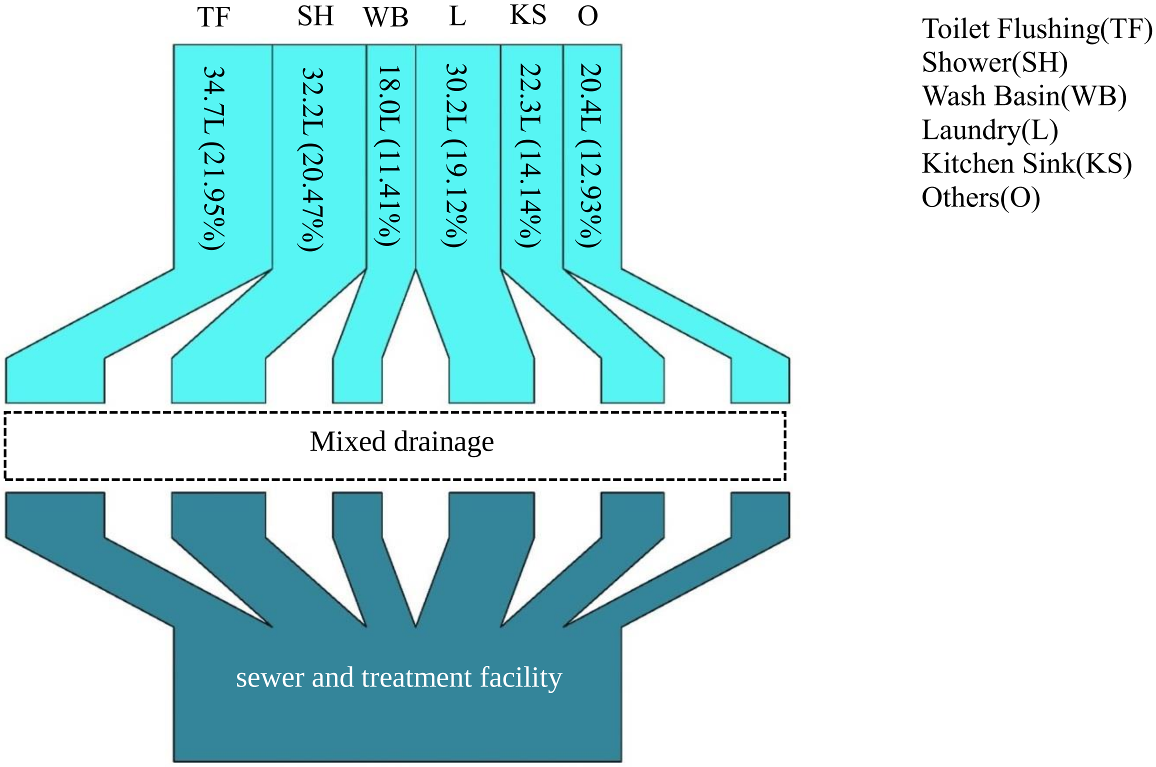


Fig.12 Water supply and drainage of traditional system

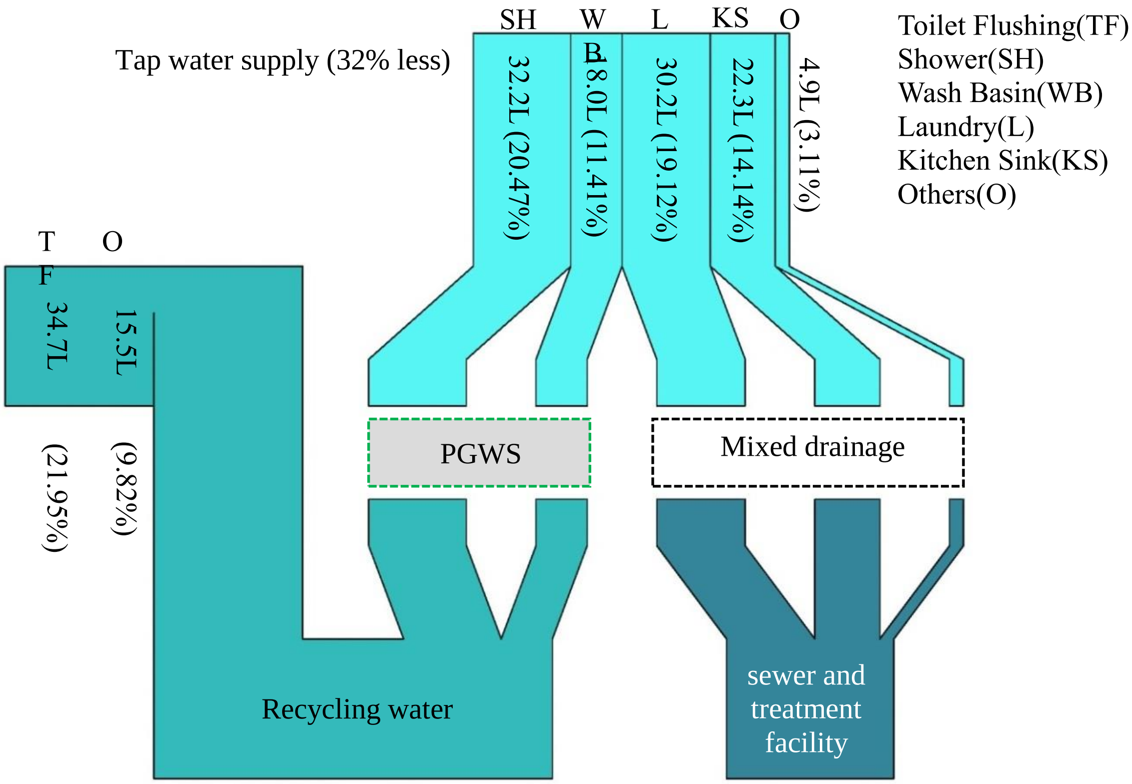


Fig.13 Water supply and drainage of PGWS

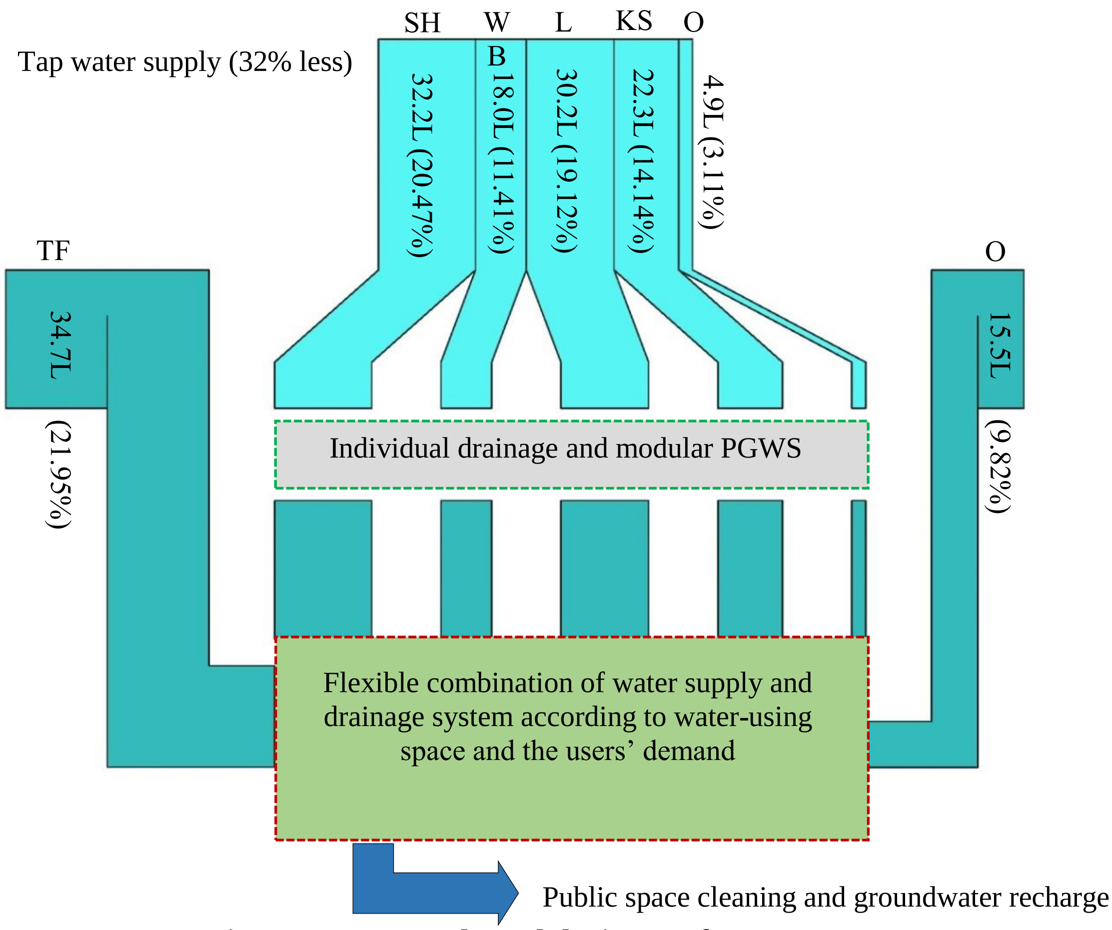


Fig.14 Water supply and drainage of modular PGWS

5 Conclusion

This experiments verified that a good effect of pollutant removal can be held under a shortened HRT(1 hour) of PGWS. According to the result, PWGS with a 1/4 planting pots of the origin can also treat grey water recycled from daily shower and basin in a 4 people family efficiently.Meanwhile, A better effect of pollutant removal is shown with a longer HRT.Thus, if the purpose of reuse require higher standard of water quility, the HRT should be prolonged appropriately. On the other hand, adding the concept of modularization to the prototype of PGWS, a system with more flexible property for source and amount of individual grey water streams can thus be developed. The convenience and individualization on its operation and maintenance are helpful for the application and promotion of the system. The concept of separating treatment of domestic grey water can exert the advantage of modularized PGWS. This system can supply not only for the demand of individual domestic reused water but also a large amount of recycled water for the public water use in urban area. This study will continue observing the efficiency of modularized PGWS in a following long term as well as the grey water treatment capacity affected by all kinds of system variables. Moreover, the combination of system and individual treatment of domestic grey water is also a main exploring area afterwards.

Acknowledgments

The authors would like to thank the Ministry of Science and Technology (MOST105- 2221-E-011-017) for financially supporting this research.

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7 Presentation of Authors

Cheng-Li Cheng is the Professor at National Taiwan University of Science and Technology. He is a researcher and published widely on a range of water supply and drainage in building. He has published extensively on a range of sustainable issues, including the water and energy conservation for green building.

Chun-HsienYeh is the Ph.D student at National Taiwan University of Science and Technology, Department of Architecture. His research is focus on water resources and Green Building.

Jr-Jie Peng is the Ph.D student at National Taiwan University of Science and Technology, Department of Architecture. His research is focus on Landscape Architecture, Urban Design and Sustainable architecture.

Hung-Piao Lin is the Master student at National Taiwan University of Science and Technology, Department of Architecture. His research is focus on water resources and Green Building.

B6 - Domestic Water Consumption in Hong Kong

Eric Wai Ming Lee (1), Katherine Yee Ping Wong(2)
1. ericlee@cityu.edu.hk
2. ping121991@gmail.com
(1)Associate Professor, Department of Architecture and Civil Engineering, City University of Hong Kong, Kowloon Tong, Hong Kong
(2)Graduate, Department of Architiecture and Civil Engineering, City University of Hong Kong, Kowloon Tong, Hong Kong

Abstract

This is an example of the layout and style to be adopted in preparing papers for submission to

Water consumption is a popular issue for people all over the world. Domestic water consumption is considered as the major water usage. Apart from the development hardware for water saving, we would investigate the correlation between family factors and the domestic water consumptions in order to propose different strategies for reducing the domestic water consumption. We collected water bills and replied questionnaires from 100 numbers of families in Hong Kong. The water bills show the actual water consumptions of the families in 7 consecutive months. The replied questionnaires collect the floor areas of the apartments, family incomes, ages, education levels etc. from the families. Statistical analysis was adopted to investigate the correlation between the family factors to the water consumption. The major family factor will be used to propose management strategy to reduce the water consumption

Keywords

Domestic water consumption; family pattern survey.

1 Introduction

Water is a vital resource to human. It does not only use to sustain human life, but also use in different industries. Without it, people cannot do their business or even live properly. In the earth, there is around 70% of its surface is filled with water. Among these water, 3% is fresh water while 97% is salt water. Since 2% of the fresh water is locked up in the polar ice and glaciers, there is only 1% fresh water can be used directly [1]. Water is a renewable resource; it should not have the problem of shortage. However, the rapid increase of human population and human activities, water is going out of supply. Even there is water recycle, it cannot bear the speed of water loss and that result in water shortage. These days, water scarcity becomes more and more serious. In the world, there are more than 1 billion people live without clean drinking water. Nearly 510millions people in 31 countries are suffering from water scarcity. More importantly, there are around 25millions people die every year from unclean water [2, 3]. The existence of water scarcity is a signal to arouse people awareness towards the problem. There are 783 million people live in an area that is insufficient of save water. It lacks about 7800 million metre cubes water in average. The shortage of water in Turkey, Egypt and Syria are 3900 million metre cubes, 1200 million metre cubes and 1800 million metre cubes respectively [4]. Although not all countries are facing the water shortage problem, it is necessary to aware of the problem and find ways to resolve this as this problem would spread out to any places in the world. According to a report of the United Nations in 2013, 50% global population will live in water stressed areas by 2030. For the highly populated area in China, like Beijing, its water supply will deplete by 2030. Similarly, the Colorado River in the United States will have the problem of drought. The Colorado River is the water source of ten million people and farm lands, it would be a serious problem if the river is out of water supply [2]. It is undoubted that water is going out of supply within 17 years. It is necessary to control the use of water in the world.

2 Domestic water consumption

Water is mainly use in three areas, industrial, domestic and commercial. Among these three usages of water, domestic is the most popular one. It almost is the major water consumption area in the world. According to “Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study”, 70% of waste water are caused by domestic sector [5]. By the momentum theory, input and out are in proportion. Thus, the more fresh water it used, the more waste water it gave out. It clearly shows that most of the water is used in domestic sector.

2.1 Domestic water consumption in different cities around the world

In the past, people do not have a sense of energy saving. People just think about the development of countries and personal enjoyment, it results in excessive use of energy. Some of the resources, like water, is renewable, however, due to abuse using, it becomes out of supply. According to Human Development Report 2006, the average water consumption of European countries ranges from 200-300Litres a person per day while the US reached 575Litres a person per day in the year between 1998 and 2000 which is greatly larger than the global average water consumption per person per day. The global standard of water consumption per person is 130 Litres per day [2]. The outbreak of water scarcity urges countries to concern the water-saving issue. For example, the greatest water consumption country – the United States have organized a water saving policy called EPA’s approach in 2010. This approach reduced the water use by 18.7 percent when comparing to 2007 baseline. [6] Saving water becomes a global target.

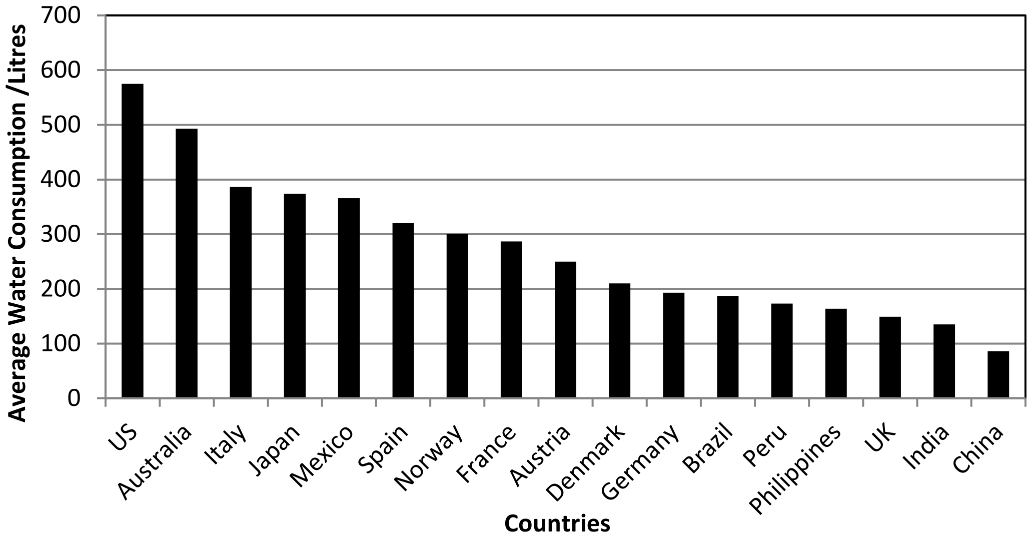


Figure 1 – Average water consumptions in different counties [2]

2.2 Domestic water consumption in Hong Kong

In Hong Kong, nearly 90% of water is used for domestic in the past. Start from 1961, the water consumption per capita increased by 7%. The daily consumed water per person grew from $0.102m^3/day$ to $0.203m^3/day$ in 1971. From the research by Aston [7], it is estimated that the growth rate of domestic water use is 3% per year. The population growth could be one of the reasons behind the growth of domestic water usage as the population growth rate is 2.24% per year which is very close to the growth rate of the domestic water consumption. Due to the rapid development of Hong Kong, large variety of events consumes water. Even the society change, domestic is still the major sector in water consumption. It is observed from table 1 that over 50% of fresh water consumption is used for domestic purpose while service trades only use a quarter of the total. It means that domestic is still the biggest sector to be targeted to save water consumption. Controlling the water consumption in domestic may be the best way to reduce use of water.

Table 1 Fresh water consumption in Hong Kong in 2008-2012 (by sectors) [8]

Year	2008	2009	2010	2011	2012
Domestic	519	524	509	498	505
Industrial	59	55	57	58	59
Service Trades	241	238	237	236	236
Government Establishments	45	44	42	41	41
Construction & Shipping	11	11	12	14	18
Flushing	81	80	79	76	76
Total Fresh water Consumption	956	952	936	923	935

It is concerned that the level of water charge may relevant to water consumption. The water charge in Hong Kong divided into four tiers. For the first 12 units, it is free. The next 31 units cost HK$4.16 per unit. The 19 units after that 31 units cost HK$6.45 per unit. For the consumption more than 62 units, it charges HK$9.05 per unit. The percentages of water consumption of the four tiers are 14, 41, 21 and 24 accordingly. More than 40% accounts consume 43 units of water for every 4 months and quartile capita consumption is more than 62 units in four months [8]. This percentage shows that the consumption of domestic water in Hong Kong is quite high in level. To reduce the water usage, scientists and engineers spent a lot of efforts in developing different water saving devices and apparatus for the plumbing system (e.g. faucets with bubble spray aerator, rainwater and waste water recycling, etc.). Instead of investigating the hardware development, we would focus on investigating family factor(s) correlating to water consumption.

Since water charge is fixed, it would not be consider at the moment, other factors within a family will be considered. In view of the water scarcity problem in global, more has to be done to reduce the water stress. Domestic is the basic water consumption area in Hong Kong and the basic area to consume water, it is needed to have more understanding in this area. Therefore, a survey is done in this area to learn the factors affecting domestic water consumption so as to develop more measures to control the water usage. In this survey, it will do a research in family water consumption. With the family background, it is hope that the research can find out the dominant factors that affecting domestic water consumption, a more accurate equation or model to calculate the water consumption per family and suggest ways to trim the domestic water consumption.

3 Family factors

Different factors related to domestic water consumption are found from the literature review. From [9], it suggested that there are lots of factor could affect the level of water consumption which includes climate, culture, economy, individual demands, occupant attributes, appliance characteristics, demographic data, geographical locations, building ages and architectural designs. These criteria are useful in estimating the water consumption of the occupants but not all criteria are useful in the research. It is no doubt that culture would affect the water usage. Since we only consider the domestic water consumption in Hong Kong, the climate and culture factors are ignored.

The climate may influence the water consumption. In summer and winter, the average monthly water consumptions are different. However, according to the water bills we collected, the climate has less effect to water consumption. Most of the families have little variations in water consumption throughout the year. Therefore, this factor is also ignored in this study.

Besides, the appliance characteristics will not be considered in this study. Since it is a small scale study when comparing to others, it is very difficult to know what appliances do every interviewers have and what are the properties of each appliances. It is impossible to do such a detail survey at this stage. Although the characteristics of appliance will not be considered, the number of water supply objects will be counted. For an example, how many basins or toilets are there is a house. These would be used to estimate the amount of water usage.

Economy could be a factor affecting water consumption. In the survey of Wong and Mui, they consider the economy of a country, like GDP [9]. Since this research investigates the water consumption of household, instead of GDP, we adopted the income of the family as one of the factor. For example, the water charge per 100 cubic metres in Hong Kong is quite cheap when comparing to other cities. The cost in Hong Kong is 15%, 17.6% and 21.4% of New York, Tokyo and Paris respectively. It may result in high water usage as people think that the water charge is cheap [10]. The individual demands and occupant attributes are very difficult to define. In this research, these two criteria will not be put into survey, but some of the related criteria (e.g age, education level, etc.) are considered in this research to know the characteristics of the user so as to better estimate the water consumption of the user. Moreover, the family size will be considered as the water bill will record the whole family usage as one unit. This may benefit in estimating the water consumption.

Apart from the characteristics of the family and the family members, geographical locations will take into account. The distribution of the geographical locations may reflect the amount of water usage of financial background of the user. By collecting the demographic data, the water consumption might relate to the distribution of district as the different types of housing distribution or different district populations. There are 18 districts in Hong Kong. The research will divide the collected water bills into these districts and study whether the water consumption and location have relationship.

In terms of building ages and architectural designs, they will not be considered yet as there is insufficient information. More research will be done to find out whether they will affect water consumption significantly. Finally, from article “Attitudes to conservation and water consumption”, it raises another area to investigate – attitude. [11] Since attitude is a wide topic, it is hard to mark it or qualify it. Thus, this cannot be made it out in this study. Besides, education level and wealthy level of a family might affect the water consumption attitude so it will be added to this research. After our analysis, we determined 6 family factors as shown in table 2 to study their effects to the monthly water consumption.

Table 2 Selected family factors to be studied on their contributions to the monthly water consumption

No.	Family factors
x_1	Apartment area of the family
x_2	Average Income of the family
x_3	No. of family members
x_4	Average age of the family
x_5	Average education level of the family
x_6	Ratio of family members working

4 Data collection

Total 500 questionnaires were sent out and we received 100 responses. The collected data are statistically presented in Figure 2. It shows that most of the apartment area is less than 25m^2

which is not uncommon in Hong Kong due to the high population and limited land for residential development. The average monthly income varies from HK$2,000~13,000. Most of the families have 4 members with average age around 37. The survey result also shows that most of the family members are holder of certificate or diploma with no doctorate degree. Also, it shows that most of the families have half or less family members working.

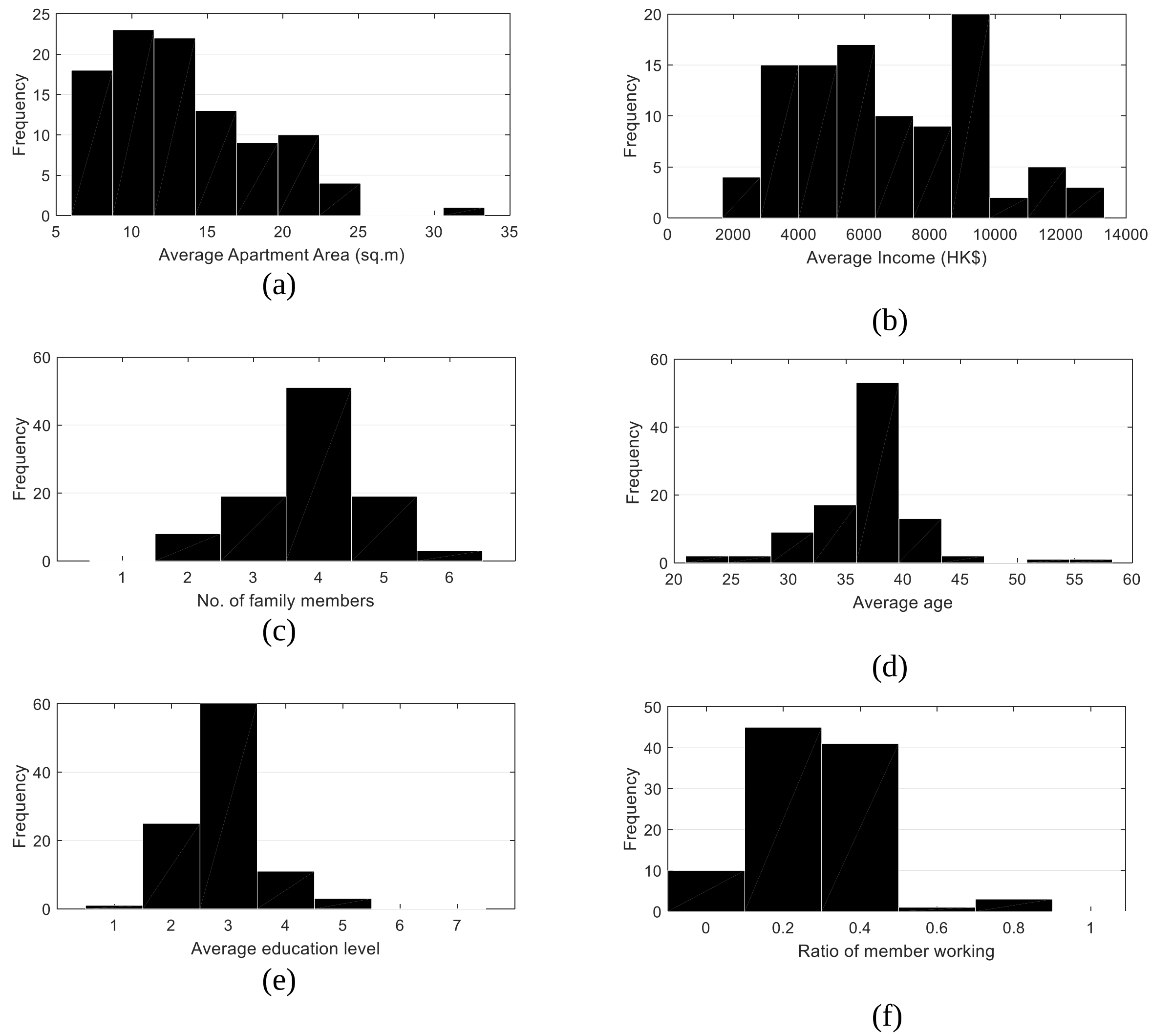


Figure 2 – Statistical presentation of the factors collected from the survey

4 Statistical Analysis

The correlations between each factor and the water consumption are analyzed below. It is purposed to investigate the most dominant factors which has the highest impact to the water consumption so that we can investigate on the possible strategy to reduce the water consumption.

4.1 Multiple Linear Regression (MLR)

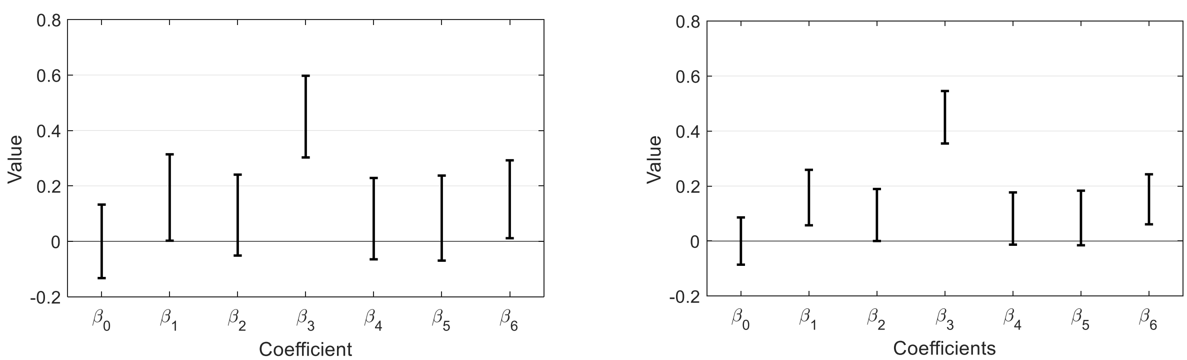
It is a simple approach to determine the correlation between factors and the water consumption. The correlation is assumed to be linear in nature. By assuming y to be the water consumption, the linear regression is to determine the coefficients of the following linear equation of which $\hat{x}_i$ are normalized value of x_i. The normalization converts the data of each factor to zero mean and unit variance.

$$y = \beta_0 + \beta_1\hat{x}_1 + \beta_2\hat{x}_2 + \beta_3\hat{x}_3 + \beta_4\hat{x}_4 + \beta_5\hat{x}_5 + \beta_6\hat{x}_6$$

By applying MLR, the coefficients are determined as follows.

$$y = 0 + 0.1581\hat{x}_1 + 0.1947\hat{x}_2 + 0.4500\hat{x}_3 + 0.0819\hat{x}_4 + 0.0839\hat{x}_5 + 0.1518\hat{x}_6$$

The result shows that all factors are, in general, positively correlated with the water consumption. In order to further investigate the confidence of this result, we plot the 85% and 65% confidence intervals of the determined coefficients in figure 3(a) and 3(b). Figure 3(a) shows that only the 85% confidence intervals of the coefficients β_1, β_3 and β_6 fall into positive side. It implies that we have 85% confidence level that the factor x_1 (i.e. apartment area of the family), x_3 (i.e. no. of family members) and x_6 (i.e. Ratio of family members working) are positively correlated with the water consumption. If we further reduce the confidence level to 65%, as shown in figure 3(b) the confidence interval of coefficient β_2 also falls into positive side. It implies that there is 65% confidence level that the factor x_2 (i.e. average Income of the family) is positively correlated with the water consumption.



(a) (b)

Figure 3 – Confidence interval of the coefficients determined by MLR; (a) 85% confidence level; (b) 65% confidence level

4.2 Mutual Information

In order to further justify the above statistical results, we adopted Mutual Information (MI) to evaluate the dependencies between the water consumption and each factor as a second measure. MI is one of the measures in information theory to evaluate the mutual dependency between two random variables. MI is developed from information entropy and relative entropy which measures the uncertainty embedded in the received information. The information entropy of a probability distribution is defined by Shanon [12] as follows.

$$H = -\sum_{i} p_i log(p_i)$$

High entropy means the uncertainty is high and vice versa. MI is defined by the entropy and relative entropy as follows. High MI implies high mutual dependence of the two variables. $I(X,Y)$ is the MI between variables X and Y. $H(X)$ and $H(Y)$ are respectively the entropies of probability distributions of variable X and Y.

$$I(X,Y) = H(X)H(Y) - H(X,Y)$$

We use the MI formula developed by Kraskov et al. [13] to estimate the MI between the water consumption and each of the factors. The results are shown as follows. Table 3 shows that the factors with high MI are x_1 and x_3 which agree with the results we obtained from MLR. The MIs of the factors x_2 and x_5 are almost 1/20 of the highest one. It implies that they are not strongly dependent to the water consumption.

Table 2 Selected family factors to be studied on their contributions to the monthly water consumption

Factor	Description	Mutual information : $I(y, x_i)$
x_1	Apartment area of the family	0.2066
x_2	Average Income of the family	0.1061
x_3	No. of family members	1.9990
x_4	Average age of the family	0.0777
x_5	Average education level of the family	0.1062
x_6	Ratio of family members working	0.0682

We further analyse the factors by combining the results obtained from MLR and MI as shown in Table 3. It summaries the MIs of the factors representing in percentage of the maximum. The result of MLT indicates the confidence levels of the factors positively correlated with the water consumption.

Table 3 Summary of the factor dependency determined by MLR and MI

Factor	Description	MI (% of maximum)	MLT Confidence level
x_1	Apartment area of the family	10.34%	85%
x_2	Average Income of the family	5.31%	65%
x_3	No. of family members	100.00%	85%
x_4	Average age of the family	3.89%	< 65%
x_5	Average education level of the family	5.31%	< 65%
x_6	Ratio of family members working	3.41%	85%

The summary shows that the most dominant factor to water consumption is the number of family members. It is not surprising since most of the plumbing guides use this factor to determine the daily water consumption or water storage. The second important factor is apartment area which is in general proportional to the number of family members. Therefore, this good correlation is reasonable. The other dominant factors are the average income of the family and ratio of family members working. The two factors may have some relation since the average income is higher if more family members are working. MLR indicates that they have positive effects to the water consumption. The MI reveals that the factors are non-strong dependent factors to the water consumption. The last two factors (i.e. average age and average education level of the family) are considered weakly correlated to the water consumption.

5 Conclusions

Water saving is a major consideration in sustainable lives. Different plumbing hardware engineering designs have been developed for this purpose. This paper investigated the family factors and their correlation with the domestic water consumption in order to achieve water saving from software approach. It was found that the domestic water consumption is closely related to the number of family members and the floor area of the family apartment. The most interesting finding is that average family income is also the factor has positive effect to the water consumption. It implies that it is quite likely that a family with high water consumption is likely a rich family. The existing water tariff in Hong Kong is proportional to the water consumption but becomes flat rate at HK$9.05/$m^3$ when the water consumption is more than 62m^3 per 4 months. In view of this research result, it is propose to remove the flat rate so that the water tariff is always proportional to the water consumption. That is, large domestic water consumer should pay more money to penalize their large water consumption.

Acknowledgments

The work described in this paper was fully supported by a grant from the Research Grants Council of Hong Kong Special Administrative Region, china [Project No. CityU 11203615].

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5 Presentation of Author

Eric W.M. Lee is currently an Associate Professor and Assistant Head in Department of Architecture and Civil Engineering, City University of Hong Kong. Before joining academic, he was a building services consulting engineer worked on different plumbing and drainage designs in commercial, hospital, hotel, institution and residential developments. He was the leading plumbing engineer of the 2IFC building (420m high) which is now the 2nd highest building in Hong Kong.

B7 - Study of the water using efficiency with different water ejection type in the showerheads

H.T. Tseng(1) , M.C. Lee(1) , M. Okamoto(2), S. Mio(2), C.L. Cheng(3), W.J. Liao (4)

(1) MCJL@nutc.edu.tw, National Taichung University of Science and Technology, Department of Interior Design, 129, Sec.3, Sanmin Road, Taichung , 404, Taiwan
(2) TOTO LTD, 2-8-1 Honson,Chigasaki-shi, Kanagawa 253-8577, Japan
(3) National Taiwan University of Science and Technology, Department of Architecture
(4) China University of Technology, Department of Interior Design, Taipei, Taiwan

Abstract

Hot water using efficiency is the important issue to face the climate change, not only the water demand but also energy consumption. Most hot water demands in the bathroom or shower room in hot and humidity area. Develop a showerhead with water saving, comfortable, and high clean efficiency would be a good solution for this issue.
The effective of water saving is related to the showerhead water ejection type. Through the study of the different forms of effluent in the showerhead, and whether the water consumption and the special outlet hole design under different water pressure affect the user's choice and water saving degree for the showerhead, and the amount of hair will be included in one of the experimental conditions, Summed up the corresponding amount of departure. The purpose of the experiment is to understand the relationship between the angle of the showerhead and the design of the number of water holes for the user's habit and the amount of relative relationship, and then summed up the comfortable and water-saving type.

Keywords

hot water, saving efficiency, using comfort, cleaning performance, water ejection patterns, hair volume

1 Introduction

Water consumption has been regarded as civilized indicator. For pursuing more comfortable life, living content are improved, requirements for water equipment and hot water are increased [1]. Water conservation is considered to be the most important factor for protecting water resource, saving energy and reducing carbon. In Taiwan, the largest amount of water usage is toilet flushing, then bathing, clothes washing, faucet (wash basin, kitchen sink) and others. The hot water requirements in bathrooms are majority, so saving water efficiently, keeping water cleaning, and using water comfortably become important issues gradually.

In domestic water supplying system, the hot water usage generates quite energy, and the carbon dioxide emission from domestic water is 89% of sum, which generates the largest amount of carbon dioxide. (Reffold et al. [3]). Domestic water is convenient, but it wastes energy and creates carbon dioxide at the same time. Consequently, conserving water can reduce energy wasting and carbon dioxide emission. (Lee [4] and Lai[5]). The places where more hot water be used are kitchen, bathroom and washbasin. The hot water usages in these three places include showering with showerhead and hair rinsing, as shown in Fig.1.

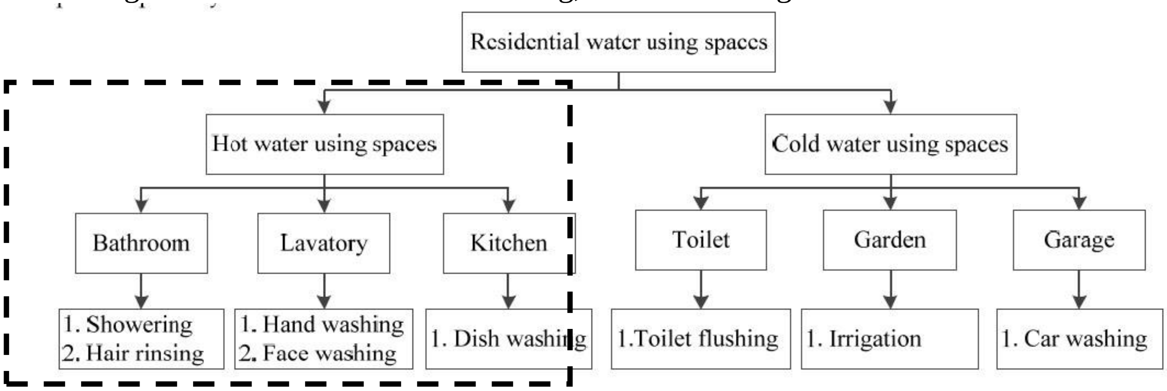


Figure 1. Domestic water using spaces and behaviors

source：[6] (by [7] refresh the drawing)

Although water-saving shower nozzles and faucets are used, they can't meet the goal definitely. Lee[8], Afonso[9], Toyosada[10], Lin[11] and others claimed that each person's water consumption per time is related to the comfort of water equipment. In the construction of water supplying system, the major assessments of comfort include adequate pressure, adequate amount and appropriate temperature. Appropriate water pressure, flow, temperature and usage can effectively reduce water consumption. Chen[13]and Lee[14]claimed that different types of shower nozzles affect the water consumption and comfort. The comfort and water requirements in buildings are always related to water pressures. Appropriate water pressure not only improves comfort but also shortens time. Lee et al. found that water consumption during bathing was related to shower comfort and also affected by water pressure [15].

According to previous experiments, more than 850 people were invited to do a bathing experiment to measure their water requirements and asked about shower behavior. The results show most people in body shower cleaning and hair cleansing (about 60%)[16], as shown in Figure 2. Hair cleaning requires more water than the other activities. The cleaning performance is affected by the showerhead ejection type. The survey of water flow, temperature and pressure among 23subjects and 12 types of shower nozzle, as shown in Figure 3. It shows that the hair cleaning efficiency is related to water consumption, so the type of shower nozzle is the focus of water conservation [17].

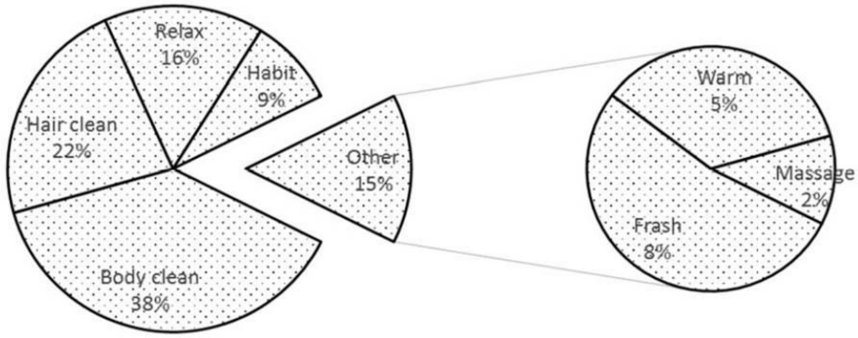


Figure 2. Investigation of shower purpose

Showerhead	Flow Rate	Temp	Force	Coverage	Rinse	% No Buy
S	2.5					0%
R	2.5					11%
L	2.0					14%
M	2.0					14%
V	2.5					20%
E	2.5					25%
K	1.6		X			40%
Q	1.5					43%
U	1.5			X		57%
N	1.5					60%
O	1.5					63%
H	2.5		X			63%
A	2.5			X	X	67%
F	1.0		X	X	X	71%
I	2.5		X	X		75%
C	0.7	X		X	X	83%
G	1.5		X	X	X	83%
P	1.5					83%
J	2.5	X	X	X		83%
T	1.5		X	X	X	100%
B	2.0	X	X	X	X	100%
D	2.5					100%

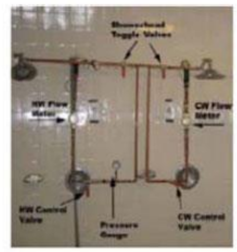


Table 2: Importance of Various Showerhead Attributes

Category	Level of Importance
Strength of spray	Extremely Important
Hair rinsing ability	
Overall appeal of spray	Very Important
Spray coverage / width of spray	
Distribution of spray	
Face rinsing ability	Quite Important
Body rinsing ability	
Noise level	
Size of showerhead	Only Slightly Important
Variety of sprays provided	
Attractiveness of showerhead	Not at all Important

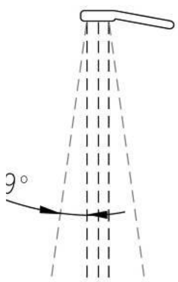
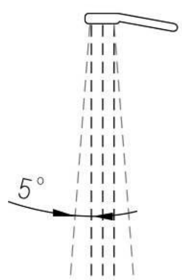
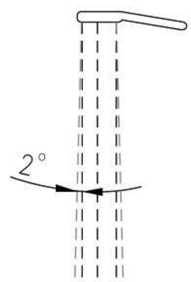
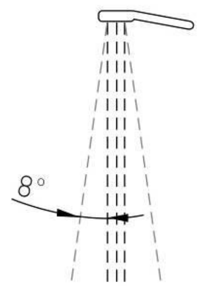
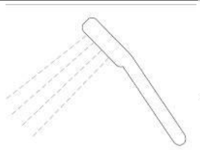
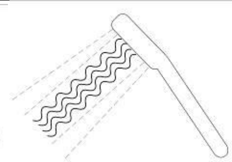
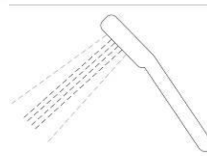
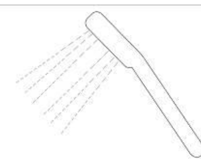
Figure 3. The Results of showerhead performance study

The purpose of the experiment is to find the relationship among angles, hole quantity of shower nozzle as well as user habits, discuss the usage of hot water equipment (shower nozzle, and find the appropriate and water-saving flow characteristics.

2 Methodology

This study is to discuss the flow characteristics of comfort and water conservation, so we chose four types of shower nozzles, which represented different water supplements (as shown in Table 1), and invited 31 subjects (1 predictor and 30 subjects) to get the relationship between washing behavior and time.

Table 1 Physical properties of representative showerhead (showering)

Shower ID	A	B	C	D
Showerhead				
Spray angle(°)				
Water ejection type	 Straight line	 Swirl type	 Hollow water	 Spread
Holes	40	64	60	48
Water Pressure at 6.5L/min [MPa]	0.037	0.023	0.026	0.020

Besides using the instruments such as fluid flow meter, fluid pressure gauge, fluid thermometer and alcohol thermometer, we used the data logger to record the flow, pressure and comfortable temperature. The instruments are shown in Figure 4-1. Consider a flow meter, a pressure gauge and a thermometer as a set, as shown in Figure 4-2. Hot water temperature was controlled by the subjects to get more comfortable showering.

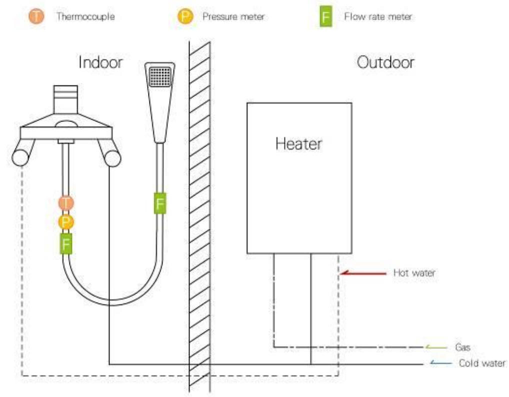


Figure 4-1. Instruments establish the concept diagram

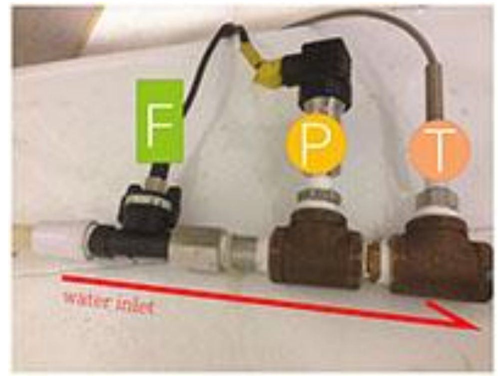


Figure 4-2. Instruments combine

According to the 2014 survey, the water pressure in Taiwan was usually designed for low-pressure water supplement, as shown in Figure 6. In light of water conservation and safety, manufactures usually regulate the pressure range of water supplement. Find the appropriate range for 4 shower nozzles, as shown in Figure 6. In order to meet the requirements of water pressure, the Variable frequency pump was installed at the entrance of water supplement (Figures 7-1 & 7-2), the flow meter was installed at the exit of the shower nozzle (Figure 7-3), and we proved that we can get data we set under the same water pressure.

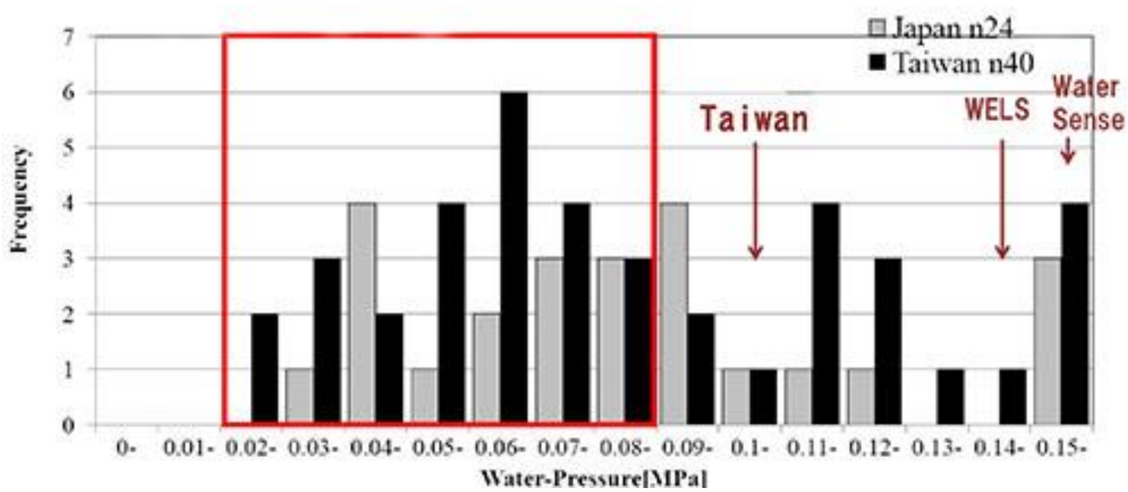


Figure 5. Taiwanese and Japanese water pressure scope

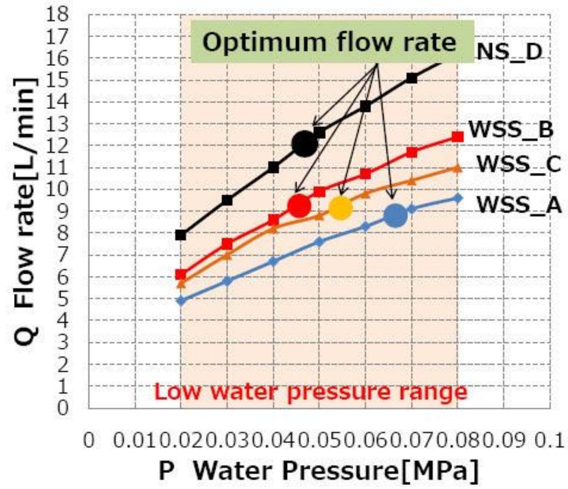


Figure 6. Four showerheads use flow and time diagram

Figure 7-1. Variable frequency pump Figure 7-2. Controller panel of pump

Figure 7-3 Flow rate meter

Let the 30 subjects (Table 2) use the equipment (Figure 8), and tested the four types of showerhead ejection.

Table 2. Number of persons surveyed

	Female	Male	Total
20~30's	15	5	20
40~50's	5	5	10

Figure 8. Experimental shower room in National Taichung University of Science and Technology, iGrEAT Laboratory

3 Investigation

The experiment was divided into three stages. The first stage was physical experiment. Under the same conditions of water supplement, hair cleaning time was recorded and the subjects voted for comfort. The second and third stages were mental experiment on comfort under the same and different water pressure. The procedure is shown in Fig. 9.

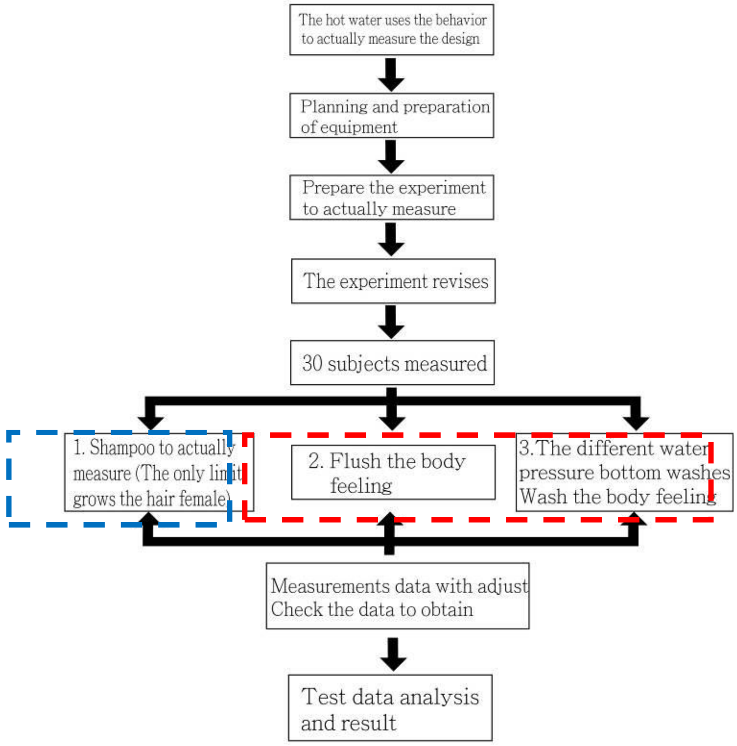


Figure 9. Experiment flow chart blue dotted line frames test for physical level / the red dotted line frame test for the mental level

3.1 Layout and preparation for equipment

In the beginning, we set up the equipment such as shower nozzles and the other instruments (Figure 10-1 & 10-2), and discussed the adjustment of the instruments (Figure 10-3)



Figure 10-1. & 10-2. installs and instrument of gearing

Figure 10-3. Install the scene The scene adjustment discussion

3.2 Before experiment

The first subject followed the original procedure (Table 3), but we found that the rest time was too long to make mental and physical influence.

Table 3. The original shampoo experiment process

(5min)	(15min)				(5min)	(5min)
Description	Cleaning evaluation				5min (take a rest) Dry hair	Comfort assessment
	Clean the hair	Cleaning evaluation *2 type	5min (take a rest)	Cleaning evaluation *2 type		

3.3 The experiment adjustment

After discussion, we decided to adjust experiment, so we canceled the rest time.

3.4 Subject's test (procedure introduction)

Face to face introduction made the subjects know the procedure deeply (Figure 11) and they could ask questions immediately. Consequently, we could decrease error.

Figure 11. The experiment explains in detail

3.5 Hair cleaning test

Firstly, we took the plastic band as hair band (Figure 12-1) to get the circle of hair (figure 12-2) as hair volume modal of women.

Figure 12-1. & 12-2. Tested female hair volume plastic tape

We discussed the comfort and cleaning effect among 4 types of shower nozzles. Each subject should test four types of shower nozzles under the same condition: flow was 65/min. We made the comparison of comfort and cleaning effect, and gave them name such as red, yellow, blue, purple, so that the subjects could easily fill in the questionnaire. Each subject should use four shower nozzles to complete cleaning procedure orderly (Figure 13-1). Each shower nozzle should get shampoo, and the repetition should be the same. The procedures of each subject were not really the same. After cleaning hair, we put magnets on the white board (Figure 13-2) to show time and data. Besides, different color represented for different ejection type of showerhead.

Figure 13-1. Showerhead cleans the sequence

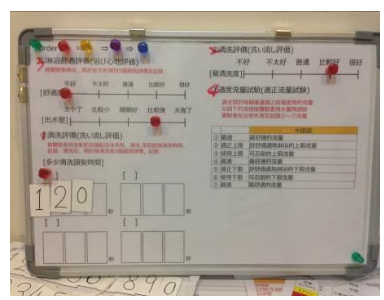


Figure 13-2. Test questionnaire marked in whiteboard

3.6 Flushing feeling measurement

The subjects were tested under the same water pressure, and we would get the relationship between comfort and pressure of shower nozzles (figure 14). The grades of comfort were divided into very bad, bad, so so, good, very good. The grades of water pressure were divided into very small, small, fit, large, very large. On the white board, different color magnet represented for different type of shower nozzle.(figure 15)

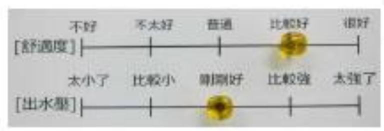


Figure 14. Experiment shower head flush position

Figure 15. Relative color shower head placed in the magnet

3.7 Feeling under different water pressure

The subjects were tested under different water pressure, and we would get the relationship between comfort and pressure of shower nozzles. Consequently, we would find the appropriate pressure and the available range. The subjects could use the valve to control flow, and the shower nozzle position was shown as figure 14.
The questionnaire is shown as table 4.

Table 4 Experiments design the problem

No	Question
1	The most comfortable flow
2	Comfortable range of maximum flow
3	Can tolerate the maximum flow
4	The most comfortable flow
5	Comfortable range of minimum flow
6	Tolerable minimum flow
7	The most comfortable flow

4 Result and Discussion

Under different water pressure, the results of different shower nozzles are showed as figure 16-1. The results showed that the cleaning effect was not obviously related to the type of shower nozzle. The relationship between time and shower nozzles was shown as figure 16-2. The time of four shower nozzles were average 50-60 seconds, so there were no obvious difference. Consequently, the time was not obviously related to the types of shower nozzles.

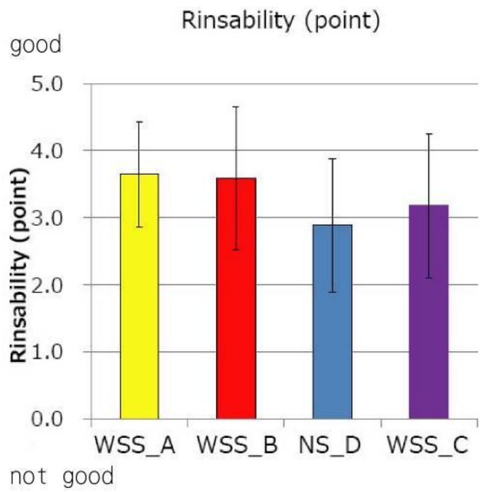


Figure 16-1. Showerhead cleaning force and relationship between the type of water

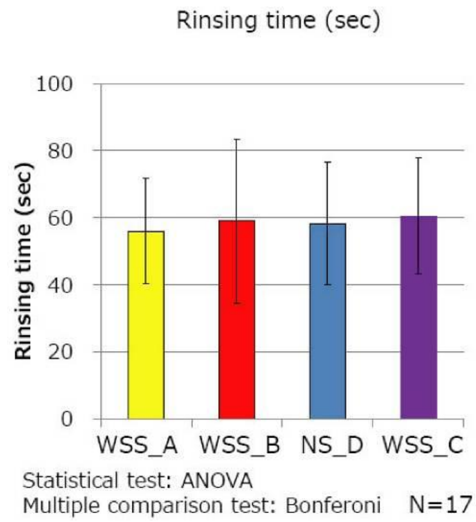


Figure 16-2. Showerhead use time and the effluent type relationship)

Under the same water pressure, the results of different shower nozzles are showed as Figure17-1. Shower Nozzle B was more comfortable than Shower Nozzle D. Because figure17-1 showed that index P was less than 0.005, helix shower nozzle was more comfortable than spraying shower nozzle. The relationship between time and shower nozzles was shown as Figure17-2. The indexes P of shower nozzles were all less than 0.001, so the more concentrative flow took shorter time. Hollow shower nozzle obviously took shorter time than the others.

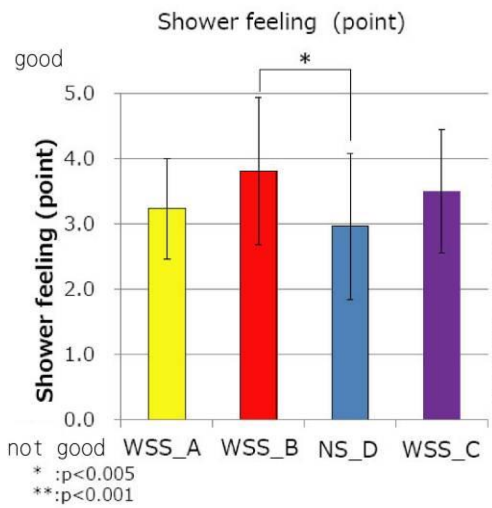


Figure 17-1. Showerhead cleaning force and the relationship between the type of water

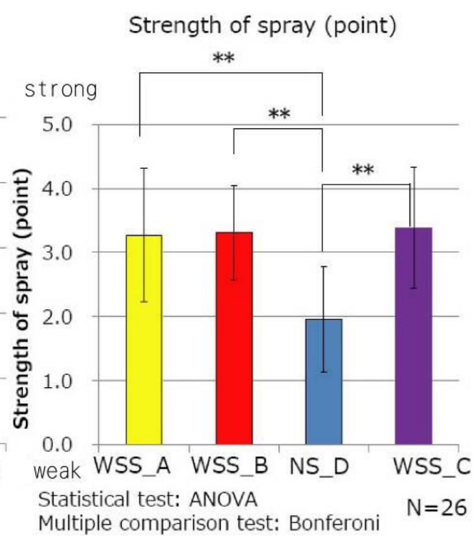


Figure 17-2 showerhead use time and effluent type relationship

The relationship between time and hair volume was shown as figure 18.
The indexes B of shower nozzles were all less than 0.1, so the hair volume was not directly related to time.

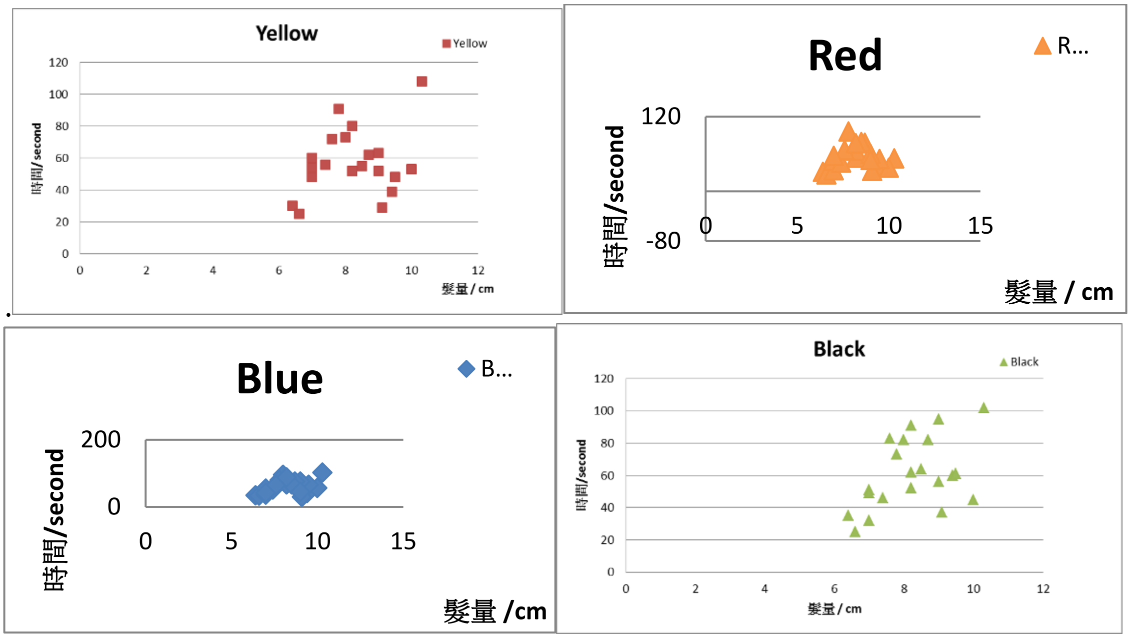


Figure 18. Four shower heads each with the subjects using the time relationship

The hole quantity of shower nozzle was approximately 40-65, and the time was approximately 54-57 seconds. Because the difference was not obvious, R=0.35, the hole quantity would not affact time (Figure 19).

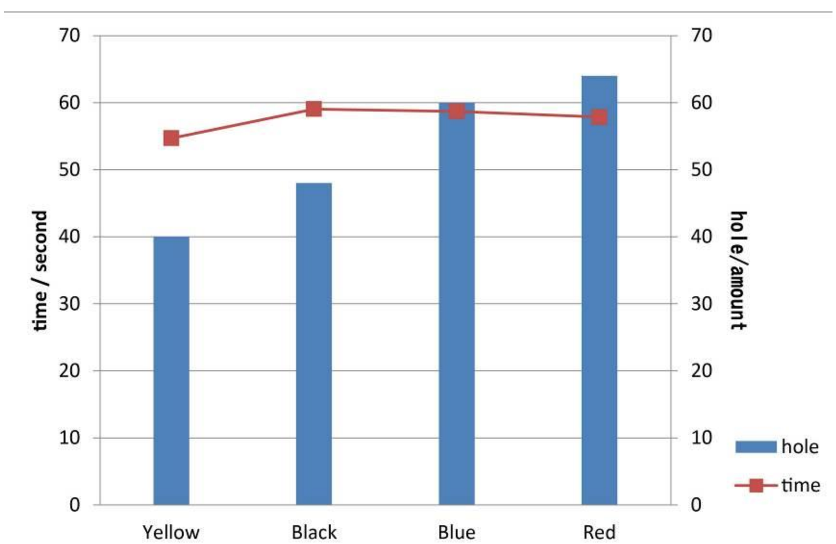


Figure 19. Shower head hole number and the measured use of time relationship

Under the same condition, the relationship between time and the ankles of shower nozzles was shown as figure 20. Obviously, we found that the time was not directly related to the ankes of shower nozzles.

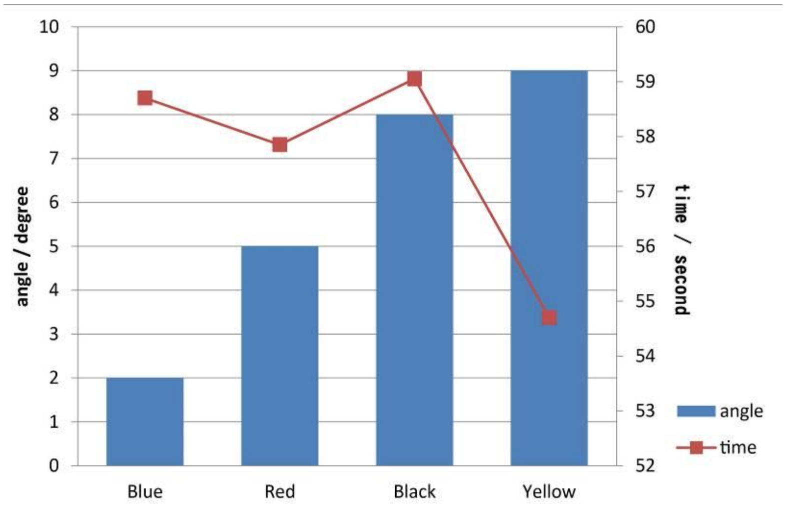


Figure 20. Showerhead water angle and the measured use of the relationship between the shower period

Flow and the angles were the opposite relationship, R=0.81 (Figure 21). Under the same water supplement, the smaller ankle got larger flow, and the more concentrative flow made more uncomfortable.

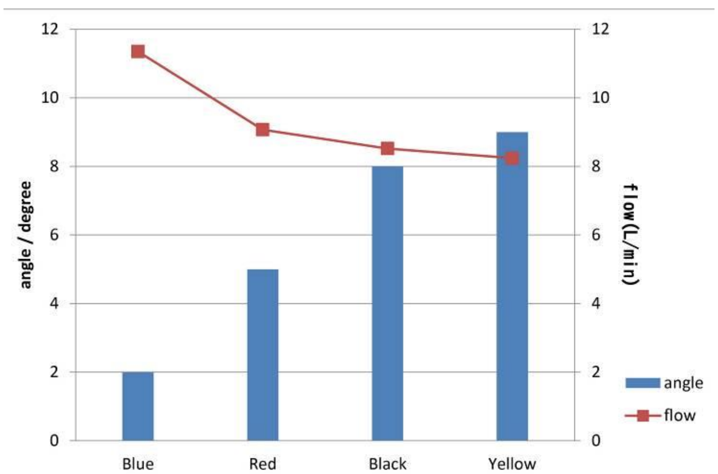


Figure 21. Showerhead in different water angle and the measured flow rate

Under low water pressure, the results of different shower nozzles are showed as figure 22. The index P was less than 0.001. Shower Nozzle B was more suitable in low- pressure areas of Taiwan because it could save more water.

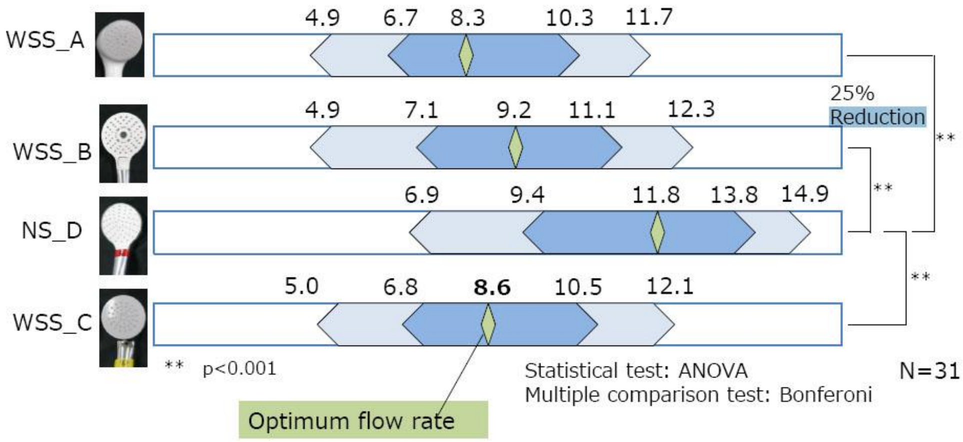


Figure 22. Showerhead perception of the best flow comparison map

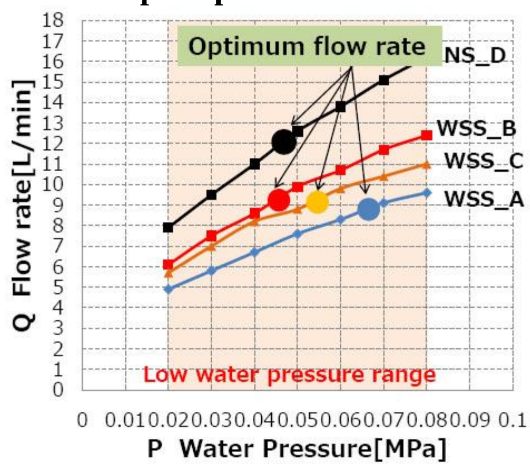


Figure 23 Showerhead perception of the best flow comparison map

5 Conclusions

According to the results, the hair volume was not directly related to the time and the angles of shoewer nozzles. The time was approximately 54-57 seconds, and it was unsually related to personal habitation.

The most comfortable flow for the subjests were 8.2- 9(L/min), and the hole quantity of shower nozzle wa s 40-64. Consequently, the quantity of shower nozzle was not directly related to comfort. Whereas, the relationship between flow and ankles was showned ad figure14. Flow and the angles were the opposite relationship ,and the more concentrative flow made more uncomfortable. Thus, the comfort wais related to the ankles of shower nozzles.

According to the experiment, Shower Nozzle B made the subjects more comfortable than the othters. Due to the difference between shower nozzle B and D, helix shower nozzle was more comfortable than spraying shower nozzle.

Due to the difference of shower nozzles, Shower Nozzle B was more suitable in low- pressure areas of Taiwan because it could save more water.

1. The comfort was related to the ankles of shower nozzles
2. The hair volume would not affect the time
3. The hole quantity would not affect cleaning effect

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7 Acknowledgment

The authors would like to thank the Ministry of Science and Technology of Taiwan, for financially supporting this research under Project Contract No. MOST 103-2221-E-025 -005 and MOST 104-2221-E-025 -012, and also thank TOTO LTD to collaborate with this research.

8 Presentation of Author

Hsiao-Ting Tseng is the graduate student at National Taichung University of Science and Technology, Department of Interior Design.

Meng-Chieh, Jeffrey Lee is a PhD in Architecture and an Associate Professor at National Taichung University of Science and Technology, Department of Interior Design. His major is water plumbing system, sanitary equipment safety and new technology development, interior environmental control and energy saving.

B8 - Vegetated wall managing grey water - wall features

Martina Rysulova (1), Zuzana Vranayova (2) Daniela Kaposztasova (3)

1. martina.rysulova@tuke.sk
2. zuzana.vranayova@tuke.sk
3. daniela.kaposztasova@tuke.sk

(1) PhD student, Technical University of Kosice, Faculty of Civil Engineering

(2)Director at Institute of Architectural Engineering, Technical University of Kosice, Faculty of Civil Engineering

(3) Vice dean for Education, Technical University of Kosice, Faculty of Civil Engineering

Abstract

The main aim of the paper is to present the essential features necessary for functional vegetated wall application. As the wall will serve as a treatment plant for grey water, there are some basics that have to be followed. The importance and suitable selection of pre-treatment, measurement or calculation of HRT and water quality on input and output. According to fact that there is number of plants and substrates suitable for vegetated wall construction, the design of vegetated wall was based according to numerical method of selection. The function of chosen plants and filter media, were afterwards tested. The results served as a selection of most suitable combination of plant and filter media for vegetated wall treating grey water. The main aim of the research is to forward the vegetated wall and its treatment ability also in grey water treatment system.

Keywords

Vegetated wall; grey water; wall features.

1 Introduction

Vegetated walls are becoming an essential part of building indoor or outdoor architecture. Besides an attractive aesthetical aspects provided by variations of plants, vegetated walls dispose with number of ecologic and economic benefits. Vegetated wall ability to manage water, serves as an attractive option for waste water treatment. Treatment technologies based on natural processes represent a systems operating under low energy and maintenance, what is more cost effective for user. This technology could be considered as an environmentally acceptable ecological treatment, which could be affordable with low capital and maintenance requirements and contribute to sustainability [1]. Therefore it is proposed to develop an efficient and sustainable system reusing grey water as an approach in sustainable water management.

2 Vegetated wall

The proposed system will operate as a bio filtration system and will provide treatment mostly through physical (straining, sedimentation) and biological (plant and microbial assimilation, other microbial processes) processes as water percolates vertically down through the filter media. It is expected that the upper layers will be less saturated and experience more aerobic conditions as the bottom layers according to gravity flow of water in wall. Important in design of grey water managing wall is also to realize some of critical aspects influencing the system function as plant selection, hydraulic retention time of filter media, periodicity of grey water inflow (user habits) and influent pollutant concentration. However primary was necessary to connect the vision of constructed wetland and vegetated wall merging and determine the principles and processes in wall.

2.1 Wall basics

It is known that the vegetated walls can undertake the constructed wetland treatment ability, and transform it onto smaller area, however with comparable treatment efficiency. For design of the wall have been purposed the vertical flow system of constructed wetland. In these systems is wastewater fed on the whole surface area through a distribution system and passes the filter media in mostly vertical path [2]. The dosing of wastewater is performed intermittently, therefore the filter media goes through saturated and unsaturated phases, along with different phases of aerobic and anaerobic conditions. The filter media acts as a filter for removing solids, a fixed surface upon which bacteria can attach and a base for the vegetation. The top layer is planted and the vegetation is allowed to develop deep, wide roots, which permeate the filter media. The vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics. However, the primary role of vegetation is to maintain permeability in the filter and provide habitat for microorganisms. Nutrients and organic material are absorbed and degraded by the dense microbial populations. By forcing the organisms into a starvation phase between dosing phases, excessive biomass growth can be decreased and porosity increased [3]. According to previous researches, more than 90% removal of BOD5, COD and TSS can be achieved with vertical flow wetlands. As the constructed wetlands age, the rate of organic removal increases. Total nitrogen and phosphorus removal in constructed wetland systems can be as high as 98–99%, respectively[4].

First idea of vegetated wall treating grey water was based on "do it yourself approach", hence the design of the wall consisted of simple plastic bottles serving as a plant pots, attached to wood pallets (Figure 1). The vertical flow of grey water in bottles is ensured with interconnection of each bottle, therefore each one serve as a small wetland with identical layers layout. It is expected that this model will help exploring a novel module of vegetated wall treating grey water.

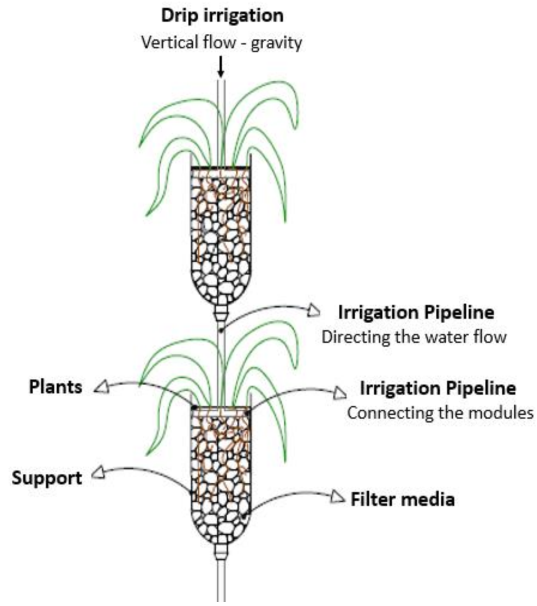

Figure 1 - Scheme of system function

2.2 Substrate - filter media

Filter media commonly used in CW are sands and gravels but the adsorption capacity of these materials can vary greatly or diminish in long term [5]. In the scope of modular vegetated walls is usually as a growing media used lightweight substrate with granular material in order to improve water retention [6]. In accordance to selected plants needs, the filter media compound was selected from 3 layers: gravel at the bottom, coarse sand and washed sand mixed with sawdust assuming the role of carbon source. Important issue is to determine the hydraulic retention time of selected plants and filter media, therefore can be established the approximate time necessary for grey water to pass through all layers. The hydraulic retention time will be determined according to purposed experiment in laboratory conditions.

2.3 Plants

Nowadays a range of plants is used for vegetated walls, however there is difference between plants selection for aesthetical purpose, or for waste water treatment. Important is to select plant tolerate for water-logged conditions but also a high nutrient environment and elevated salinity [7]. Current selection included 4 evergreen species (Table 1).

Table 1 Selection of the plants

Figure	Name	Basics
	Cotoneaster dammeri	• fast growing evergreen low shrub • height 40-50 cm • average, dry or moistsoil
	Blechnum spicant	• deer fern/ hard fern and evergreen • height 50 cm • average or moist soil
	Carex oshimensis	• evergreen arching grassy foliage • height 15-20 cm • average or moist soil
	Ophiopogonplaniscapus	• evergreen perennials forming clumps • height 20-30 cm • permeable and moist soil

2.4 Pollutant concentration

The vegetated wall will be tested in laboratories conditions, where real samples of grey water will be used. Grey water will be discharged from installed devices mostly consisting from sinks, shower and washing machine. This enable to test different variations of pollution rate, hence determine the purification ability of both light and dark grey water.

3 Conclusions

Main aim of this paper was to introduce the proposal of vegetated wall managing grey water and brief characteristic of proposed system. Is expected that prepared experiment will establish the purifying ability of selected plants and filter media, therefore the potential of this application in real conditions.

Acknowledgments

This work was supported by project VEGA n. 1/0202/15: Sustainable and Safe Water Management in Buildings of the 3rd Millennium and project of TATRABANKA Foundation n. 2015vs082 – Safe and sustainable use of water in building.

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5 Presentation of Author(s)

Martina Rysulova is a PhD. student at the Faculty of Civil Engineering, Technical University of Kosice. She is specialized in water supply and drainage systems. Recently she has been concentrated on the field of grey water reuse.

Zuzana Vranayova is the professor at the Civil Engineering Faculty, Technical University of Kosice, Department of Building Services. She is conducting various researches on her major field of study of water supply and drainage system in buildings. She is also actively involved in governmental and academic institutions and committees related to her field of study as chief coordinator and board member. She is a Chairman of Academic Senate and director of Institute of Architectural Engineering.

Daniela Kaposztasova is lecturer at the Faculty of Civil Engineering, Technical University of Kosice. She is specialized in Water supply and drainage systems. Recently she has been concentrated on the field of rainwater use and grey water reuse. She is a vice dean for education.

B9 - Comparative study of optimum flow rates for hot-water saving shower heads

Kanako Toyosada(1), Minami Okamoto(2), Koji Takeda(3)

1. kanako.toyosada@fwu.ac.jp
2. minami.okamoto@jp.toto.com
3. koji.takeda@jp.toto.com

(1) Associate Professor, Department of Environmental Science, International College of Arts and Science, Fukuoka Women's University, Japan
(2) Products R&D Dept. Research Institute, TOTO LTD., Japan
(3) Manager, Intelligent Materials Development Sect., Washlet R&D Department 1, TOTO LTD., Japan

Abstract

This study focused on shower heads, which use the majority of hot water in bathrooms. It investigated showerhead characteristics, and participants' differing "optimum flow rates" according to their personal attributes. The study also included the participants' qualitative assessment of features such as bathing comfort and droplet impact. The results showed that according to shower head characteristics, the optimum flow rate differed. In addition, a significant difference was seen in the optimum flow rate depending on the gender and age of the participants. It was found that, by gender, the flow rates rated by men were larger and, by age, for those in their 20s the preferred flow rates were larger. Further, the optimum flow rate for men in their 20s was found to be significantly larger than that of women in their 20s and men in their 40s and 50s. Even in the qualitative assessment of the showering experience, differences due to participants' personal attributes were observed.

Keywords

Monitoring tests, Bathing, hot-water saving, shower head, household

1 Introduction

Following the Paris Agreement, Japan is required to reduce CO2 emissions from the household sector by about 40% by 2030 compared to 2013. Of the household sector, hot-water supply energy accounts for about 30% of emissions, and the majority of that is bathroom-related emissions 1).

The authors focused on the shower head, which contributes to the most hot water use in the bathroom, and used data on awareness3) and participant testing2) to promote the development of water-saving shower heads that balance comfort with CO2 reduction through water saving. The rinsing time of hair did not differ significantly depending on the length of women's hair, however, it was found that there was a significant difference between the showering experiences and patterns of men and women, and there were also significant differences according to age. There has been little research on the correlation between participants' attributes and optimum flow rate, although previous research has touched on the influence of hole number and size 4), and found no correlation between optimum flow rate and participants' attributes of gender and age5).

Therefore, in this research, we examined the differences in "optimum flow rate" according to the attributes of participants and examined the relation between attributes and qualitative evaluations of "showering comfort" and "perceived spray strength".

2 Study methodology

2.1 Outline of experiment

Experiments were carried out in a shower unit room (an integrated bathroom with a shower unit and dressing room) installed in a university laboratory. The experiment outline is shown in Table 1, and the testing room's outline is shown in Figure 1. In order to verify the difference in optimum flow rate depending on gender and age, 10 subjects (total of 40 people) were included: men in their 20s, women in their 20s, men in their 40s and 50s, and women in their 40s and 50s.

In addition, in order to extract more representative data, the subjects were mainly those whose occupations were unrelated to bathing or showers. Also, those in their 20s were university students, and those in their 40s and 50s were general public and university staff. In the shower unit room, the ventilator was constantly turned on, and the room temperature was kept at 26 degrees using a fan heater inside the room and a laboratory air conditioner.
In the experiment, the shower flow rate, including the optimum flow rate, and the hot water temperature were measured. A flow regulating valve was installed in the shower unit room so that participants could test the four shower heads in order in one experiment (Figure 1). A flow sensor and a temperature sensor were installed on the back side of the room, and instantaneously displayed on the display meter on the front side of the room (Figure 1). The experiment manager recorded the flow rate while the participant was showering. For a 5-point evaluation of showering comfort and perceived strength of spray, a white board was installed in the shower unit room and immediately after each participant had tested each shower head, a magnet was affixed to the corresponding number column (5 grades of evaluation) (Figure 1).

Table 1 Test outline

Testing period	5 December 2016 – 20 January 2017
Site	Shower unit room in research building A, no. 203 (laboratory) Fukuoka Women’s University
Participants	Men and women in their 20s and men and women aged 40-60 (each group of 10, total 40 participants)
Room temperature	26℃（inside the shower unit）
Items of measurement	For 4 showerheads, optimum flow rate, upper limit of comfort flow rate, maximum limit for usage, lower limit for comfort flow rate, minimum limit for usage, hot water temperature
Interview items	For each of the 4 shower heads, a 5-point evaluation on showering comfort and the perceived strength of the spray

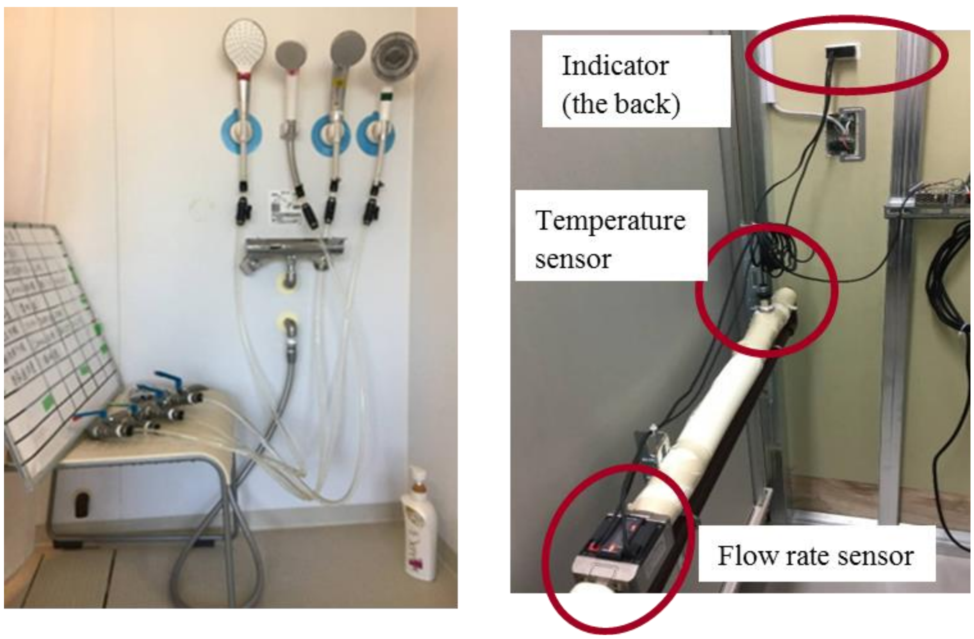


Figure 1 Shower unit room (left) and the back (right)

2.2 Tested shower heads

Table 2 shows the shower heads that were tested. Three commercially available hot water saving shower heads (A – C) and one non-hot water saving shower head (D) were used, each with different hole diameters and hole numbers. As a method of saving water, shower head A inserts air into the water droplets. B places an element that oscillates the water flow at the center part of the watering plate to increase the momentum of the water flow. C sprays water spirally while closing the water discharge holes with a high speed rotating impeller built in the back of the sprinkling plate.

Table 2 Overview of tested showerheads

	A	B		C	D
Showerhead surface					
Hole diameter [mm]	1.2	0.5	1*3	0.85	1.2
Number of holes	40	60	4	48	60
Showerhead's sprinkler plate diameter [mm]	55	85		59	92
Water Pressure at 6.5L/min [MPa]	0.037	0.023		0.026	under0.020

2.3 Experiment method

The experiment method is shown in Table 3. The Japan Valve Manufacturers Association has established the "method for monitoring water saving equipment", in which the method of monitoring emissions of shower water and measuring the optimum flow rate are specified. This study adhered to this method, as water was aimed at the chest, the number of participants was more than 10, men and women were equal in number.

The flow rate measurement was conducted according to the method shown in Table 3, in accordance with the "method for monitoring water-saving equipment". The order of the 4 shower heads was randomly set for each subject. Regarding the qualitative evaluation, after measuring the flow rate, the participant took a break for about 20 minutes, then used the 4 shower heads again, evaluating showering comfort and the strength of the spray using five stages (Table 3).

Table 3 Test method

Flow rate measurement	(1) The faucet thermostat in the shower unit is set to the participant's desired hot water temperature. (2) The participant holds the first shower head in their hand, 30 cm from their chest and they adjust the flow rate valve. They carry out the below flow rate measurement steps 1-7. 1. Optimum flow rate（ideal flow rate） 2. Comfort maximum limit（upper limit flow rate that feels comfortable to use） 3. Usage maximum limit（maximum flow rate that can be tolerated for usage） 4. Optimum flow rate（ideal flow rate） 5. Comfort minimum limit（lower limit flow rate that feels comfortable to use） 6. Usage minimum limit (minimum flow rate that can be tolerated for usage) 7. Optimum flow rate (ideal flow rate) (3) For the second shower head, perform the measurements of section 2, above. (4) For the third shower head, perform the measurements of section 2, above. (5) For the fourth shower head, perform the measurements of section 2, above.
Rest	Rest for 20 minutes.
Qualitative evaluation	(1) Flow rate is set at 6.5L/minute. (2) The faucet thermostat in the shower unit is set to the participant's desired hot water temperature. (3) The 4 shower heads in order are evaluated by pointing at the chest and evaluating showering comfort and strength of spray based on a 5-point scale. 【Showering comfort】 1：Extremely bad 2：Bad 3：Average 4：Good 5：Extremely good 【Spray strength】 1：Weak 2：Quite weak 3：Not sure 4：Quite strong 5：Strong

3 Results and discussion

3.1 Relationship between participant attributes and optimum flow rate

Table 4 shows the average value and standard error for all shower heads optimum flow rate and participant attributes, and Table 5 shows the one-way analysis of variance and the multiple comparison test (Tukey method). The optimum flow rate average value of all shower heads was 7.24 L/min, and according to participants' attributes, the result for men in their 20s was the highest and the result for women in their 40s and 50s was the lowest. Within gender, the flow rate for men in their 20s was higher than those in their 40s and 50s. In the multiple comparison test, there was a significant difference between males in their 20s and all other groups.

Figure 2 shows the results of the multiple comparison test (Tukey method) based on optimum flow rate and participant attributes for each shower head. In all shower heads, the optimum flow rate was higher for men, and the 20s group was higher compared to those in their 40s and 50s. In the multiple comparison test, there is a significant difference between the results for 20s men and 40s and 50s women for shower head A.

Table 4 Optimum flow rate（L/min，no shower head distinction）

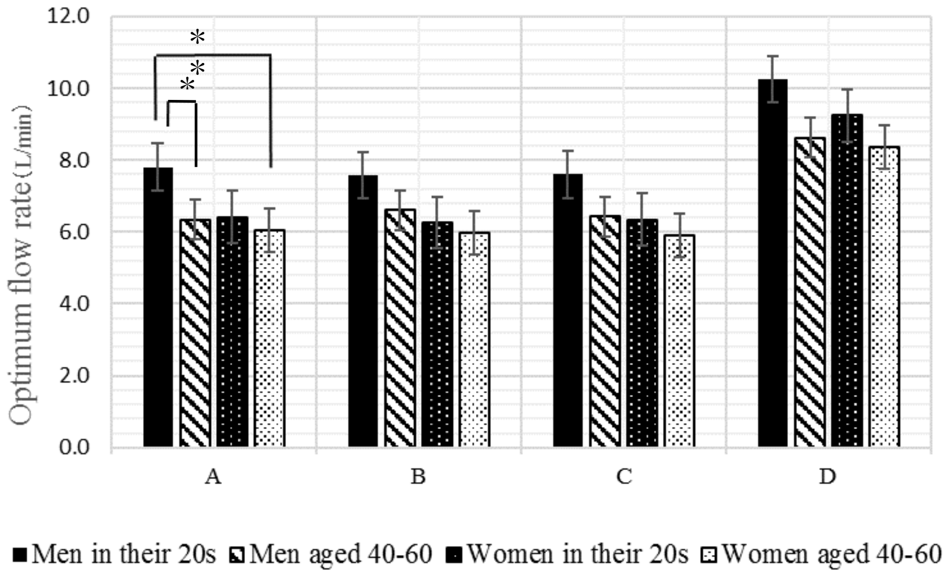
	Average value	Standard error
All	7.24	0.17
Men in 20s	8.31	0.39
Men in 40s 50s	7.00	0.33
Women in 20s	7.06	0.28
Women in 40s 50s	6.57	0.29

Table 5 Results of variance analysis of optimum flow rate (no shower head distinction)

Groups		Standard error	Significance probability (p)
Men in 20s	Men in 40s and 50s	0.4617	0.027
	Women in 20s	0.4617	0.039
	Women in 40s and 50s	0.4617	0.001
Men in 40s and 50s	Women in 20s	0.4617	0.999
	Women in 40s and 50s	0.4617	0.789
Women in 20s	Women in 40s and 50s	0.4617	0.713

P<0.05：Significant difference, 0.05≦P<0.1：Significant trend

There were significant trends in the 20s men's group and 20s women's group. Differences according to gender and age were observed. Since the shower head A is characterized by including air in the water droplets, it is characterized by a 'soft touch' feeling, so that the flow rate of the person seeking a strong feeling of touch is higher and the flow rate of the person seeking a soft bathing feeling is lower. It was inferred that this was the reason for the increased difference based on participants' attributes.



Optimal flow average（L/minute）			
A	B	C	D
6.7	6.6	6.6	9.1

＊＊：P<0.05（significant difference） ＊：0.05≦P<0.1：significant trend

Figure 2 Results from testing significant difference by each showerhead's optimum flow rate and participant's attributes

3.2 Upper and lower limits for usage and comfort for each shower heads

Figure 3 shows the average flow rate values for optimum, comfort maximum limit, usage maximum limit, comfort minimum limit and usage minimum limit for each shower head. Although the optimum flow rates of the shower heads A–C are the same, the maximum flow rate for possible usage for B is higher in comparison. Therefore, shower head B was analyzed based on participants' attributes. Notably, it was found that the maximum flow rate for possible usage for men in their 20s is quite high (Figure 4). Considering the characteristics of the shower head, it was presumed that the maximum usage limit flow rate of A, which has a soft spray sensation, would increase, however, the reason why the maximum flow rate of usage for shower head B in men in their twenties was significantly higher will need to be investigated in the future.

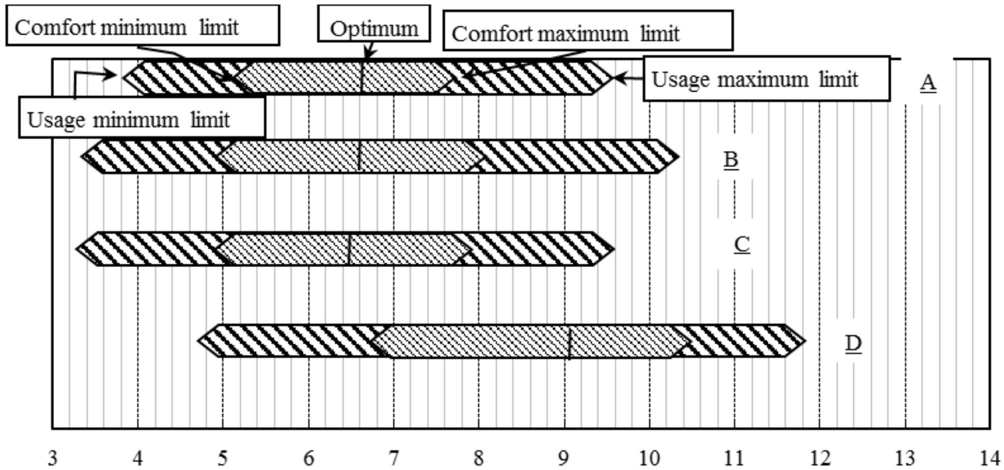


Figure 3 Average flow rate for each shower head

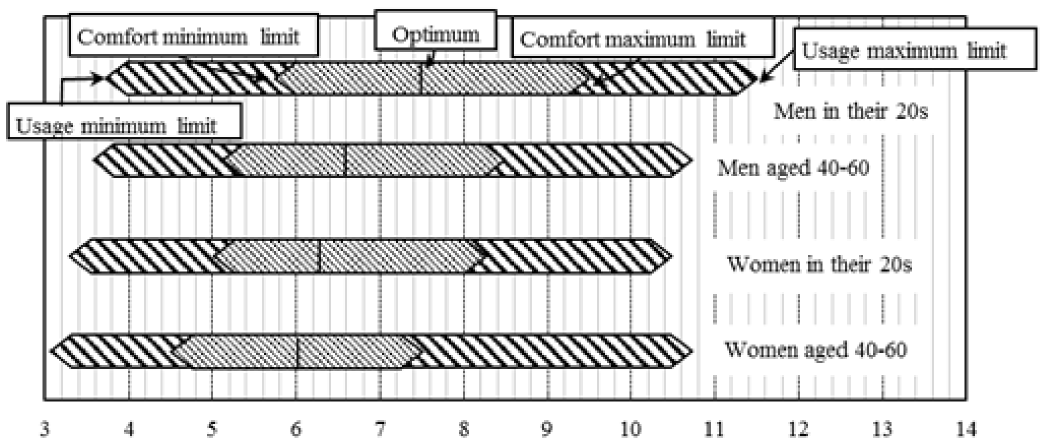


Figure 4 The average flow value for showerhead B for each participant group

3.3 Shower head qualitative evaluation results

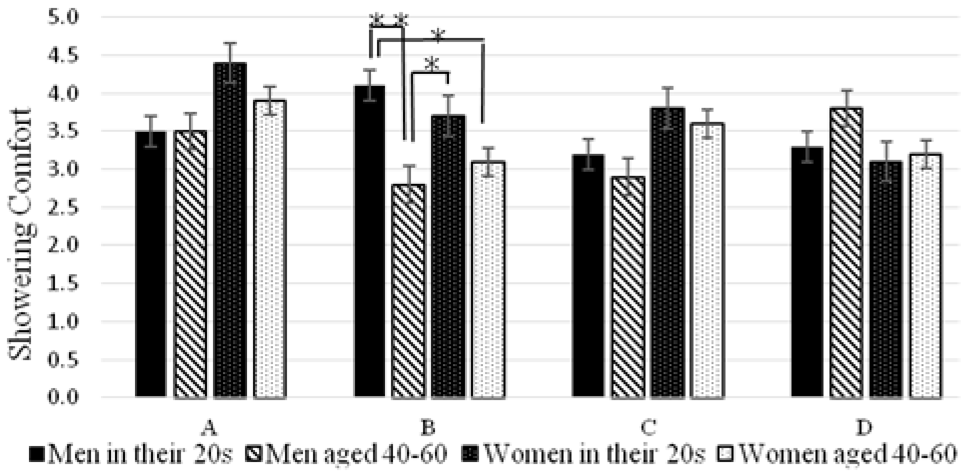
A qualitative evaluation of each shower head's showering sensation and perceived strength of spray was carried and the results are shown in Table 6. The results show the average of the five grades used, but the higher the showering comfort the higher the evaluation value and the higher the value for evaluating the strength of spray feeling, showed "the spray strength is strong". In the showering comfort evaluation, shower head A, which included air in the water droplets, was the highest, and there was no difference in the showering comfort of shower heads B or C.

Regarding the strength of spray feeling, shower heads B and C were rated the strongest, and D was the weakest. In the qualitative evaluation in this experiment, the optimum flow rate was fixed at 6.5 L/min and evaluated. As shown in Figure 2, the optimum flow rate for shower heads A–C is close to 6.5 L/min, whereas the optimum flow rate of D is as large as 9.1 L/min. It was inferred that shower head D resulted in "weak" with respect to "strength of spray feeling" because the qualitative evaluation was performed at a flow rate much smaller than the optimal flow rate.

Figure 5 shows the showering comfort evaluation results and the multiple comparison test results based on participant attributes. Men in their twenties rated shower head B the highest, and women in their twenties and men in their 40s and 50s rated A's comfort highly. Since shower head B is designed to save water while also maintaining spray strength, the high rating by men in their twenties who rate spray strength highly can be questioned. In the multiple comparison test for shower head B, there was a significant difference between men in their 20s and men in their 40s and 50s. There were also significant trends between men in their 20s and women in their 40s and 50s, and men in their 40s and 50s and women in their twenties. Notably, a characteristic of the evaluations by men in their 40s and 50s was that they were low. Regarding shower head B, a head with a larger weight than the commercially available product was used because the evaluation was carried out by a prototype (performance was equivalent to a commercially available product) at the time of the experiment. Further study is necessary, including investigating the possibility that weight brought about the reduction in showering comfort.

Table 6 Qualitative evaluation of showerheads

Showerhead	Showering comfort	Perceived strength of spray
A	3.8	3.1
B	3.4	3.4
C	3.4	3.4
D	3.4	2.0



＊＊：P<0.05（significant difference），＊：0.05≦P<0.1：significant trend

Figure 5 Significance test results based on participants' group and evaluation of each shower head's showering comfort

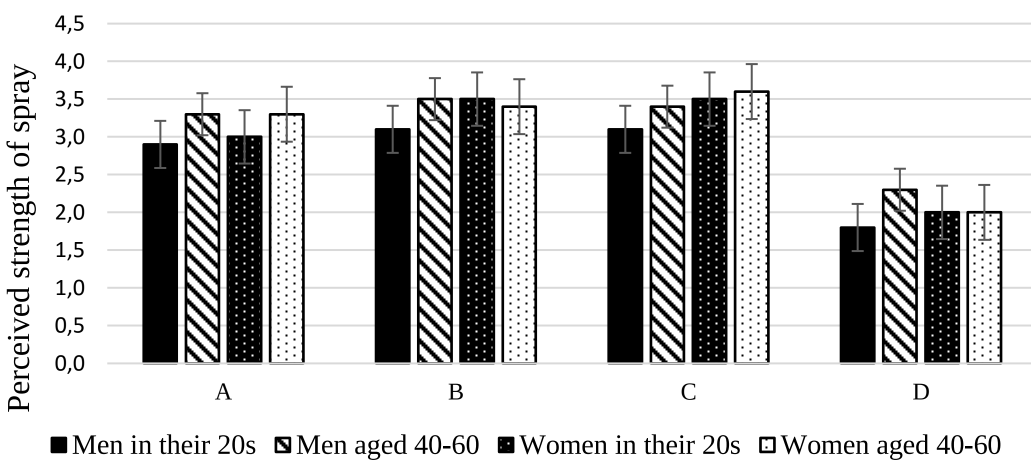


Figure 6 Significance test results based on participants' group and evaluation of strength of spray sensation

The results of each participant's evaluation of spray strength and the multiple comparison test are shown in Figure 6. Compared with the evaluations of showering comfort, there is little difference according to the participants' attributes, however, there is a tendency that men in their 20s answered "weak feeling" for all shower heads, and as mentioned above, the results suggest that men in their twenties seek a stronger spray feeling. Regarding shower heads B and C, excluding the male participants in their twenties, participants generally answered that "the spray feels strong".

4 Conclusion

In this study, the experiments showed the differences in "optimal flow rate" based on participants' attributes, and conducted qualitative evaluations of "showering comfort" and "strength of spray". As a result, it was found that, by gender, the flow rates rated by men were larger and, by age, those in their 20s preferred larger flow rates. Further, the optimum flow rate for men in their 20s was found to be significantly larger than that of women in their 20s, and men in their 40s and 50s. Particularly, in the shower head comparison, the difference in optimum flow rate for the different groups was most pronounced for shower head A, which had the feature of air in the water droplets.

It is necessary for future studies to examine whether the optimum flow rate also varies depending on the season, participants' physical condition, participants' mood, and also the correlation with the shower head's characteristics, such as water discharge capacity.

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6 Presentation of Authors

Kanako Toyosada(Dr.Eng.) is an Associate Professor at the Department of Environmental Science, International College of Arts and Science, Fukuoka Women's University.
Dr Toyosada's research focuses on the environmental impact of plumbing systems.

Minami Okamoto is a member at Products R&D Department, Research Institute of TOTO LTD.
She is engaged in the research and development of bathroom products.

Koji Takeda is a manager at Materials Development Sect., Washlet R&D Department of TOTO LTD.
He is engaged in the research and development of plumbing products.

B10 - Greywater re-use for flushing toilets

Vanessa Delair (1), Rob Melk (2) and Michael Elwell (3)

1. vdelair@aliaxis.com
2. rmelk@aliaxis.com
3. melwell@aliaxis.com

(1) Water Managment Technologies Leader, Aliaxis R&D S.A.S, 1, rue de l'Amandier, 78540 Vernouillet, France.
(2) Group Vice President High Rise Building Solutions, Aliaxis Group S.A., Avenue Arnaud Fraiteur 15-23, B1050, Bruxelles, Belgium
(3) Chief Technology Officer, Aliaxis Group S.A., 1, rue de l'Amandier, 78540 Vernouillet, France.

Abstract

In today's world our water is becoming an increasingly challenged resource and the re-use of greywater would seem to be an interesting opportunity, especially for flushing toilets. In fact, 44% of our daily consumed volume of water is dedicated to sanitary uses: showers, baths, sinks and washing machines all generating greywater, which can be transferred to replace 29% of the water that is consumed for flushing toilets [1].

So, due to the fact that its origin can be different, the chemical and micro-biological composition of the greywater has wide variability. For example, the content in terms of the Total Suspended Solids (TSS) can vary from 45 to 838 mg l^{-1}, the Chemical Oxygen Demand (COD) can range from 228 to 1898 mg O_2 l^{-1} and the content in faecal micro-organisms can go from 1.1 to 6.9 log UFC/100 ml. This wide variation in the composition has resulted in the fact that one standard treatment process cannot fit with each case. The aim of this investigation was to compare two different processes of treatment allowing the re-use of greywater: firstly, skimming which involved short storage with air being supplied and basic disinfection, and secondly, a process including primary filtration, storage with re-circulation and strong regular chlorination. Chemical and micro-biological analyses were carried out at different points of each process to assess the treatment performance and the potential health issues associated with such a re-use.

In the two processes, the stage of storage was observed to be the weak point. Even if the time for storage was different, a biological treatment resulted in the generation of primary sludge and activated sludge. Moreover, small biofilms appeared on the walls of the storage tanks

increasing the set-up of a biological treatment. This led to the generation of unpleasant odors and foams. Thus, the re-use of greywater for flushing toilets without generating health issues for the end user appears to be less straightforward than expected.

Keywords

Greywater, re-use, chemical analysis, microbiology, flushing toilets

1 Introduction

Today, the driving force for developing greywater re-use technologies is the increasing demand of an expanding population all around the world, in a context of constant urbanization growth and natural water resources depletion. Moreover, the global water resource is not well distributed on the planet, and this is why some areas are more challenged to find sustainable alternative solutions to replace drinking water in some applications like gardening, toilet flushing, washing cars or street cleaning.

Some initiatives have already been put in place; for example, the re-use of greywater for agricultural needs has been in place for a long time in both Australia and USA. However, except for Japan, the re-use of greywater inside buildings is not really widespread. Three factors contribute to this: firstly, a second network with drinking water supply is necessary in the event that there is a breakdown of the re-use system, secondly, the sanitary aspect is not well appreciated today, and thirdly the end user's perception of such a re-use is not very positive. In fact, depending of the process of treatment that is applied, the quality of the treated greywater available for re-use can vary in terms of odour, colour and chemical composition.

The greywater can broadly be defined as wastewater generated in the house by bathroom sinks, baths and showers. In some cases it can include laundry facilities, dishwashers and even kitchen sinks. However, in most of the cases, only greywater from baths and showers are considered for re-use for the flushing of toilets.

This paper describes two examples of treatment allowing the re-use of greywater for flushing toilets. It gives details in order to assess the treatment performances obtained with each process and to assess to the potential health risks of such a re-use.

2 Water quality standards for greywater recycling

In order to be able to set objectives in terms of re-used greywater quality, it is necessary to take into account the existing standards within Europe but also for the rest of the world. It is agreed that the quality can vary from one country to another (refer to Table 1) and that no standard exists for the moment in any country; only guidelines and guides of practices are in existence today. The required quality of the water depends upon the targeted application. In the UK for example, to meet the needs of the increased number of recycling systems available in this country, the Building Services Research and Information Association (BSRIA) has published guidelines for greywater re-use (BSRIA, 2001, Table 1). So, the requested quality for the re-used greywater targeted in this study will be aligned with the most common values found in the various guidelines.

Table 1: Water quality criteria for toilet flushing and other urban uses in various countries [1]

	FC (CFU/100ml)	TC (CFU/100ml)	E. coli (CFU/100ml)	BOD_5 (mg/L)	Turbidity (NTU)	TSS (mg/L)	DO (% saturation)	PH	$Cl_{2\ residual}$ (mg/L)
US.EPA[1] (g)	14 for any sample 0 for 90% samples		1	10	2			**6-9**	**CT=30**
Florida[1] (m)	25 for any sample 0 for 75% samples			20		5			**1**
Texas[1] (m)	75 (m)			5	3				
Canada[1] BC[2] (m)	2,2 median 14 any sample			10	5	10			
Germany[1] (g)	100 (g)	500 (g)		20 (g)	1-2 (m)	30	**80-120**	**6-9**	
Japan[1] (m)	10 for any sample	10		10	5			**6-9**	
S. Australia[3]			<10	<20	<2				
WHO[1] lawn irration	200 (g) 100 (m)								
EC bathing water[1,4]	100 (g) 200 (m)	500 (g) 10,000 (m)			2 (g) 1 (m)		**80-120 (g)**	**6-9**	
UK BSRIA[5] proposed (g)	14 for any sample 0 for 90% samples								

g= guideline, m=mandatory
[1] Surendran and Wheatley, 1998; [2] Ministry of Environment, Lands Parks, British Columbia (enacted July 15, 1999) ; [3] US.EPA, South Australia, 1999 ; [4] suggested as appropriate for domestic water recycling ; [5] Building Services Research and Information Association, 2001,

3 Greywater characteristics

3.1 Volumes of water required for toilet flushing

The domestic water consumption can vary between countries, depending on geographical situation (climate), culture, uses and habits. Figure 1 presents the average quantity of water consumed per person and per application, each day, in 7 countries.

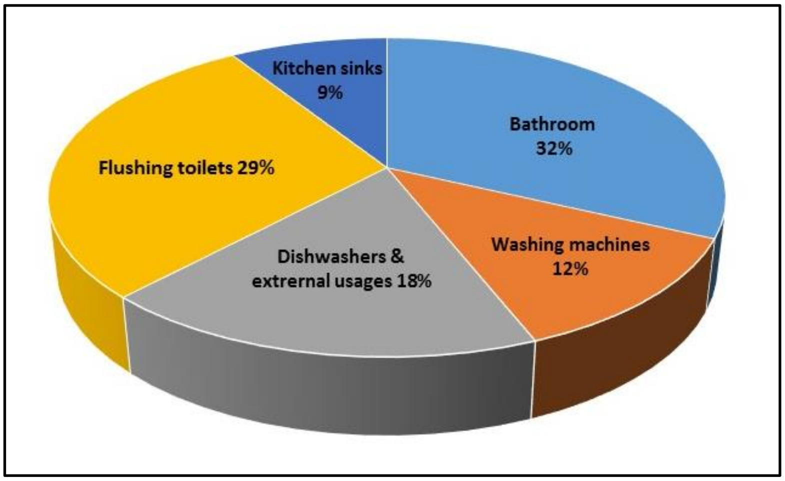


Figure 1: Average distribution of domestic water use for 7 countries1 [2]

This shows that the quantity of water used for baths and showers is similar to the one used for toilet flushing (32% vs 29%). Moreover, we need to consider that the demand of water for flushing toilets is regular throughout the year and that the production of greywater is also regular throughout the year, this is why both can be combined more easily.

3.2 Chemical and micro-biological composition

Since the greywater can be broadly generated in the house; either by bathroom sinks, baths and showers or laundry facilities, dishwashers and even kitchen sinks, its chemical and micro-biological composition can vary widely. In this investigation, we have chosen to consider only greywater from baths and showers because it is somewhat difficult to anticipate what can be disposed of in bathroom sinks or kitchen sinks.

Due to the fact that its origin can be different, the chemical and micro-biological composition of the greywater has wide variability. For example, the content in TSS can vary from 45 to 838 mg l-1, the COD can range from 228 to 1898 $mgO_2.l^{-1}$ and the content in faecal micro-organisms can go from 1.1 to 6.9 log UFC/100ml (Table 2, column EG).

Examining only the composition of greywater deriving from bathrooms (Table 2, column EGsdb), a wide variability in the composition can be observed: the content in TSS can vary from 5 to 520 mg l-1, the COD can range from 55 to 927 $mgO_2.l^{-1}$ and the content in faecal micro-organisms can go from 0.0 to 6.6 log UFC/100ml.

1 7 countries : USA, UK, Canada, Italy, Australia, Brazil, France.

Table 2: Chemical and micro-biological composition of different types of greywater [2].

		ERD			EN			ESEP			$EG_{Cuisine}$		
		ẋ	min	max	ẋ	min	max	ẋ	min	max	ẋ	min	max
Volume	$L.pers^{-1} j^{-1}$	147,00									22,00	6,00	30,00
pH		8,10	5,50	8,50	8,94	8,87	9,08	7,45	6,60	8,70	7,34	5,62	8,20
Cond	$\mu S.cm^{-1}$	1525,00	1279,00	1771,00				1111,00	325,00	1385,00	1881,00	617,00	2721,00
Turb	NTU								22,00	>200			
MES	$mg.L^{-1}$	446,00	227,00	1230,00	3180,00	920,00	4320,00	74,00	26,00	330,00	462,00	0,00	1371,00
DCO	$mg\ O2.L^{-1}$	1012,00	250,00	1174,00	2260,00	806,00	3128,00	290,00	204,00	376,00	1163,00	0,00	2889,00
DCO_D	$mg\ O2.L^{-1}$	239,00	95,00	383,00							623,00	0,00	1470,00
DBO5	$mg\ O2.L^{-1}$	274,00	150,00	500,00	1037,00	410,00	1400,00	166,00	60,00	292,00	708,00	9,00	1581,00
COD	mg C.L-1	235,00	173,00	297,00				89,00	57,00	121,00	233,00	113,00	519,00
TensAn	$mgSABM.L^{-1}$		6,00	13,00							35,00	0,00	118,00
Ntot	mg N.L-1	101,70	20,00	123,90	150,00	130,00	180,00	66,40	39,90	92,90			
NTK	mg N.L-1	73,30	30,00	112,80					2,10	31,50			
NH_4^+	$mg\ NH4+.L^{-1}$	49,00	20,00	92,40				58,20	19,00	90,60	2,70	0,00	5,40
NO_3^-	$mg\ NO3-.L^{-1}$	1,90	0,00	3,60				2,90	0,70	5,10	3,10	0,50	5,80
Ptot	$mg\ P.L^{-1}$	9,00	4,00	25,00	42,70	21,00	58,00	2,10	0,60	27,30		0,00	0,10
Ctot	logUFC/100m	7,00	6,00	7,20				6,80	5,60	8,00			
Cféc	logUFC/100m	6,70	5,00	6,90				6,20	4,70	8,10	5,40	4,80	10,80
EnCO	logUFC/100mL		4,00	5,00								3,70	9,00

		EG_{LL}			EG_{SdB}			EG		
		ẋ	min	max	ẋ	min	max	ẋ	min	max
Volume	$L.pers^{-1} j^{-1}$	21,00	17,00	26,00	47,00	15,00	60,00	**110,00**	**80,00**	**170,00**
pH		7,80	7,50	10,00	7,50	6,40	8,10	**7,37**	**6,06**	**8,93**
Cond	$\mu S.cm^{-1}$	1929,00	190,00	2457,00	1456,00	82,00	2119,00	**1471,00**	**116,00**	**2393,00**
Turb	NTU	108,00	14,00	296,00	93,00	0,00	240,00	**73,00**	**25,00**	**265,00**
MES	$mg.L^{-1}$	140,00	68,00	280,00	170,00	5,00	520,00	**331,00**	**45,00**	**838,00**
DCO	$mg\ O2.L^{-1}$	1293,00	725,00	1815,00	458,00	55,00	927,00	**621,00**	**228,00**	**1898,00**
DCO_D	$mg\ O2.L^{-1}$	1080,00	996,00	1164,00	252,00	9,00	568,00	**473,00**		**1071,00**
DBO5	$mg\ O2.L^{-1}$	467,00	48,00	472,00	240,00	50,00	631,00	**291,00**	**58,00**	**1049,00**
COD	mg C.L-1	281,00			74,00	0,00	154,00	**172,00**	**18,00**	**621,00**
TensAn	$mgSABM.L^{-1}$	42,00			45,00	0,00	103,00	**37,00**	**0,00**	**95,00**
Ntot	mg N.L-1		6,00	21,00	8,60	2,00	17,00	**9,20**	**4,40**	**15,10**
NTK	mg N.L-1		1,00	40,00		4,60	20,00		**3,00**	**26,40**
NH_4^+	$mg\ NH4+.L^{-1}$	5,90	0,10	11,30	1,20	0,00	15,00	**1,50**	**0,10**	**4,70**
NO_3^-	$mg\ NO3-.L^{-1}$	1,80	0,10	2,00	3,40	0,10	6,00	**2,40**	**0,10**	**5,70**
Ptot	$mg\ P.L^{-1}$		0,10	57,00		0,10	2,00	**7,50**	**0,10**	**14,20**
Ctot	logUFC/100m	5,80	1,90	5,90	5,10	1,80	7,40	**7,10**	**1,80**	**8,70**
Cféc	logUFC/100m	4,70	0,00	6,60	3,80	0,00	6,60	**58,00**	**1,10**	**6,90**
EnCO	logUFC/100mL		0,00	6,10	3,00	0,00	5,40	**3,30**	**0,80**	**5,60**

By the end user, greywater can be *perceived* as "lightly" loaded in organic material and bacteria. However, the reality is somewhat different: for some parameters the values are in close proximity to the values observed for raw wastewater (refer to Table 2, column ERD). Specifically, the COD can range from 250 to 1174 $mgO_2.l^{-1}$ that is quite close to the range for greywater from showers.

From the micro-biological perspective, even if greywater does not contain black water, it contains a lot of microorganisms, such as faecal coliforms. In fact, it was observed that their content in greywater deriving from showers can reach values of around 6.9 log UFC/100ml. This is comparable to what can be observed in raw wastewater (refer to Table 2).

The fact that greywater can contain a large amount of potential pathogen bacteria, like faecal coliforms, lends support to the fact that the health considerations of greywater re-use for flushing toilets are very important indeed. In fact the end user can be accidentally exposed to such pathogens with the re-used greywater.

The wide variation in the composition also lends support to the fact that one standard treatment process cannot fit with each case. In this paper, two different processes of treatment allowing the re-use of greywater were assessed and compared. Each process has been designed and set up with the following objectives:

- To reach the requested values for re-used greywater
- To re-use greywater from showers for flushing toilets.
- To assess the health risk and the reliability of such a re-use

4 Two cases

4.1 Case 1: Aerobic process with short storage and basic disinfection

In this case, the process being assessed was comprised of the following stages: skimming which involved short storage with air being supplied and a basic disinfection. The device was set up in a factory. So, the test plan included 2 showers per day and flushing done manually to try to reproduce what can take place in a house. Samples were taken at the inlet meaning on raw greywater and in the toilet-pan of the system. Samples were subjected to chemical and micro-biological analyses in order to assess the treatment performance and the potential health issues of such a re-use.

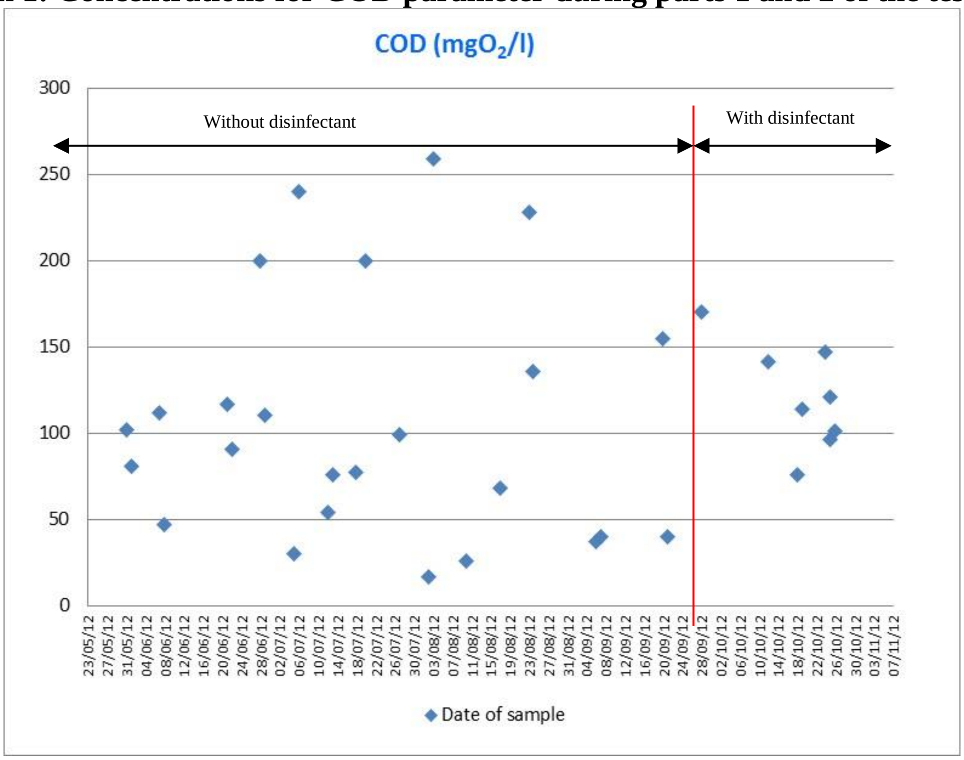
Table 3: Chemical and micro-biological parameters followed [3].

Measured parameters	Frequency of measurement
Chemical parameters	
Suspended Solids (SS) (mg/l)	At every sampling
pH	At every sampling
Turbidity (NTU)	At every sampling
Dissolved Oxygen	Continuous measurement
COD and/or BOD_5 (mgO_2/l)	At every sampling
Greywater flow rate (volume of shower)	At every sampling
Fresh water flow rate	Sometimes
Nitrogenous (NTK, mgN/l)	At every sampling
Phosphorous (P, mg/l)	Sometimes
Micro-biological parameters	
E. coli (CFU/100ml)	At every sampling
Faecal coliforms (CFU/100ml)	At every sampling
Enterococci (CFU/100ml)	At every sampling

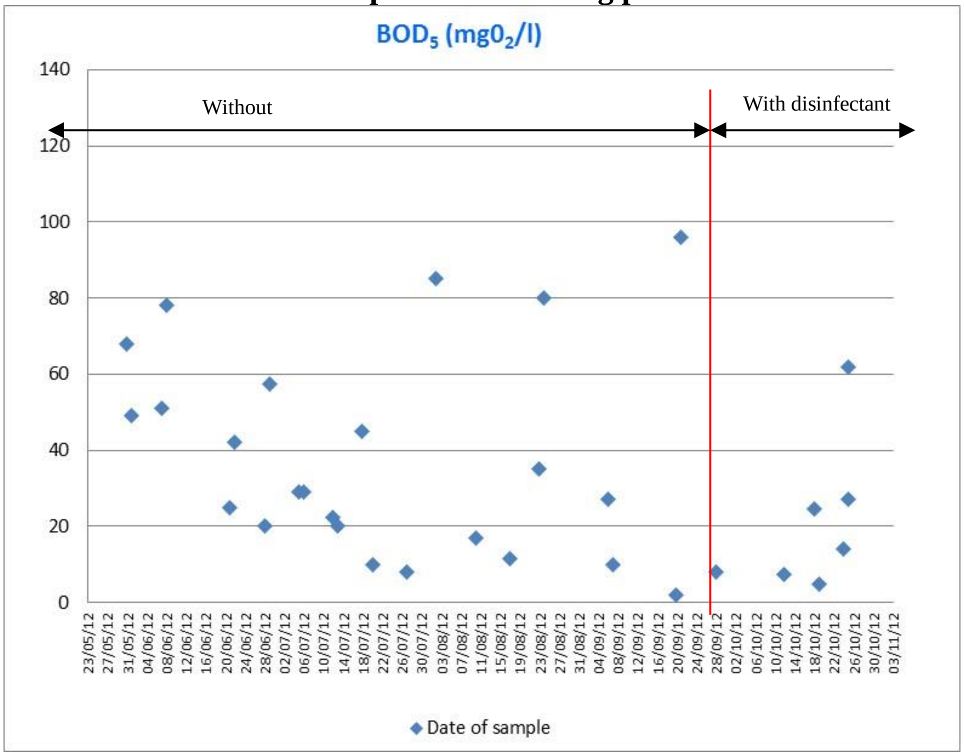
In addition to the chemical and micro-biological parameters reported, some secondary parameters were also recorded such as; electrical consumption, the cleanliness of the toilet pan based on the colour change, the odour emission, the failure frequency recording the number and type of malfunction (part failure, leakage…), the tank contamination (appearance of a biofilm on the storage tank walls), the water saving efficiency (taking account the quantity skimmed), and the acoustic properties.

At the beginning the test was launched without disinfectant in order to try to quantify the added value of the disinfection on the treatment performances. The following graphs (Graph 1, graph 2 and graph 3) show the results obtained in the outlet for the parameters COD, BOD_5 and SS.

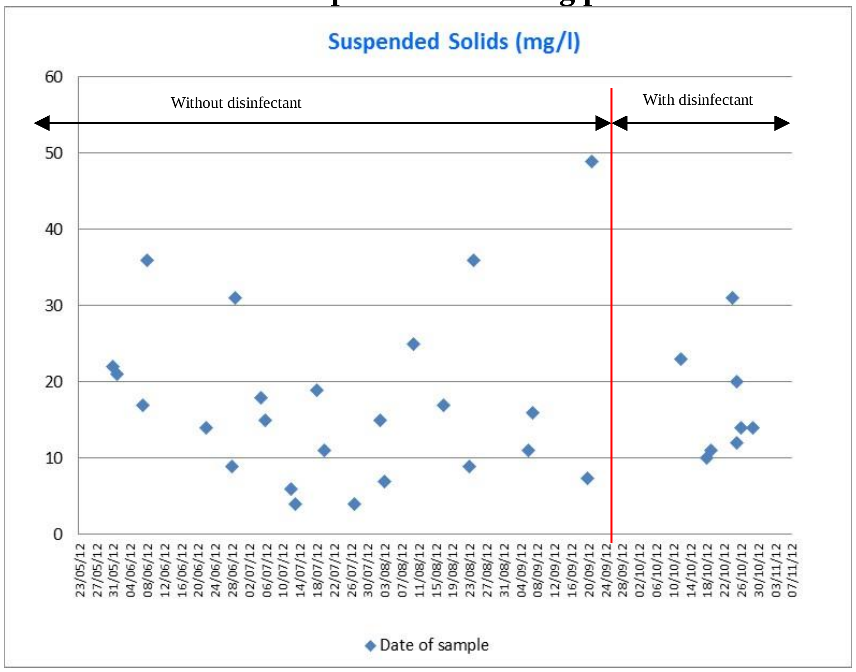
Graph 1: Concentrations for COD parameter during parts 1 and 2 of the tests [3].



Graph 2: Concentrations for BOD_5 parameter during parts 1 and 2 of the tests [3].



Graph 3: Concentrations for SS parameter during parts 1 and 2 of the tests [3].



In each graph, it will be noticed there is a high dispersity of the results. Moreover, the use of disinfectant induced no real improvement on the COD and BOD_5 results. Due to the simultaneous presence of dissolved oxygen supplied by the air blower, the presence of active micro-organisms and nutriments there happened a biological treatment in the system. The treatment efficiency on COD is around 64,5% in average and around 76% for the BOD_5 parameter in average. Even if it appeared a biological treatment in the system, it was not enough to reach low contents of organic material in the toilet pan.

A high quantity of Suspended Solids was often noticed in the samples (the treatment efficiency for SS was only around 58%). Over the period of evaluation, a biofilm appeared on the walls of the storage tank and some parts of the biofilm were sometimes washed, generating particles in the toilet pan and Suspended Solids in samples. Table 4 summarizes all the results obtained on chemical parameters.

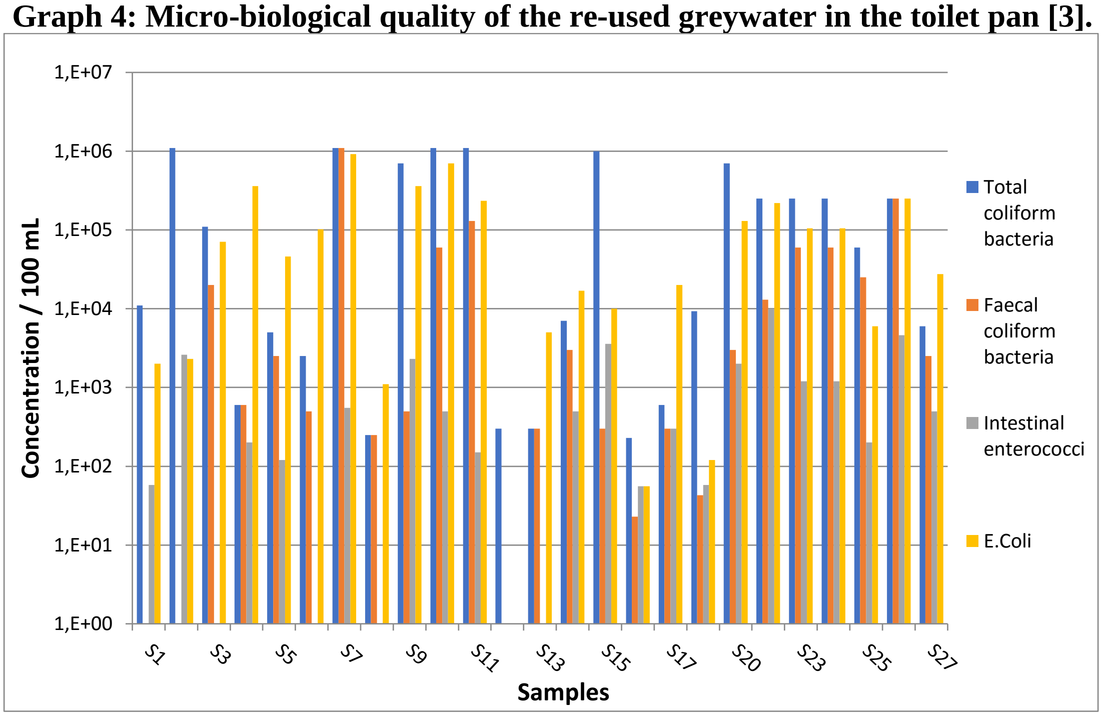
Table 4: Average results obtained on chemical parameters [3].

		Average content without disinfectant			Average content with disinfectant
Parameter	Unit	Average	Min	Max	Average
COD	(mgO_2/l)	109	17	258.8	112
BOD_5	(mgO_2/l)	38.2	2	96	21
Suspended Solids (SS)	(mg/l)	17.5	4	491	17
NTK	(mgN/l)	6.8	1.5	27.8	6.5
Turbidity	(NTU)	15	1	41	18
P	(mgP/l)	1.1	0.45	2.3	

This summary confirms that the disinfection did not appear to influence the key chemical parameters measured in our study. It was just noticed that it reduced the biofilm growth on the walls of the storage tank but nevertheless the reoccurrence of the biofilm was observed on the walls from time to time. The time of storage had a little influence on the quality of the treated water, because longer the time of contact with dissolved oxygen was, better the organic material treatment was.

Concerning the micro-biological parameters, the conclusions are similar: high dispersity of the results, high concentrations of bacteria in the samples even if a simple disinfection was running on the system.

Graph 4: Micro-biological quality of the re-used greywater in the toilet pan [3].



The average concentration for total coliforms was 105.5 CFU/100 ml and 104.87 CFU/100 ml for faecal coliforms. Concerning E.coli, the average concentration was 105 CFU/100 ml. The faecal coliforms analyses were not made for sample 1, sample 2 and sample 12. Finally, the average concentration for intestinal enterococci was 103.1 CFU/100 ml. These values appeared to be quite close to the ones found in the bibliography. However, the variations from a sample to another one were very important.

So, in this specific case, for the chemical and micro-biological parameters, the re-used greywater did not respect any thresholds of guidelines. Moreover, for the secondary parameters that were also recorded: the toilet pan was often dirty and biofilms appeared on the walls of the storage tank of the system. In fact, as the contents of organic material (nutriments) were quite high in the re-used greywater, the growth of biofilm was important. This result might also be partly influenced by the fact that the PE tank was translucent and not fully opaque to light. The top of the tank wall was colonized by algae and the bottom by biofilm.

4.2 Case 2: Anaerobic process with recirculation and strong chlorination

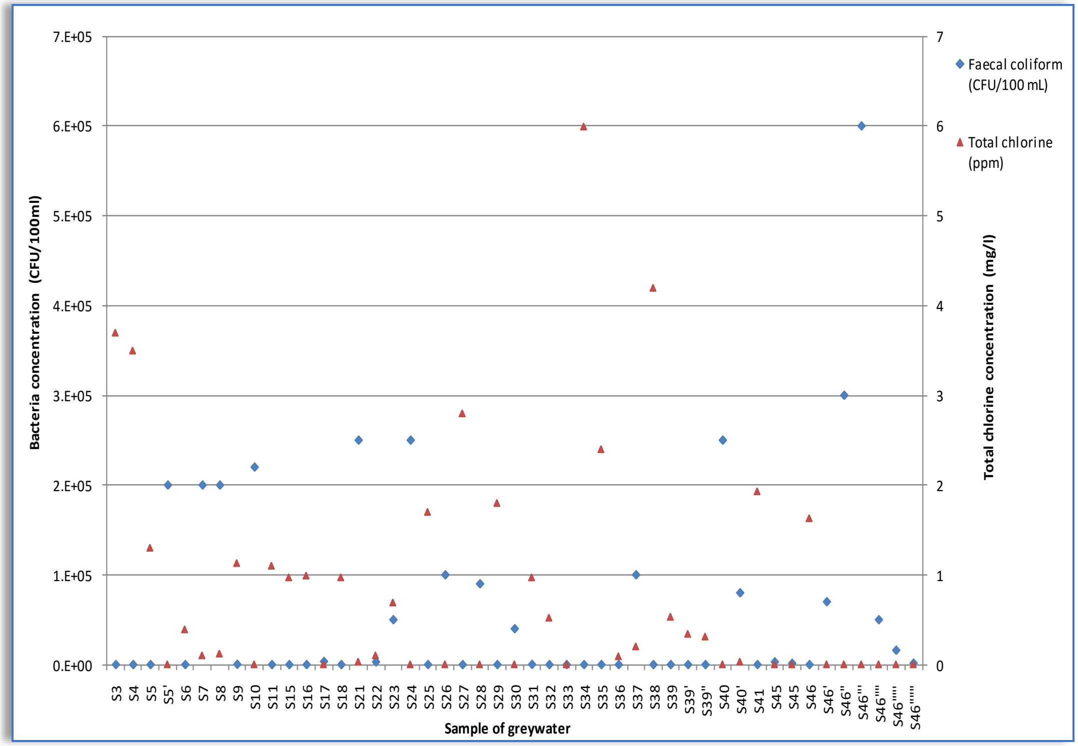
In this second case, the process under assessment comprised of the following stages: primary filtration (100 microns), settlement, chlorination, storage with recirculation and re-chlorination every 8 hours. As in case 1, chemical and micro-biological analyses were carried out at different points in the process to assess the treatment performance and the potential health issues of such a re-use. The same tests were applied as explained before, with the same sampling and analyses performed except on the phosphorous parameter. The average results observed with this technology of treatment were the followings (refer to Table 5):

Table 5: Average results obtained on chemical parameters with the second system [3].

Parameter	Average	Min	Max
$[COD]_{outlet}$ (mgO_2/l)	136.7	62	447
$[BOD_5]_{outlet}$ (mgO_2/l)	29.5	2	52
$[SS]_{outlet}$ (mg/l)	11,9	3,5	30
$[Turb]_{outlet}$ (NTU)	23,2	2	49
$[NTK]_{outlet}$ (mgN/l)	7,9	3	25

There was also a quite high dispersity in the results. It was shown that there was a removal of organic material within this system due to the filter, the settlement in the tank and the injection of chlorine. The time of storage had no influence on the chemical quality of the treated water. The results obtained on chemical parameters were improved with this treatment system in comparison with the previous one. But nevertheless, these did not reach the targeted values. Concerning the micro-biological parameters, the obtained results were related to the level of chlorination applied (refer to Graph 5).

Graph 5: Comparison between total chlorine level and faecal coliform concentration in the greywater [3].



This graph highlighted the close relationship existing between residual total chlorine and faecal bacteria concentration.

It showed the importance to have enough total chlorine in order to avoid the revivification of bacteria. Indeed, when the concentration of total chlorine was higher than 0.5 ppm no faecal coliform were detected in the samples. However, as soon as the chlorine level dropped to zero there was a high risk of swift revivification. For example, in the sample S46, just after a shower, there was no faecal bacteria detected because the chlorine concentration was high. However, only twenty hours after, the residual total chlorine was zero in the toilet pan and it was noticed a fast revivification. Indeed, faecal bacteria concentration was around 7.104 CFU/100 ml. Also, it was noticed that homogenization of the chlorinated greywater is a key factor to have good performance results because, when greywater is not well mixed, it appeared different layers in the tank with different contents of organic material, chlorine and bacteria that disturbs the treatment process.

Thus, in this second system, the toilet pan was separated from the global system of reuse, meaning that they worked independently. Indeed in the first one, it was a complete integrated system, in which the toilet pan was directly connected to the main storage tank. So, in the second process, even if the contamination process was well managed when the rate of chlorine was correct, it was also noticed some biofilm development in the toilet cistern. This did not help the end user to improve its general perception on such a reuse

Figure 2: Visual aspect of the interior of the toilet cistern after 6 months of use [3].

Finally, the use of strong chlorination in a wet atmosphere allowed the generation of corrosion on different parts of the system.

5 Conclusion: Challenges of water re-use

In comparing the two processes, the stage of storage was observed to be the weak point. Although time for storage was different, a biological treatment resulted in the generation of primary sludges and activated sludges. Moreover, small biofilms appeared on the walls of the storage tanks increasing the set-up of a biological treatment. This led to the generation of unpleasant odours and foams. Thus, the re-use of greywater for flushing toilets without generating health issues for the end user would seem to be less straightforward than expected.

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Session C Building water supply and drainage and intelligentization

C1 - A proposal of a method for planning and designing water supply and drainage facilities for buildings managed under BCP or LCP

Saki Watari (1), Masayuki Otsuka (2), Takafumi Matsuo (3)
1. m17J3025@kanto-gakuin.ac.jp
2. dmotsuka@kanto-gakuin.ac.jp
3. mattum314@yahoo.co.jp
(1)Graduate Student, Graduate School of Engineering Kanto Gakuin University, Japan
(2)Prof. Dr. Eng, Department of Architecture and Environmental Design,
College of Architecture and Environmental Design, Kanto Gakuin University, Japan
(3)M. Eng, Panasonic Corporation, Japan

Abstract

In Japan, long-term damage and disruption was caused to water and sewage services by the Great East Japan Earthquake in 2011 and the Kumamoto Earthquake in 2016. Subsequently, people were unable to use clean water and drain wastewater in their houses and buildings, and their lifelines were paralysed. Water supply drainage facilities are extremely important at the time of huge disaster in the light of BCP (Business Continuity Planning) or LCP (Life Continuity Planning). However, no specific planning design or method with consideration for disaster prevention has been sufficiently verified.
With this background, in this report, amounts of water required for everyday life activities from the time of disaster to full recovery are sorted stage by stage, thereby proposing a water usage amount which is a water supply unit amount required during the time of disaster.
After that, a planning design and the procedures thereof are proposed to determine a tank capacity sufficient for said water supply unit amount and a sewage tank capacity sufficient for temporarily storing domestic wastewater until recovery is achieved.
Lastly, said procedures are used to estimate the capacity of water supply drainage equipment for typical apartment housing.

Keywords

Business Continuity Planning (BCP); Life Continuity Planning (LCP); Water Supply and Drainage; Planning and Design; the Time of Disaster; the Aftermath of Disaster

1 Background and objectives of the study

In recent years, Japan has suffered large-scale disasters including the Great East Japan Earthquake in 2011 and the Kumamoto Earthquake in 2016. These disasters caused extensive damage to lifelines, such as water and sewage services. Damage reports[1)2)] predict that if Japan were struck by a large-scale disaster again, water and sewage services would be interrupted for as long as one or two months. In particular, BCP (Business Continuity Planning) or LCP (Life Continuity Planning) could not be more important for buildings and residents in securing water supply and drainage facilities. Nevertheless, no specific planning and designing method with consideration of BCP or LCP has been satisfactorily verified.

With this background, in the study, first, amounts of water required for daily life activities during the period from the time of disaster to full recovery are sorted, stage by stage, thereby suggesting amounts of water used during the period, which are water supply unit amounts.

Next, a planning and designing flow is proposed to determine the capacity of a water tank for storing water in an amount considered sufficient to survive a disaster and the capacity of a drainage tank for temporarily storing wastewater in the aftermath of disaster.

Lastly, by using the proposed flow, water tank capacities adequate for water supply and drainage facilities for standard apartment housing are estimated. The study also includes a basic discussion on the practicality of the proposed flow in the future.

Incidentally, the disasters described in this report refer to earthquakes.

The items discussed in the study are as follows:

(1) Suggested amounts of water used in the aftermath of disaster, which are water supply unit amounts

(2) Estimation of lifeline recovery periods

(3) Proposal of a planning and designing flow to determine water tank capacities adequate for water supply and drainage facilities

(4) Estimations in the case of apartment housing

2 Study overview

2.1 Suggested amounts of water used in the aftermath of disaster, which are water supply unit amounts

Previous studies[1)-5)] and disaster prevention plans by local authorities were examined to identify suggested amounts of water required for daily life in the aftermath of disaster. First, amounts of emergency water according to the disaster prevention plans by local authorities are referred to as 'locally determined water amounts'. The locally determined water amount is the amount of water supplied to the residents of a community by its local authority in the aftermath of disaster when water and sewage services are interrupted. Meanwhile, total amounts of water required for specific daily activities in the aftermath of disaster when water and sewage services are interrupted, according to the previous reports other than the disaster prevention plans by local authorities, are referred to as 'water amounts determined in previous reports'. Moreover, amounts of water to be secured in the aftermath of disaster, which are determined by the authors by calculating on the basis of locally determined water amounts and water amounts determined in previous reports, are referred to as 'suggested water amounts'.

2.2 Planning and designing method for determining water tank capacities for water supply and drainage facilities

In this report, a planning and designing flow is proposed to determine water tank capacities for water supply and drainage facilities with consideration of BCP or LCP. Bearing in mind the securing of sufficient water for daily life in the aftermath of disaster, the elevated water tank system is selected from among various water supply systems. In Japan, a planning and designing method for determining water tank capacities for water supply and drainage facilities under general circumstances is called 'ordinary-time design'. The ordinary-time design uses the effective capacities[6)] of a water-receiving tank and an elevated water tank, which are determined by maximum daily water usage. Moreover, in this report, a 'time-of-disaster design' is proposed as an initial step, where the capacities (effective capacities) of water tanks in a building for storing clean water and wastewater to prepare for disasters, the entire amounts of which are also stored at ordinary times, are calculated.

2.3 Apartment housing conditions considered in the estimations

Table 1 shows apartment housing conditions considered in the estimations that determine water tank capacities for water supply and drainage facilities. The housing subjected to the estimations is a newly built block of apartments located in the inner area of Yokohama City of Kanagawa Prefecture in Japan, and accommodates 300 residents. Moreover, the location is free from tsunami damage, and the housing is provided with a water purifier that turns well water into clean water in the event of a disaster. In addition, even in the situation where the power supply has been cut off, it is assumed that the pumps for water supply and drainage facilities can still be driven by solar power to operate some of the facilities.

Table 1 Apartment housing conditions for the estimations

Building overview		100 apartments (10/floor), 300 residents
		Water collecting area (roof) 965.69[m^2]
Location		Inner area of Yokohama City, Kanagawa
		(Min. monthly amount of rainfall approx. 54.8[mm], annual amount of rainfall approx. 1570[mm])
Water usage at normal times		250 [L/(person・day)] (water usage ratio: clean water 80%, non-potable water 20%)
Water supply and drainage facility configuration and available functions		1. Elevated water tank system
		2. Toilets: flush water 6.0 [L/time], low-level cistern type
		3. Well water available
		4. Power generation by battery and solar power
Toilets		Average use of 6 [time/(person・day)]
		Flush water usage in the aftermath of disaster Day 1-7: 12 [L/(person・day)], from Day 8 and onwards: 36 [L/(person・day)]
Wastewater disposal		Drainage tanks are installed
		When functioning: wastewater is discharged into the sewer
How to use water in the aftermath of disaster		According to the manager's instructions
Water supply and drainage facility grade	1	One-system water supply configuration (Used by 300 residents)
	2	Two-system water supply configuration (Used by 300 residents)
	3	With emergency toilets (The residents use the regular toilets)

Fig. 1 is a plane view of the underground pit of the apartment housing. The pit is divided into 20 sections each having an effective capacity of approximately 6m×5m×2m (effective depth).

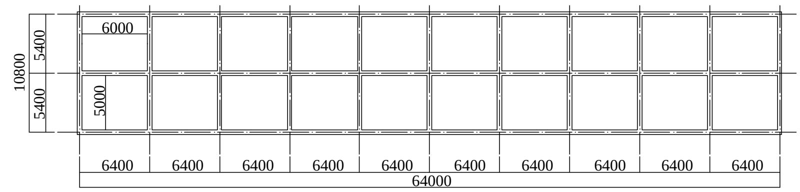


Fig. 1 Plane view of the underground pit of the apartment housing (non-scale)

2.4 Water supply and drainage system grades

Fig. 2 is a schematic view of the water supply and drainage system grades. Water supply and drainage systems are grouped into three grades according to the standard of system with consideration of the type of water supply system and BCP or LCP. Grade 1 refers to the common type of apartment housing using a one-system water supply configuration. Grade 2 refers to apartment housing using a two-system water supply configuration, which is not adopted in general. These systems are only for handling clean water. Grade 3 refers to apartment housing capable of accommodating on the premises thereof emergency toilets of a super water-saving type with a flush water amount of 1L or less[7)], in the case of adopting the one-system configuration or the two-system configuration. It is assumed that these emergency toilets are adequately provided to manage 50 people per day, who are non-residents of the apartment housing. In performing the estimations, these conditions are given in order to identify the amounts of water used by the residents and non-residents of the apartment housing, respectively, and the amounts of wastewater discharged by them respectively. Incidentally, the rainwater utilisation facilities are also considered in the implementation of grade 3. The estimations are also performed on the assumption that emergency toilets of a super water-saving type with a flush water amount of 1L or less are used.

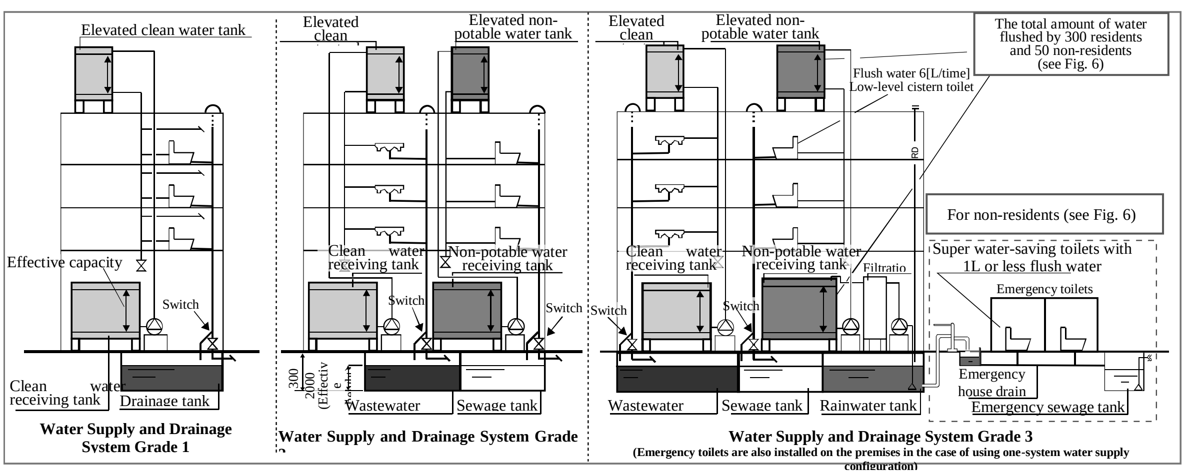


Fig. 2 Schematics of water supply and drainage system grades

3 Results and considerations

3.1 Suggested amounts of water used in the aftermath of disaster, which are water supply unit amounts

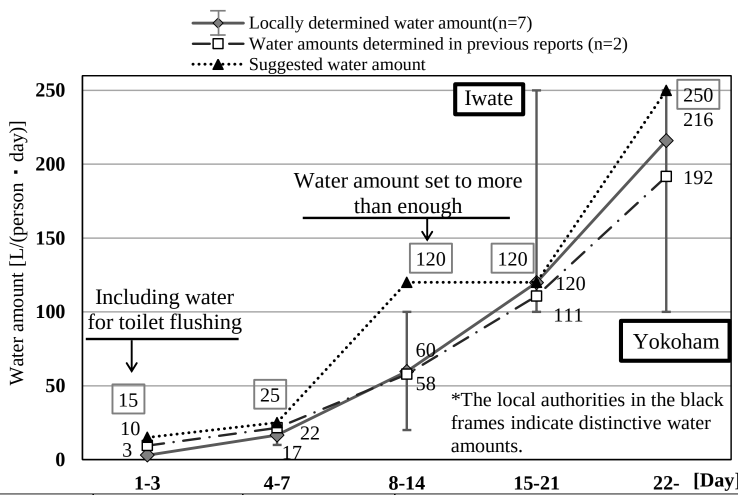
Table 2 shows locally determined water amounts and water amounts determined in previous reports[1)-5)] that correspond to the number of days of recovery from a disaster. Moreover, Fig. 3 shows the averages of the abovementioned water amounts in Table 2 and suggested water amounts. According to Fig. 3, the locally determined water amounts for approximately the first seven days are set to 3 to 17[L/(person・day)], which are less than the water amounts determined in previous reports for the same period, 10 to 22[L/(person・day)]. However, from the 8th day and onwards, the trend reverses, i.e., the locally determined water amounts are set higher than the water amounts determined in previous reports.
According to a past damage report[1)], securing water for flushing toilets and sewage treatment were particularly challenging in the aftermath of the Great Hanshin Awaji Earthquake and the Great East Japan Earthquake. With these issues in mind, the suggested water amounts were determined. Incidentally, the suggested water amounts were calculated on the assumption that toilets with 6.0L flush water, the most widespread toilets in Japan, were used. Moreover, the estimations in this study use the suggested water amounts as amounts of water used in the aftermath of disaster. The suggested water amounts were calculated mainly with a focus on the following.

・Day 3 of the disaster: 15[L/(person・day)] (including toilet flush water)
・Day 8-14: 120[L/(person・day)], similar to Day 15-21 (in order to secure higher daily amounts of water than the locally determined water amounts or the water amounts determined in previous reports)
・The water in suggested amounts is secured from the water-receiving tank or elevated water tank.
・In the case where water cannot be secured from the water tanks, due to poor water quality for example, emergency water, well water, etc., is used.

Table 2 Water usage amounts corresponding to the assumed number of days of recovery

	Document	Day	Water amount [L/(person・day)]
Locally determined water amounts	Iwate 3)	1-3	3
		4-7	3～20
		8-14	20～100
		15-21	100～250
		22-28	250
		29 and onwards	Water recovery
	Fukushima 3)	1-3	3
		4-7	10
		8-14	50～100
		15-28	150～200
	Urayasu 3) Kobe 3)	1-3	3
		4-10	20
		11-21	100
		22-	250
	Yokohama 1)	1-3	3
		4-7	10
		8-	20
		Recovery period	100
	Tokyo 4) Japan Water Works Association 1)	1-3	3
		4-10	20
		11-20	100
		21-30(28)	250

	reports	Day	Water amount [L/(person・day)]	Purpose of use
Water amounts determined in previous reports	reports 2)	1-3	3	Drinking / cooking(3)
		4～7	20	Drinking / cooking(3), Toilet flushing(11～16), Face washing(6)
		8～13	40	Drinking / cooking(3), Toilet flushing(11～16), Face washing / bathing(15), Clothes washing (10)
		14～28	100	Drinking / cooking(21), Toilet flushing(14), Face washing / bathing(44), Clothes washing(19), Other (2)
		29 and onwards	173.3～294.8	Water restored to the normal level
	reports 5)	1-3	16	Drinking（7）, Daily use（2), Miscellaneous use （7）
		4～10	23	Drinking（10）, Daily use（4）, Miscellaneous use （9）
		11～20	100	
		21～30	250	



Clean water supply interruption	Day 1-3	Day 4-7	Day 8-21	Day 22 and onwards
Suggested purpose of use	15[L/(person• day)]	25[L/(person• day)]	120[L/(person• day)]	250[L/(person• day)
	Drinking Toilet flushing	Drinking / cooking Toilet flushing	Drinking / cooking / bathing Toilet flushing / clothes washing	Same as Day 8-21

Fig. 3 The averages of the water amounts in Table 2 and suggested water amounts corresponding to the assumed number of days of recovery

3.2 Assumed periods of lifeline recoveries

Table 3 shows the recovery levels of the lifelines set in this report. In the report, the recovery period of each lifeline, from the time a disaster strikes to cause interruption to the time recovery is achieved, is divided into four levels. The number of days for clean water recovery in Table 3 corresponds to the gradual change of the suggested water amount shown in Fig. 3. It is supposed that recovery levels I and II refer to the scale of disaster causing damage that can be repaired quickly, level III refers to the same scale as that of the Kumamoto Earthquake, and level IV refers to the same scale as that of the Great Hanshin Awaji Earthquake, the Great East Japan Earthquake or the Nankai Trough Megathrust Earthquake.

Table 3 Lifeline recovery levels

Recovery level		Ⅰ	Ⅱ	Ⅲ	Ⅳ
Recovery period	Clean water supply	3 days	7 days	21 days	2 months(60 days)
	Sewage disposal	2 days	4 days	2 weeks(14 days)	5 weeks(39 days)
	Electric power	1 days	2 days	1 week(7 days)	2 weeks(14 days)

3.3 Proposal of a planning and designing flow for determining water tank capacities for water supply and drainage facilities

Table 4 shows the conditions of water usage in the aftermath of disaster, which are used in the estimations to determine water tank capacities for water supply and drainage facilities. Fig. 4 shows the planning and designing flow, which is proposed in this report, for determining water tank capacities for water supply and drainage facilities. The estimation conditions and the steps of using the flow are also explained below. The estimations are performed on newly built apartment housing. In addition, different water usage amounts and recovery periods are used, as appropriate, according to the assumed scale of damage.

Estimation condition 1: The estimations are performed on apartment housing on the basis of 80% clean water and 20% non-potable water.[8)]
Estimation condition 2: The recovery levels in Table 3 are used, corresponding to the recovery periods of the clean water supply in Table 4 [1].
Estimation condition 3: The suggested water amounts indicated in Fig. 3 are used as the water usage amounts in the aftermath of disaster in Table 4 [2].

Table 4 Conditions of water usage in the aftermath of disaster

In the aftermath of disaster

(The figures in white are the values suggested in this report.) (i=recovery levels I-IV)

Recovery level	[1] Clean water recovery period [Day]	[2] Water usage [L/(person・day)]	[3] Water usage/no. of days [L];[1]×[2]		[4] Total water usage/recovery level[L]		
			[3'] Clean water [3]-[3"]	[3"] Non-potable water q_{w-i} ×[1]	Clean water + non-potable water	Clean water	Non-potable water
I	1-3 (3)	15	9	36	45	9	36
II	4-7 (4)	25	52	48	145	61	84
III	8-21 (14)	120	1176	504	1825	1237	588
IV	22-60 (39)	250	8346	1404	11575	9583	1992

Figures in ( ): assumed no. of days for recovery Toilet flush water usage in the aftermath of disaster: q_{w-i} [L/(person・day)]

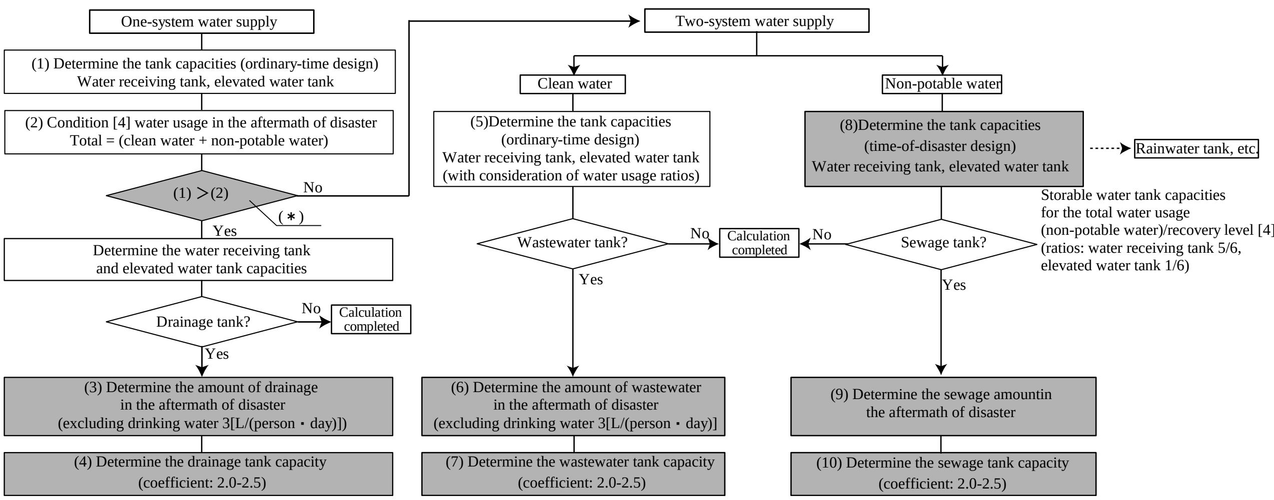


Fig. 4 Planning and design flow for determining water tank capacities for water supply and drainage facilities

One-system water supply configuration

Step 1.1

・ Calculate the capacities of the clean water tanks (water-receiving tank, elevated water tank) by using the ordinary-time design.

Step 1.2

・ Add up the capacities of the tanks and compare the total with the total water usage (clean water + non-potable water) per recovery level (Table 4 [4]). (Fig. 4 ＊)

The total water usage corresponds to the number of people who use water.

・ If the total tank capacity is less than the total water usage, adopt the two-system water supply configuration (clean water and non-potable water)

Step 1.3

・ Obtain the amount of drainage in the aftermath of disaster by subtracting the assumed amount of drinking water (a minimum of 3[L/(person・day)]) from the total water usage (clean water) per recovery level. (Fig. 4 (3))

Step 1.4

- Obtain the capacity of the drainage tank by multiplying the drainage amount by the coefficient.

Two-system water supply configuration
(Clean water)
Step 2.1

- With the water usage ratios in mind, calculate the capacities of the clean water tanks (water-receiving tank, elevated water tank). (Fig. 4 (5))

Step 2.2

- Obtain the amount of wastewater in the aftermath of disaster by subtracting the assumed amount of drinking water (a minimum of 3[L/(person・day)]) from the total water usage (clean water) per recovery level. (Fig. 4 (6))

Step 2.3

- Obtain the capacity of the wastewater tank by multiplying the wastewater amount by the coefficient.

(Non-potable water)
Step 2.4

- Calculate the capacities of the non-potable water tanks (receiving tank, elevated tank) by using the time-of-disaster design. (Fig. 4 (8))
- The effective capacity ratios (5/6, 1/6) used in the time-of-disaster design are temporarily determined from the ordinary-time capacity ratio between the water-receiving tank and the elevated water tank (1/2:1/5=5:1).
- The determined effective capacity ratios (5/6, 1/6) are used for proportionally dividing the tank capacities so that water in an amount corresponding to the total water usage (non-potable water) per recovery level (Table 4 [4]) is regularly stored.

Step 2.5

- The amount of sewage in the aftermath of disaster should be equal to the total water usage (non-potable water) per recovery level (Table 4 [4]). (Fig. 4 (9))

Step 2.6

- Obtain the capacity of the sewage tank by multiplying the sewage amount by the coefficient.

3.3.1 Estimation conditions for water tank capacities for grade 3 water supply and drainage facilities

The estimation conditions for grade 3 systems are as follows.
Estimation condition 1

- The amount of water for flushing emergency toilets:
  q_{w-i} =1[L/time]×6[time/(person・day)]

Estimation condition 2

- Total water usage (non-potable water) per recovery level:
  (Table 4 [4] × 300 persons) + (q_{w-i} × 50 persons × no. of days for recovery)

Estimation condition 3

- 40[L/time] of flush water is sent into the emergency house drain every 90 times the emergency toilets are flushed, and the sewage is carried into the emergency sewage tank[7]. This is to avoid problems caused by sewage stagnation in the emergency house drain.
  → Rainwater is used for cleaning the emergency house drain.

Estimation condition 4

- The amount of sewage, which is used for determining the capacity of the emergency sewage tank, includes 160[L/day] of water for cleaning the emergency house drain.

Estimation condition 5

- The period during which the emergency toilets are used is from the day a disaster strikes to the day the sewage system is restored.

Estimation condition 6

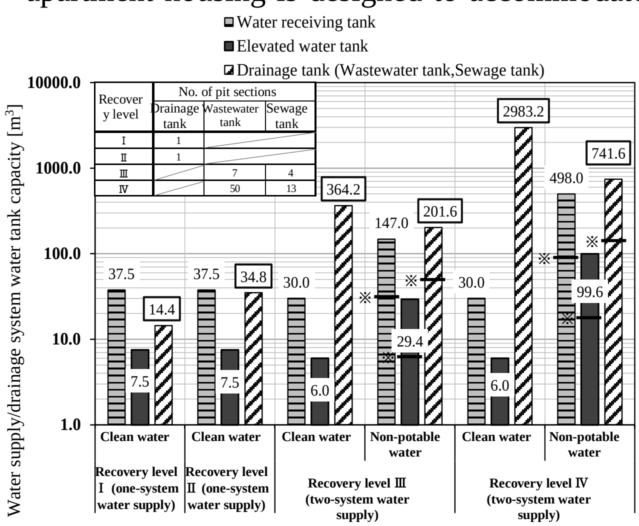
- The capacity of the rainwater tank is calculated using the calculation method described in the reference document[9].

3.4 Example results of the estimations performed on apartment housing

Fig. 5 shows the results of the estimations performed on grade 1 and 2 water supply and drainage systems to determine water tank capacities per recovery level. When calculated according to the planning and designing flow, the total water tank capacity, by the ordinary-time design, for recovery level I and II is greater than the total water usage (clean water + non-potable water) per recovery level, and only clean water is needed to cover the total water usage/recovery level. This refers to grade 1 where the one-system water supply configuration should be adopted. As for recovery levels III and IV, the total water usage (clean water + non-potable water) per recovery level is greater than the total water tank capacity, and this means that the two-system water supply configuration should be adopted.
Fig. 6 shows the results of the estimations performed on a grade 3 water supply and drainage system to determine water tank capacities per recovery level. As in Fig. 5, the results indicate that the one-system water supply configuration should be used for recovery levels I and II, and the two-system water supply configuration should be used for recovery levels III and IV even when taking into consideration the total usage of non-potable water by the non-residents (q_{w-i} × 50 persons × no. of days for recovery).
According to Fig. 5 and Fig. 6, the number of drainage tanks and the number of rainwater tanks requiring the underground pit were associated with the number of sections of the pit to identify the effective capacity of each tank. There are five types of water tanks requiring the underground pit; drainage tank, wastewater tank, sewage tank, emergency sewage tank and rainwater tank. Fig. 7 shows the use range of the underground pit. In any grade, the capacity of each water tank for recovery levels I and II is manageable by securing three to four sections of the underground pit (inside dimensions of each section 6m×5m×2m (effective depth)) of the apartment housing, and this is considered fairly realistic. However, the water tank capacities for recovery levels III and IV are too great to manage only with the underground pit of the apartment housing, and a possible measure to overcome this is, for example, providing temporary drainage tanks on the premises separately from the underground pit, collecting wastewater by vacuum vehicle, or using a disaster prevention-type ultra super water-saving

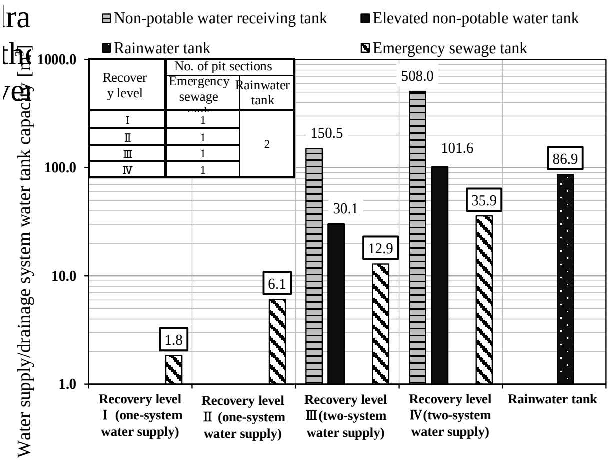
toilet system if its capacity is adequate for the premises area or the number of users[10]. In addition, it would be necessary to develop an ultra super water-saving toilet unit both for ordinary time and for emergency (a variable type 6.0[L/time] to 1.0[L/time]).

Water tank capacities for recovery levels III and IV, in an assumed situation where the apartment housing is designed to accommodate ultra super water-saving toilets for ordinary ... ith solid lines in Fig. 5. It is evident that the ... ra ... th ... ver



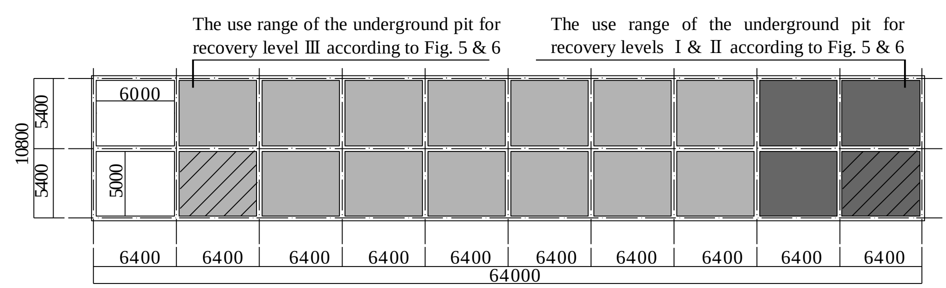
※The solid lines indicate water tank capacities when 1.0L of cleaning water is used at a time.

Fig. 5 Estimated water tank capacities for residents only (Water supply/drainage system grades 1 & 2)



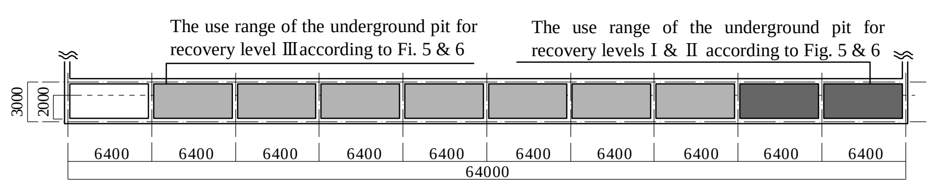
※The values of the clean water tank and drainage tanks (wastewater, sewage) are as in Fig. 5.

Fig. 6 Estimated water tank capacities when including non-residents (Water supply/drainage system grade 3)



※The hatched areas indicate emergency sewage tanks.

(1) Plane view of the underground pit (non-scale)



(2) Cross-sectional view of the underground pit (non-scale)

Fig. 7 The use range of the underground pit

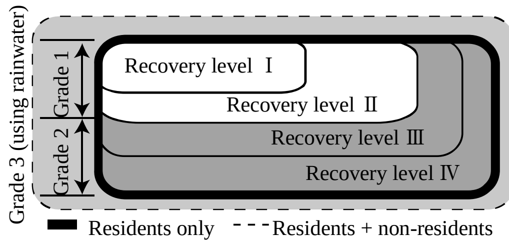


Fig. 8 Relationship between the recovery level and the water supply/drainage system grade

4 Summary

As it could be the case that amounts of emergency water planned by local authorities are not sufficient for daily activities in the aftermath of disaster, in this report, amounts of water to be secured for daily life in the aftermath of disaster were determined with ample water in mind. Furthermore, a planning and designing flow to determine water tank capacities adequate for water supply and drainage facilities was proposed, with BCP and LCP in mind, in order to address problems such as securing enough water for flushing toilets and disposing of the wastewater from the toilets.

Hypothetical recovery levels I to IV were set for calculating estimated water tank capacities for water supply and drainage facilities, and the results indicate that non-potable water should be introduced when considering BCP or LCP. Incidentally, it would also be necessary to consider resilience improvement in system construction to ensure flexible handling of situations, such as urgent water usage restriction, supply and aid from outside, and the use of alternative means.

The study was carried out by taking the case of an inner area, and further study will be carried out with a focus on coastal areas and on the planning of an emergency toilet system.

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6 Presentations of Authors

Saki Watari is a graduate student of the Otsuka laboratory, Kanto Gakuin University. She is a member of AIJ(Architectural Institute of Japan) and SHASE(Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). Her current study interests are the planning and design of sanitary equipment considering disasters.

Masayuki Otsuka is the Professor at Department of Architecture and Environmental Design, Kanto Gakuin University. He is a member of AIJ (Architecture Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan).His current research interests are the hybrid drainage system that uses both force feed type and gravity type drainage methods compatible with commercial building conversion.

Takafumi Matsuo is a master of engineering of Panasonic Corporation. He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His current study interests are the simulation method of predicting the discharge characteristics of water-saving toilets when installed to the fixture drain using toilet paper.

C2 - Calculator for Estimating Peak Water Demand in Residential Dwellings

Dan Cole (1), Steven Buchberger, Ph.D, P.E. (2), Toritseju Omaghomi (3), Timothy Wolfe, P.E. (4), Jason Hewitt, P.E. (5)

1. dan.cole@iapmo.org
2. buchbesg@ucmail.uc.edu
3. omaghotu@mail.uc.edu
4. twolfe@trcww.com
5. jason.hewitt@cbengineers.com

(1) Technical Services Manager, The IAPMO Group, USA
(2) Professor and Head of the Department of Civil Engineering, Architectural Engineering and Construction Management at the University of Cincinnati, USA
(3) PhD student in Environmental Engineering at the University of Cincinnati, USA
(4) Professional Engineer for TRC Worldwide Engineering, USA
(5) Professional Engineer for CB Engineers, USA

Abstract

This paper summarizes a recent five-year study to estimate peak water demands in residential buildings fitted with efficient fixtures. A large database of indoor residential water use measured at over 1,000 homes in the United States was compiled. The database was used to estimate the probability of water use (p) and the rate of water use (q) at six different fixture types: bathtub, clothes washer, dishwasher, faucet, shower and water closet. The p and q parameters were used to develop a statistical framework that predicts the 99th percentile of the peak indoor water demand in single and multi-family residential dwellings. The statistical procedure was coded in a Water Demand Calculator (WDC) that is available as a downloadable Microsoft Office Excel spreadsheet. The WDC spreadsheet requires as input only the number and type of fixtures installed in the building. Preliminary results show that the WDC provides peak flow predictions that are much lower than conventional "Hunter-curve" type estimates and, hence, more representative of peak water use in contemporary premise plumbing systems with efficient fixtures.

Keywords

Peak demand, probability of fixture use, design flow rate, binomial distribution, 99th percentile, exhaustive enumeration, Hunter Number, zero-truncated binomial distribution, q1 + q3, water demand calculator

1 Introduction

Residential water use has changed dramatically in the past several decades. This study was motivated by the need to develop a probability model for predicting peak water demands in buildings. The largest U.S. database containing residential end uses of water surveys was used to estimate fixture use probabilities and flow rates. Because the dataset provided statistics for residential end use only, the scope of research was narrowed to single and multi-family residential dwellings.

Plumbing fixture water consumption is today significantly less than the flows predicted by conventional computations for peak demand modelling. The scope of research focused on determining fixture use probabilities and flow rates only for indoor water-conserving plumbing fixtures. Residential indoor efficient fixtures considered in the database were water closets, showers, dishwashers, clothes washers, and faucets (kitchen and lavatory). Bathtubs were also included but are not considered water-conserving since there are no design benefits for installing low-flow tub spouts. The end result was a statistically based probability model that would predict the peak water demand for single and multi-family dwellings having water-conserving plumbing fixtures. This model would be used to predict the peak water demand for the building supply and principal branches and risers of a residential plumbing system.

2 Water use database

2.1 National survey

The database consists of water use measurements taken between 1996 and 2011 at over 1,000 single-family homes across the United States. The water use data were recorded with a portable data logger connected to the main water supply pipe in each home. The data logger recorded the volume of water flowing through the main pipe every 10 seconds. The recorded flows were analyzed by Aquacraft, Inc. using their proprietary software and disaggregated into individual water use events. Each water use was associated with one of three mutually exclusive household draws: an indoor fixture, an outdoor fixture, or a leak. Only indoor fixture use is considered in this study.

To facilitate queries, the water use data are stored in MS Access format. As shown in Table 1, the database contains two types of information, namely (i) household survey data and (ii) measured flow data. The household survey data reflect characteristics of the home, the residents and the water fixtures; the measure flow data describe the duration, volume, and number of water use events at each fixture group identified in the home. The maximum data-logging period at each home was 14 days. To capture the diurnal variation in indoor residential water use, results for each fixture in each home were summarized on an hourly basis.

Table 6 Survey and measured water use data in the MS Access database

Household Survey Data	Measured Flow Data
- Number of residents and age distribution	- Number of times a fixture was used
- Type of fixtures	- Duration of each fixture use event
- Number of each fixture type/group	- Volume of each fixture use event
- Number of renovated or retrofitted fixtures	- Daily observed fixture peak flow
- Number of bedrooms and bathrooms	- Logging dates

The national distribution of 1,058 surveyed households is summarized in Table 2. A small percentage (2%) of homes was dropped from the analysis due to vacations or other conditions that gave zero or minimal water use. The remaining 1,038 homes had a total of 2,821 occupants who generated nearly 863,000 water use events during 11,385 home-days of monitoring. On a per household basis, this translate to an average of 11 trace days per home, 2.72 residents per home and 831.4 water use events per home.

Table 7 Homes surveyed

Location by State		Number of Homes	Number of Occupants	Survey Years
Arizona,	AZ	17	41	2007 - 2009
California,	CA	447	1326	2006 - 2009
Colorado,	CO	206	533	1996, 2007 - 2010
Florida,	FL	32	78	2007 - 2009
Kentucky,	KY	58	128	2007
Nevada,	NV	20	593	2007 - 2009
New Mexico,	NM	237	44	2010 - 2011
Oregon,	OR	24	66	2007 - 2009
Utah,	UT	17	56	2007 - 2009
Responded to Survey		1058	2865	-
Invalidated Homes		(20)	(44)	-
Total Analyzed		1038	2821	-

2.2 Water use data

Six unique fixtures were common to most of the 1,038 participating homes (see Table 3). The database does not differentiate between kitchen faucets and lavatory faucets; therefore, both are included in the fixture group “faucet”. Water use falling outside these six categories was lumped into “Other”. For instance, some homes had evaporative coolers, water treatment devices, or unknown fixtures. In addition, leaks were common. The total volume of water used at each fixture differs due to the fixture function and frequency of use. Table 4 is a breakdown of water use per capita in 1038 households. Water closets had the highest use as gallons per capita daily (GPCD), while dishwashers had the lowest use. The mean daily water use was 60.10 GPCD. Nearly 98% of the homes registered a leak. Although leakage accounted for nearly 17% of the volume of daily water use, leaks are not a design factor and, hence, are not considered further.

Table 8 Six fixture groups were common to most homes

Fixture Group	Abbreviation	Number of Homes w/ Group	Number of Fixtures in Group	Average Fixtures per Home
Bathtub	B	519	852	1.64
Clothes washer	C	1,002	1,002	1.00
Dishwasher	D	722	728	1.01
Faucets	F	1,038	4,013	3.87
Shower	S	1,014	2,132	2.10
Water closet	T	1,037	2,502	2.41

Table 9 Frequency and volume of water use at 1038 single family homes

Fixture	Water use events (per capita per day)	Volume (GPCD)
Bathtub	0.08	1.54
Clothes washer	0.97	14.31
Dishwasher	0.33	0.77
Faucet	22.74	11.87
Shower	0.76	12.59
Water closet	5.80	15.18
Others	9.74	3.84
Leaks	50.11	11.98
Totals (excluding leaks)	40.42	60.10

3 Estimating fixture parameters

There are three key parameters in most models formulated to predict peak residential water demand, namely:

- n = number of fixtures in the dwelling
- p = probability that a fixture is in use during the peak period
- q = flow rate at a busy fixture

The fixture count, n, is simply the number of indoor fixtures at the dwelling. The fixture count is easily determined directly from the construction plans. In contrast, the p-values and q-values are more elusive. Both must be estimated from observations of fixture use at residential buildings.

3.1 *p*-values

The probability of fixture use is estimated as a dimensionless ratio

$$p = \frac{duration\ of\ time\ that\ the\ fixture\ is\ busy\ (i.e., running\ water)}{duration\ of\ time\ that\ the\ fixture\ is\ observed}$$

The "duration" terms needed in the numerator and the denominator were obtained for each fixture group from a careful analysis of the national database of high resolution water use recorded at over 1,000 single family homes. Residential water use follows a strong diurnal pattern. This implies that estimates of *p* will vary from hour to hour. For purposes of estimating peak demand, the critical period of observation is the hour of the day at each household in which the largest volume of water is used.

The national database revealed that residential water use tends to be greater on weekends than on week days. For this reason, weekends were used to identify the peak hour of water use. For a given fixture group, estimates of the peak hour probability of use will vary from household to household, even after classifying by number of occupants. A weighting scheme, based on the duration of the observation window at each home, was used to combine the collection of computed *p*-values into a single representative estimate for each fixture group. The resulting *p*-values, rounded off to the nearest 0.005, are listed in Table 5. While these *p*-values are derived exclusively from water use data measured at single-family homes, in this study, they are conservatively assumed to also apply to buildings with multiple residential units.

Table 10 Recommended probability of fixture use (*p*) and fixture flow rate (*q*)

FIXTURE	DESIGN PROBABILITY VALUE, *p* (%)	MAXIMUM RECOMMENDED DESIGN FLOW RATE *q* (GPM)
Bar Sink	2.0	1.5
Bathtub	1.0	5.5
Bidet	1.0	2.0
Clothes Washer	5.5	3.5
Combination Bath/Shower	5.5	5.5
Dishwasher	0.5	1.3
Kitchen Faucet	2.0	2.2
Laundry Faucet	2.0	2.0
Lavatory Faucet	2.0	1.5
Shower, per head	4.5	2.0
Water Closet, 1.28 GPF Gravity Tank	1.0	3.0

3.2 *q*-values

Efficient and ultra-efficient fixture flow rate percentiles were queried from the database. All the recommended fixture flow rates in Table 5 are above the mean (greater than the 75^{th} percentile) for efficient fixtures except for the shower. The shower flow rate recommendation of 2.0 gpm is based on the EPA WaterSense Specification for Shower Heads and is above the mean for ultra-efficient showers.

The flow rate recommendations for both the lavatory faucet and kitchen faucet are well above the mean for all faucets within the database, exceeding the 90th percentile. This is because the recommendation was based upon the EPA WaterSense High-Efficiency Lavatory Faucet Specification and the 2015 IAPMO Green Plumbing and Mechanical Code Supplement (GPMCS) for kitchen faucets. The GPMCS allows a kitchen faucet flow rate at a temporary maximum 2.2gpm if it defaults back to 1.8gpm. Therefore, the higher flow rate is recommended.

Some fixtures in Table 5 are not included in the database. The bar sink faucet has a comparable flow rate with the lavatory faucet. A residential laundry faucet with an aerator can have a flow rate of 1.5 gpm or 2.0 gpm, the higher flow rate being recommended. Similarly, the bidet faucet flow rate was recommended at 2.0 gpm.

The combination bath/shower has two water outlets that are mutually exclusive. Water will flow either through the tub spout or the shower head from the same fixture fitting. The recommended design flow rate for this fixture fitting is based upon the flow rate for the tub spout and is the same as the bathtub flow rate.

4 Estimating design flow

4.1 Hunter's method

Roy Hunter (1940) demonstrated that the use of water fixtures in a building can be described with the binomial probability distribution. Given a group of *n* identical fixtures each with probability *p* of being used, Hunter showed the probability of having exactly *x* fixtures operating simultaneously out of *n* total fixtures has a binomial mass function,

$$\Pr\left[x\ busy\ \ fixtures \middle| n, p\right] = \binom{n}{x} \left(p\right)^{x} \left(1-p\right)^{n-x} \qquad x = 0,1,\ldots,n \qquad [1]$$

Most buildings have an assortment of fixtures. Each fixture group has their own unique values for *n* and *p* and, hence, their own distinct version of Equation [1]. Hunter used the 99th percentile from Equation [1] as the design standard for estimating peak demand. He recognized, however, that when estimating the load on the building it was not legitimate to simply add the 99th percentile from each fixture group. In a clever move, Hunter introduced *fixture units* to merge the 99th percentile curves for each fixture group into a single design curve giving the 99th percentile of peak demand at a building based on the total fixture units. The final result, called Hunter's Curve, is the theoretical basis for many plumbing codes around the world (IAPMO, 2015).

4.2 Wistort's method

Robert Wistort (1994) proposed using the normal approximation for the binomial distribution to estimate directly peak loads on plumbing system. Similar to Hunter's approach, the number of busy fixtures *x* is considered to be a random variable with a binomial distribution having a mean $E[x] = np$ and variance $Var[x] = np(1-p)$. From the normal approximation, the estimate of the 99th percentile of the demand in a building with *K* different fixture groups is,

$$Q_{0.99} = \sum_{k=1}^{K} n_k p_k q_k + \left(z_{0.99}\right)\sqrt{\sum_{k=1}^{K} n_k p_k \left(1-p_k\right) q_k^2} \qquad [2]$$

In this expression, n_k is the total number of fixtures belonging to fixture type k, p_k is the probability that a single fixture in fixture type k is operating, q_k is the flow rate at the busy fixture type k and $Z_{0.99}$ ($Z_{0.99}$=2.33) is the 99th percentile of the standard normal distribution. The chief advantage of Wistort's method is that it avoids the need for fixture units and is readily extended to other types of fixtures, provided suitable values for p and q are available.

The normal approximation used in Wistort's method works best when the dimensionless term $H\left(n,p\right) = \sum_{k=1}^{K} n_k p_k \geq 5$. This term is coined the *Hunter Number* and it represents the expected number of simultaneous busy fixtures in the building during the peak period. In the context of residential plumbing, p_k values tend to be small (average $p \approx 0.03$) so the total number of fixtures must be relatively large (e.g., $\Sigma n \geq 150$) to satisfy the condition $H(n,p) \geq 5$. Consequently, Wistort's method will be suitable for estimating demands at buildings with many residential units, but it is not appropriate for single family homes.

4.3 Modified Wistort method

Single family homes have few occupants and few fixtures. In these cases, idle fixtures are the norm even during the period of peak water use. In a building with K different and independent fixture groups, the probability, P_0, that all fixtures are idle (i.e., zero demand) is,

$$P_0 = \prod_{k=1}^{K} \left(1-p_k\right)^{n_k} \approx \exp\left[-H\left(n,p\right)\right] \qquad [3]$$

For example, in a 2.5 bath home a typical value for the *Hunter Number* is $H(n,p) = 0.30$. Equation [3] gives $P_0 \approx 0.74$. This implies that the home draws water about 26 percent of the time during the peak demand period, otherwise the entire home is idle. With the conventional binomial distribution, the high probability of idle fixtures in a single-family home exerts a strong "downward pull" on the mean number of busy fixtures which, in turn, leads to a significant low bias in the estimated peak flow.

Plumbing systems are not designed for "zero flow" and so this condition should not influence the size of a plumbing system. Therefore, a *zero-truncated binomial distribution* (ZTBD) was proposed to describe the conditional probability distribution of busy fixtures in any building, including single family homes. Assuming that a normal approximation can be used to describe the upper tail of the ZTBD, the expression for the 99th percentile of the demand in a building with K different fixture groups is,

$$Q_{0.99} = \frac{1}{1-P_0}\left[\sum_{k=1}^{K} n_k p_k q_k + \left[\left(1+P_0\right) z_{0.99}\right]\sqrt{\left[\left(1-P_0\right)\sum_{k=1}^{K} n_k p_k \left(1-p_k\right) q_k^2\right] - P_0\left(\sum_{k=1}^{K} n_k p_k q_k\right)^2}\right] \qquad [4]$$

When $H\left(n,p\right) > 5,\ P_0 \to 0$ and Equation [4] reduces to Equation [2]. For this reason, the ZTBD approach is called the "Modified Wistort Method" (MWM). In practice, the transition from Equation [4] to [2] typically requires at least 100-150 fixtures in the building. Results of Monte Carlo computer runs to simulate indoor residential water use indicate that MWM works well when the Hunter Number $H(n, p) \geq 1.25$. A nice feature of MWM is that when *n*=1 and *k*=1 (last fixture on the water supply line in the building) Equation [4] simplifies to $Q_{0.99} = q$. The design flow is simply the nominal demand of the final fixture.

4.4 Exhaustive enumeration

Hunter and Wistort focused on the 99th percentile of the demand expected during the peak period in a building. With today's computational tools it is possible to numerically generate the entire probability distribution of the water demands at any point and any time in the water supply system of a building. "Exhaustive Enumeration" involves identifying and ranking all possible demand events for a given premise plumbing configuration.

While simple in principle, exhaustive enumeration may not yet always be practical. Due to combinatorial explosion, the size of the problem grows geometrically. A typical single family home with 12 independent fixtures will generate 2^{12} = 4,096 demand outcomes. While enumeration is helpful, it is restricted to scenarios where the total fixture count *n* is less than or equal to 30. Additional examples featuring exhaustive enumeration can be found in Buchberger *et al* (2012) and Omaghomi and Buchberger (2014).

4.5 q1+q3 method

During development of the exhaustive enumeration approach, it was observed that certain combinations of fixtures consistently tended to yield the 99th percentile design demand, especially along branch lines at the household level. This led to the "q1+q3" method which works as follows: Using recommended fixture demand values, rank all fixtures along a branch line in descending order. For instance, the fixture with the largest demand receives rank of 1 (q1), the fixture with the second largest demand receives rank of 2 (q2), and so on until all fixtures on a designated branch are ranked. The q1+q3 method simply adds the demands for the rank 1 and the rank 3 fixtures to obtain an expedient and reasonably good estimate of the 99th percentile demand, often identical to the value generated by a full exhaustive enumeration.

To demonstrate, consider a clothes washer with its demand of q1=3.5 gpm, a kitchen faucet with its demand of q2=2.2 gpm, a laundry faucet with its demand of q3=2.0 gpm and a dishwasher with its demand of q4=1.3 gpm. According to the q1+q3 method, the design demand is 3.5 gpm + 2.0 gpm = 5.5 gpm, produced by simultaneous use of the clothes washer and the laundry faucet. This agrees with the result for a busy time exhaustive enumeration. Excellent results with the q1+q3 method have been obtained for *n* approaching 10 or 15 fixtures, provided the overall average *p*-value is not too high.

If a branch has *n*=2 fixtures, then q3 = 0 and the design demand is q1, that is, the greater of the two fixture demands. Finally, if a branch is supplying only one fixture, then the design demand is q1.

4.6 Method summary

Various methods for estimating peak demands in buildings were examined, developed and tested. The problem is challenging because the solution strategy changes with the spatial scale of the plumbing system. On a large scale [i.e., total fixture count, *n* > 200], individual fixtures do not appreciably affect the performance of the water supply system. As a consequence, solutions like the Wistort method using well-established continuous probability distributions can be applied readily to estimate demands. On a small scale [*n* < 20], individual fixtures exert a significant impact on system behavior. At this level, solutions like exhaustive enumeration or q1+q3 are needed as they account for discrete fixtures in premise plumbing.
Table 6 summarizes the four main methods investigated for estimating peak demands in residential buildings. The applicability of each method corresponds generally to a region [A, B, C, D] in the *n-p* plane of Figure 1. The separation between regions [B] and [C] is not crisp and is restricted by fixture count. These regions are delineated by diagonal lines that represent a constant *Hunter Number*.

Table 6 Methods to estimate peak demands in residential buildings with efficient fixtures

Region	Spatial Scale	Range for $H(n,p)$	Method
A	Small	$0 < H(n,p) < 0.25$	Exhaustive Enumeration; q1+q3
B	Small to Intermediate	$0.25 \leq H(n,p) < 1.25$	Exhaustive Enumeration
C	Intermediate to Large	$1.25 \leq H(n,p) < 5.00$	Modified Wistort Method
D	Large	$H(n,p) \geq 5.00$	Wistort Method

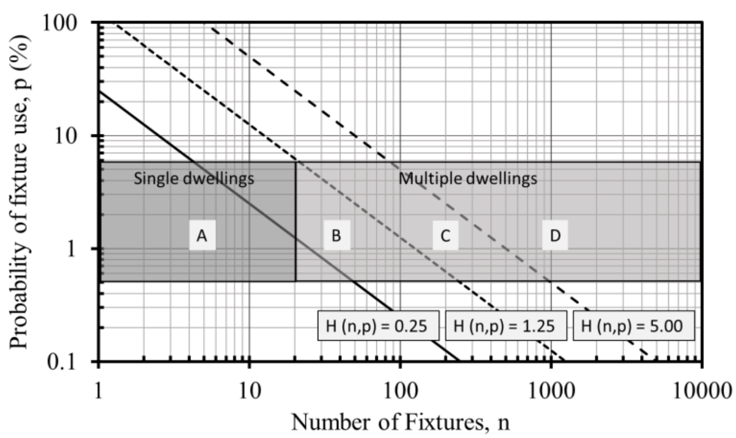

Figure 1 Approximate Regions of Applicability

5 Water demand calculator [WDC]

Aside from the q1+q3 method for single family households, the other three approaches for estimating peak water demand in a building are cumbersome to use, even when the designer knows all the required input parameters (i.e., *n*, *p*, *q*) for each fixture group. To encourage proper use and promote uniform application of these proposed new approaches for estimating peak indoor demands, a Water Demand Calculator (WDC) was developed. The WDC is a downloadable Microsoft Office Excel spreadsheet.

A screen shot of the template for the WDC is shown in Figure 2. In this template, the WDC has white-shaded cells and gray-shaded cells. The values in the gray cells are derived from a national survey of indoor water use at homes with efficient fixtures. These values cannot be changed. The white-shaded cells accept input from the designer. For instance, fixture counts from four fixtures are entered in Column [B]; the corresponding recommended fixture flow rates listed in Table 5 are already provided in Column [D]. The flow rates in Column [D] may be reduced only if the manufacturer specifies a lower flow rate for the fixture. Column [E] establishes the upper limits for the flow rates entered into Column [D]. Clicking the ***Run Water Demand Calculator*** button gives 5.5 gpm as the estimated indoor water demand. This result agrees with the exhaustive enumeration result for the 99th percentile and appears in the lower left corner box of the WDC in Figure 2.

	[A] FIXTURE	[B] ENTER NUMBER OF FIXTURES	[C] PROBABILITY OF USE (%)	[D] ENTER FIXTURE FLOW RATE (GPM)	[E] MAXIMUM RECOMMENDED FIXTURE FLOW RATE (GPM)
1	Bar Sink	0	2.0	1.5	1.5
2	Bathtub	0	1.0	5.5	5.5
3	Bidet	0	1.0	2.0	2.0
4	Clothes Washer	1	5.5	3.5	3.5
5	Combination Bath/Shower	0	5.5	5.5	5.5
6	Dishwasher	1	0.5	1.3	1.3
7	Kitchen Faucet	1	2.0	2.2	2.2
8	Laundry Faucet	1	2.0	2.0	2.0
9	Lavatory Faucet	0	2.0	1.5	1.5
10	Shower, per head	0	4.5	2.0	2.0
11	Water Closet, 1.28 GPF Gravity Tank	0	1.0	3.0	3.0
12	Other Fixture 1	0	0.0	0.0	6.0
13	Other Fixture 2	0	0.0	0.0	6.0
14	Other Fixture 3	0	0.0	0.0	6.0

Total Number of Fixtures 4

99th PERCENTILE DEMAND FLOW = 5.5 GPM

RESET

RUN WATER DEMAND CALCULATOR

Figure 2 Screen shot of the input/output template for the Water Demand Calculator

6 Example with single and multi-family dwelling

Several examples using the WDC are presented in Tables 7 and 8 for estimating peak cold water and hot water demand, respectively. Both Tables include four scenarios ranging from a single-family dwelling [region A in Figure 1] to a multi-family building with 27 identical units [region D in Figure 1]. The estimated 99th percentile of the cold-water demand exceeds the 99th percentile for the hot water demand by an average of about 4 percent. The slightly higher demand for cold water is due to the fact that there are 10 cold water fixtures, but only 8 hot water fixtures in this example. The peak demands for the cold water case would be used to size the main cold water only branch. For comparison, q1+q3 gives a design demand of 9.0 gpm for the cold-water branch. The WDC checks q1+q3 against exhaustive enumeration and selects the greater result (in this case 11.0 gpm for both the cold-water branch and the hot water branch).

Table 7 WDC Example Cold Water Demand for Single and Multi-Family Units

Fixture	*p*-value	*q*-value (gpm)	Number of Each Fixture, *n*			
			1 Unit	3 Units	9 Units	27 Units
Clothes washer	0.055	3.5	1	3	9	27
Combo tub/shower	0.055	5.5	2	6	18	54
Dishwasher	0.005	1.3	0	0	0	0
Kitchen faucet	0.020	2.2	1	3	9	27
Lavatory faucet	0.020	1.5	3	9	27	81
Water closet	0.010	3.0	3	9	27	81
		Total **Cold Fixtures**	10	30	90	270
		Region on Figure 2	A	B	C	D
Dimensionless Hunter Number, *H*(*n*,*p*)			0.275	0.825	2.475	7.425
Prob[zero demand during peak period]			0.760	0.438	0.084	0.001
99th Percentile Demand $Q_{0.99}$ (gpm)			**11.0**	**15.5**	**24.6**	**52.6**

Table 11 WDC Example Hot Water Demand for Single and Multi-Family Units

Fixture	*p*-value	*q*-value (gpm)	Number of Each Fixture, *n*			
			1 Unit	3 Units	9 Units	27 Units
Clothes washer	0.055	3.5	1	3	9	27
Combo tub/shower	0.055	5.5	2	6	18	54
Dishwasher	0.005	1.3	1	3	9	27
Kitchen faucet	0.020	2.2	1	3	9	27
Lavatory faucet	0.020	1.5	3	9	27	81
Water closet	0.010	3.0	0	0	0	0
		Total **Hot Fixtures**	8	24	72	216
		Region on Figure 2	A	B	C	D
Dimensionless Hunter Number, *H*(*n*,*p*)			0.25	0.75	2.25	6.75
Prob[zero demand during peak period]			0.779	0.472	0.105	0.001
99th Percentile Demand $Q_{0.99}$ (gpm)			**11.0**	**14.5**	**23.7**	**49.6**

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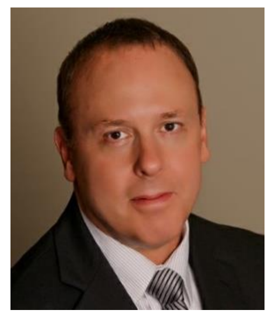
8 Presentation of Authors

Daniel Cole is the Technical Services Manager at International Association of Plumbing and Mechanical Officials (IAPMO). He is a licensed Journeyman Plumber in the State of Illinois and member of the American Society of Plumbing Engineers (ASPE). He has published several articles on Hunter's curve and the fixture unit methodology. His research focus is on the plumbing investigations performed at the National Bureau of Standards (now NIST) with a particular interest in the work of Roy B. Hunter. He also has a focus on promoting water efficiency standards for the built environment.



Steven Buchberger, Ph.D., is Professor and Head of the Department of Civil Engineering, Architectural Engineering and Construction Management at the University of Cincinnati. He is a registered professional engineer in Colorado. His teaching and research focus on reliability-based design in water resources and urban hydrology. Professor Buchberger has advised 60 graduate students at UC. He served as Associate Editor of *ASCE Journal of Water Resources Planning and Management* for ten years and was the Chief Editor of two special issues on Water Distribution Systems Analysis.

Toritseju Omaghomi is a PhD student in Environmental Engineering at the University of Cincinnati. Her Masters in Environmental Engineering was an analysis of methods for estimating water demand in buildings and a Bachelor's degree in Agricultural Engineering focused on soil and water conservation. Her research interest includes water conservation, modelling and integrated engineering of water resource at a regional and household scale. Her current research involves sustainability concerns associated water conservation measures implemented in buildings and the transition to a sustainable design method for water supply in buildings.

Timothy Wolfe is a registered professional engineer and has worked as a building design consultant engineer since 2004. He is currently a senior engineer at TRC Worldwide Engineering – MEP, LLC., and is responsible for managing the plumbing department across four US offices and two international offices. Tim has been a member of ASPE since 2011 and is actively involved with the Central Indiana Chapter including serving on the board as the Vice President, Legislation officer from 2013-2015.

Jason Hewitt is a professional engineer with 9 years' experience designing high rise building along the west coast. He currently works for CB Engineers as the Seattle office manager. He is a founding member of the Seattle ASPE Chapter and served on the board as Vice President Technical and Legislative from 2009 to 2016.

C3 – Customized design of residential grey water and rainwater systems using SIMDEUM, a stochastic demand model

See A0-Keynote-10 Using a stochastic demand model to design cold and hot water installations inside buildings.

C4 - Estimation of water supply loads for the company cafeteria, hot-water service rooms and restrooms in an office building

Saburo Murakawa (1), Daisuke Ikeda (2), Akihiro Doi (3)
1. muraka@hiroshima-u.ac.jp, saburo.murakawa@gmail.com
2. d.ikeda@socon.co.jp
3. doi.akihiro@takenaka.co.jp
1. Hiroshima University
2. Sogo Setsubi Consulting
3. Takenaka Corporation

Abstract

The new dynamic calculation method of water supply loads in the buildings developed by authors has been advanced for the verification of accuracy in the committee of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan: SHASE. The calculation program can be called MSWC: Murakawa's Simulation for Water Consumption. It is useful to design the plumbing systems and to do management in the buildings. These calculation results such as instantaneous flow rates, hourly loads and daily loads are processed statistically and offered for the plumbing designers. In the last year's 42nd CIB-W062 symposium, the authors showed the calculation results of water consumption of the toilet bowls in an office building: T-building.

In this paper, the authors show the calculation results of water supply loads for the company cafeteria, hot water service rooms and restrooms where tap water is supplied in the same T-building. As for the calculation in the cafeteria, unit model is set up as the whole based on the hourly measurement data by BEMS in T-building and the past research results. The models for other water supply systems are set up by the behaviour of individual employee's water usage. As for the calculation results in each use, the average values of 5, 10 and 60 seconds according to the statistics of each failure factor are compared as the instantaneous flow rates.

Keywords

Office building; Company cafeteria; Hot-water service room; Washbasin in restroom; Water supply load; Simulation technique

1 Introduction

The authors have developed the dynamic calculation method for cold and hot water supply loads based on the data of water uses in the time series throughout the day by using a personal computer. The calculation method has been reported at the international symposium of CIB-W062 [1~7, 10. 11]. Now, the loads such as instantaneous flow rates, hourly and daily water supply consumption can be easily calculated by the developed simulation program that is called MSWC.

At the 42nd symposium of CIB-W062, the authors showed the water consumption that had been measured at each water usage by BEMS (Building Energy Measurement System) in an office building: T-building, and set up the models to estimate the water supply loads based on the analysis of hourly and daily data measured throughout the year. And, the calculated results using MSWC program were compared with the measured values in toilet flushing systems, and the accuracy was confirmed [12].

In this paper, for the same T-building, the authors show the calculation results of water supply loads for company cafeteria, hot water service rooms and restrooms where tap water is supplied in the office building. As for the calculation in the cafeteria, one unit model is set up as the whole based on the hourly measurement data by BEMS in T- building and the past research results. The models for other water supply systems are set up by the behaviour of individual employee’s water usage. Regarding the instantaneous flow rates in each use, the average values of 5, 10 and 60 seconds according to the statistics of each failure factor are discussed.

2 Outline of the subject building

The outline of T-building is shown in Table 1. T-building is an own office building located in Tokyo. The total floor area is 29,747m^2 which has a convenience store, company cafeteria and coffee shop for the employees. The employed enrollment is assumed about 1,900 people, and the ratio of male and female is about 4:1. The personnel density for the office area is about 0.07 [people/m^2], which is lower than 0.1~0.2 [people/m^2] that is commonly used as a design reference. The total number of washbasin in the restrooms is 77 pieces.

Figure 1 shows the water supply systems and measurement points of water consumption. The water supply system is a receiving tank and booster pumps. As the source of water for toilet flushing system, tap water and rain water are used. The tap water is also sent to the other water supply systems by booster pumps. The water consumption in the employee’s cafeteria was measured at the point of M9 and M10 is analyzed.

3 Water consumption of tap water

Table 2 shows the statistical values of water consumption per day and per people in each water supply system. The values were analyzed with the cumulative value for 365 days per year, and 240 days on weekdays except Saturdays, Sundays and holidays which are working days of the building. In case of tap water consumption in the office, the values are obtained from recorded data: M1- M2 - (M4~M7) - (M8~M11).

Table 1 - Overview of the subject building

Building name	T-building	
Building application	Office	
Ownership form	Own Building	
Completion	October 2014	
Total floor area	29,747	m^2
Office area	24,269	m^2
Ratio of effective office area	81.6	%
Number of seats	2,347	seats
Employed enrollment	1,900	people
	(assumed value)	
Gender ratio	Male : Female = 4 : 1	
Construction	S and CFT structure	
Scale	7th Floor above ground, penthouse second floor	
Water supply system	Receiving tank and booster pomp system, Rainwater harvesting system	
Number of plumbing fixtures	Male's water closet	: 41
	Uriral	: 47
	Female's water closet (with device of imitative sounds)	: 39
	Washbasin	: 56
	Small washbasin for brushing teeth	: 21
	Sink for cleaning	: 16

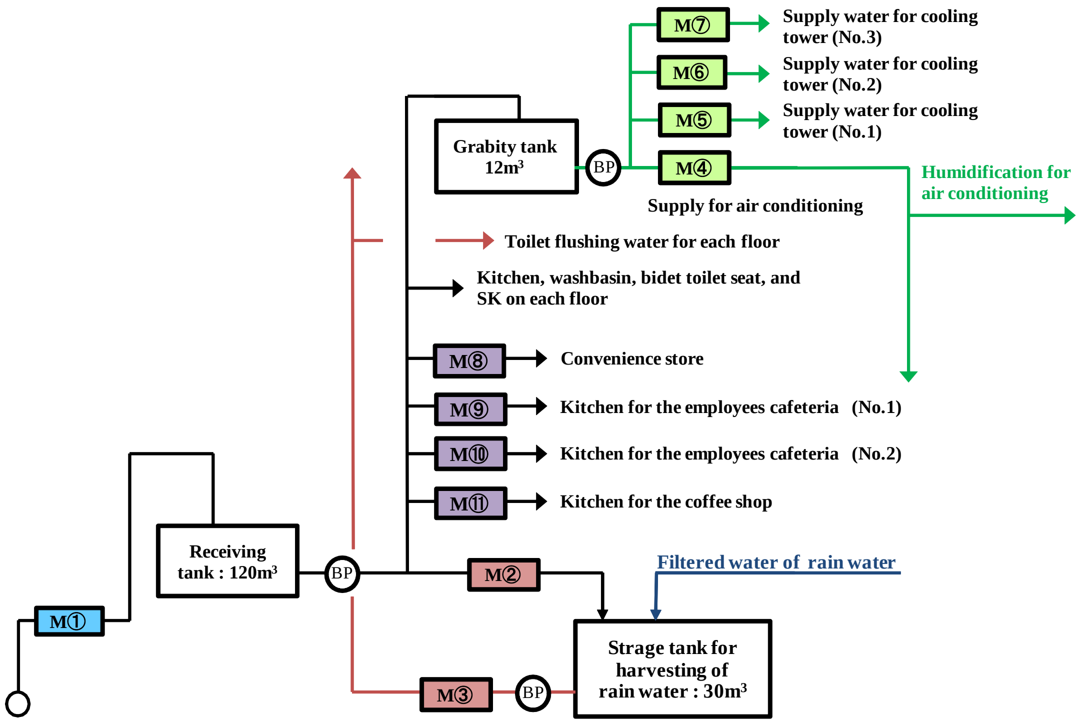


Figure 1 – Water supply systems and measurement points

The average water consumption of the building as the whole is 79.15 [m^3/day] and 41.66 [L/people/day] for 365 days, and 112.69 [m^3/day] and 59.31 [L/people/day] for 240 days. The value for the latter 240 days corresponds the lowest value excluding the employee's cafeteria which is conventionally used in the practical design: 60~100 [L/people/day]. The average consumption of tap water is 13.79 [m^3/day] and 7.26 [L/people/day] for 365 days, and 19.80 [m^3/day] and 10.42 [L/people/day] for 240 days. The above values of tap water include the consumption in the hot-water service rooms, washbasin and warm water washing toilet seat, cleaning water and sprinkling water excluding the kitchen system, air conditioning system and make-up water of the rainwater system.

Table 2 – Statistics of water consumption per unit in each system

		in the office						systems			Tap water			Rain water					
		Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value
Daily water consumption (m^3/day)	Annual value (365 days)	85.99	40.79	13.79	34.01	27.00	15.20	58.01	36.80	10.87	63.99	59.00	34.24	47.99	20.01	5.05	169.99	154.00	79.15
	Value of working day (240 days)	69.01	43.00	19.80	34.01	28.01	22.61	58.01	40.05	12.90	63.99	60.06	50.69	47.99	25.99	6.69	169.99	157.00	112.69
Water consumption per people (L/people/day)	Annual value (365 days)	45.26	21.47	7.26	17.90	14.21	8.00	30.53	19.37	5.72	33.68	31.05	18.02	25.26	10.53	2.66	89.47	81.05	41.66
	Value of working day (240 days)	36.32	22.63	10.42	17.90	14.74	11.90	30.53	21.08	6.79	33.68	31.61	26.68	25.26	13.68	3.52	89.47	82.63	59.31

4 Estimation of tap water consumption for washbasin in the restrooms and hot-water service rooms

4.1 Setting up simulation models

The estimation of water supply loads for washbasin in the restrooms and hot-water service rooms is done by MSWC program in the same way as the toilet flushing system of T-building shown at the 42nd CIB-W062 symposium.

Figure 2 shows the model of occupied ratio to the number of workers in T-building. The ratios in the time zone from 7 o'clock to 8 o'clock were adjusted based on the standard model that was shown in the previous studies [6, 10], because the start time of work in T-building is about 30 minutes earlier than the general offices.

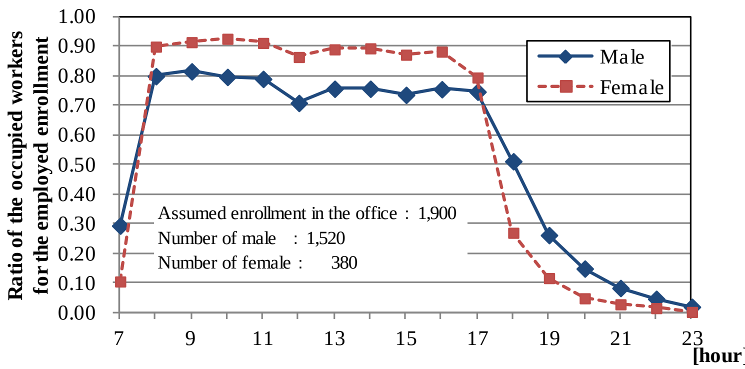


Figure 2 – Model of the occupied ratio of workers for the employed enrolment

washbasin in the restrooms and hot-water service rooms, respectively. The frequencies of water usage of washbasin were adjusted by multiplying the values of the previous reports [6,10] by 0.9 to 1.25 times, which is the same way as treated in the toilet flushing system of T-building.

As for the system in hot-water service rooms, in the previous papers, we set up the simulation models which were different values and distributions for the duration time of hot-cold water discharge in the segmented time zones. However, in this paper, the calculation models for discharge flow rates and distributions were set based on the values at the time zone from 7 o'clock to 8 o'clock, and the frequencies of other time zones were corrected by the reference values. In addition to these corrections, since the uses of refresh corners and hot-water service rooms were found to be higher than those of other general offices, the frequencies of water usage in each hourly time zone were multiplied by 1.2 times to the previously reported values.

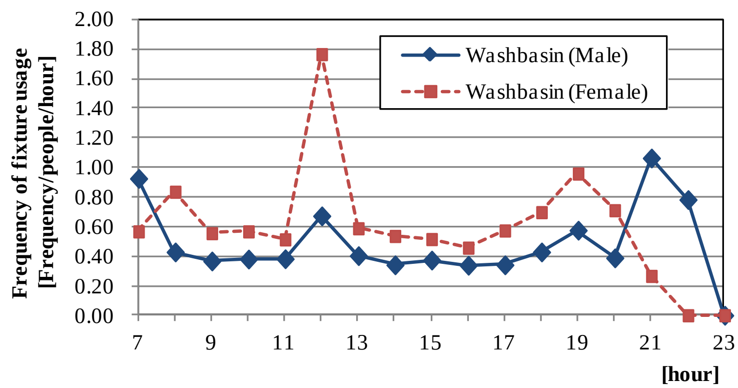


Figure 3 – Models of hourly frequencies of washbasin usage in the restrooms

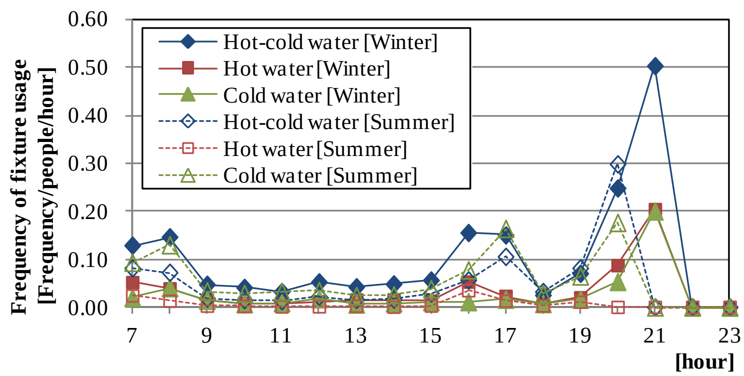


Figure 4 – Models of hourly frequencies of water usage in the hot-water service rooms

Table 3 shows the simulation models of each system installed in the hot-water service rooms and restrooms. In case of the hot-water service rooms, the models were set separately for summer and winter.

Table 3 – Simulation models to calculate the tap water supply loads

		Washbasin		Hot-water service room (summer)			Hot-water service room (winter)		
		Male	Female	Hot-cold water	Hot water	Cold water	Hot-cold water	Hot water	Cold water
Arrival model	Arrival interval distribution	Exponentioal distribution							
	Arrival ratio [people/min]	Setting in each time zone							
	Number of fixture	40	37	14	14	14	14	14	14
Occupancy model	Duration time of occupancy [sec]	12	17	45	16	14	35	10	5
	Distribution	Hyp.2	Hyp.2	Exp.	Exp.	Hyp.2	Hyp.2	Hyp.3	Hyp.2
Water volume model	Duration time of water discharge [sec]	6	11	45	16	14	35	10	5
	Distribution	Erl.3	Erl.3	Exp.	Exp.	Hyp.2	Hyp.2	Hyp.3	Hyp.2
	Flow rate [L/min]	5	5	10	8	10	10	8	10
	Distribution	Erl.10	Erl.10	Erl.3	Erl.4	Erl.3	Erl.3	Erl.4	Erl.3
Fixture operation model	Frequency of fixture operation	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

4.2 Calculation results of the water supply loads by simulation technique

4.2.1 Instantaneous water supply loads

In order to grasp the fluctuation of instantaneous flow rates, the sample in which the water consumption per day is the median value of the whole was selected from 100 simulation trials. Figure 5 and Figure 6 show the examples of washbasin in the restrooms at the time zone of 12 o'clock and hot-water service rooms at the time zone of 8 o'clock, respectively.

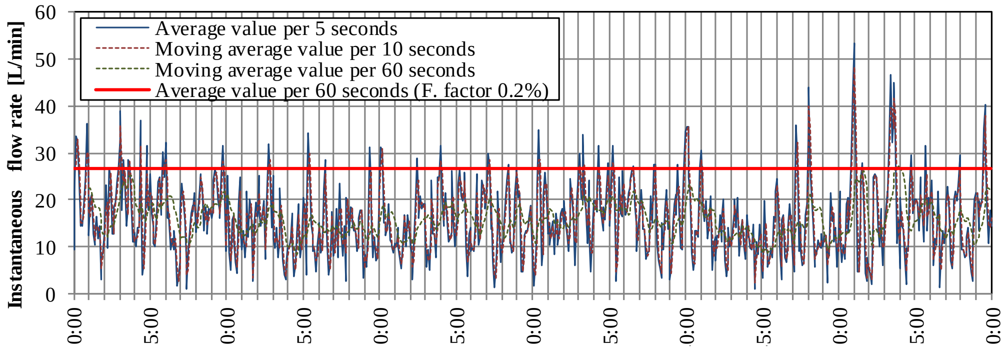


Figure 5 – Example of instantaneous flow rates for washbasin in the restrooms

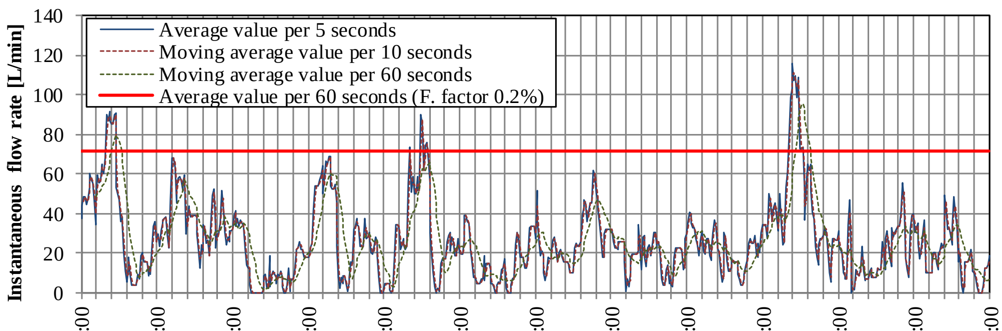


Figure 6 – Example of instantaneous flow rates for hot-water service rooms

The average values every 5 seconds, moving average values every 10 seconds and 60 seconds based on the 5 seconds value are shown in each figure. In addition, the 60 seconds value as the failure factor 0.2% for simulation of 100 trials is shown in each figure.

In case of the 5 second values for washbasin in the restrooms, a relatively high instantaneous load occurs at interval of 1 to 3 minutes. The peak flow rate is about 25 [L/min] to 50 [L/min]. Since the duration time of water discharge per one time is short, the peak flow continues for about 5 to 10 seconds, and then decreases. There is no big difference between the 5 seconds average value and the moving average value of 10 second. However, the fluctuation of moving average value of 60 seconds is averaged and shows the lowered values.

In case of the hot-water service rooms, the 5 seconds average value shows the peak value of 60 to 110 [L/min], occurring at relatively long interval of 5 to 20 minutes. Because the duration time of water discharge per one time is long, there is not much difference between the 5 seconds average value and the 10 and 60 seconds moving average value.

As for the instantaneous water supply loads, Table 4 shows the calculation results of the maximum and each failure factor for male, female and the whole washbasin in the restrooms. The analysis results are shown at the time zone of 12 o'clock when the peak value appears in the day. Similarly, Table 5 shows the calculation results of the hot-water service rooms in summer and winter, which are shown at the time zone of 17 o'clock and 8 o'clock, respectively.

Table 4 – Statistics of instantaneous water supply loads for washbasin in the restrooms

		Failure factor						
		Maximum	0.1%	0.2%	1.0%	5.0%	10.0%	50.0%
Washbasin (for male) [L/min]	Average value per 5 seconds	37.1	22.1	21.6	19.1	14.8	12.5	5.3
	Average value per 10 seconds	33.5	22.9	21.6	17.9	13.6	11.5	5.5
	Average value per 60 seconds	15.0	12.6	11.9	11.0	9.4	8.6	6.0
Washbasin (for female) [L/min]	Average value per 5 seconds	43.8	34.2	32.1	26.6	20.4	17.2	8.2
	Average value per 10 seconds	43.7	32.1	29.8	25.2	19.3	16.5	8.3
	Average value per 60 seconds	21.0	19.3	18.7	16.7	14.2	12.9	8.7
Washbasin (whole) [L/min]	Average value per 5 seconds	60.5	45.5	42.7	36.3	29.1	25.4	14.3
	Average value per 10 seconds	54.6	42.3	39.5	33.9	27.4	24.2	14.4
	Average value per 60 seconds	29.8	27.3	26.8	24.3	21.2	19.8	14.8

Table 5 – Statistics of instantaneous water supply loads for hot-water service rooms

		Failure factor						
		Maximum	0.1%	0.2%	1.0%	5.0%	10.0%	50.0%
Hot-water service room（in summer）[L/min]	Average value per 5 seconds	135.4	103.0	96.1	78.6	61.4	52.9	26.4
	Average value per 10 seconds	128.5	100.2	93.4	77.2	60.4	52.1	26.3
	Average value per 60 seconds	102.0	84.8	81.0	66.6	53.5	47.3	26.8
Hot-water service room（in winter）[L/min]	Average value per 5 seconds	129.9	94.3	88.1	72.8	55.3	47.0	22.3
	Average value per 10 seconds	128.0	91.8	85.8	71.7	54.4	46.2	22.4
	Average value per 60 seconds	96.1	75.5	71.7	63.3	48.8	42.0	22.8

For the instantaneous loads of washbasin system, there is no big difference between the 5 seconds value and the 10 seconds value. However, the 60 seconds value is averaged, and the maximum value is almost same as the failure factor 5% value of 5 seconds value. The calculation values of female washbasin show larger than the values of male washbasin, even though the number of fixtures is small, because the duration time of occupancy and water discharge is slightly longer than those of male.

Even in the hot-water service rooms, like washbasin in the restrooms, there is no big difference between the 5 seconds value and 10 seconds value. The maximum value of 60 seconds approximates to the failure factor 0.1% value of the 5 seconds value. The difference is small compared to the washbasin system.

4.2.2 Hourly water supply loads

Figure 7 and Figure 8 show the hourly water supply loads for washbasin in the restrooms and hot-water service rooms, respectively. In case of the washbasin system, the failure factor 50% value at the time zone of 8 o'clock and the peak value at the time zone of 12 o'clock show about 530 [L/hour] and 900 [L/hour], respectively. At other working hours, the hourly values show about 400 [L/hour].

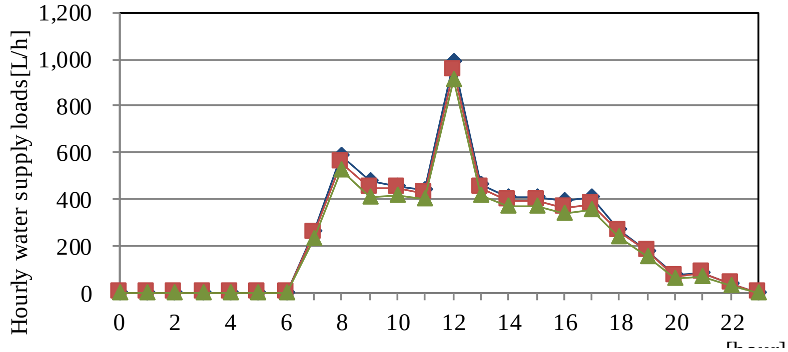


Figure 7 - Calculation results of hourly water supply loads for washbasin system

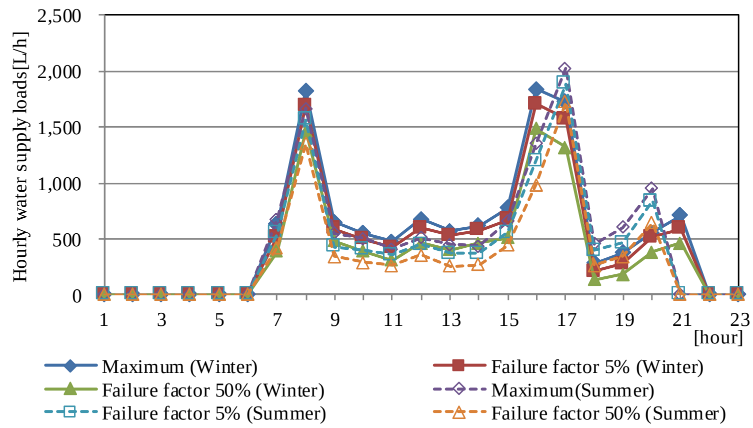


Figure 8 - Calculation results of hourly water supply loads for hot-water service rooms

In case of the hot-water service rooms in winter, the failure factor 50% values at the peak time zones of 8 o'clock and 16 o'clock show about 1,500 [L/hour], and the average values for other working hours show about values of 400 [L/hour] to 500 [L/hour]. On summer season, the failure factor 50% value at peak time zone of 17 o'clock shows about 1,700 [L/hour].

4.2.3 Discussion for the calculation results of water supply loads

Table 6 shows the water supply loads in each system mentioned above, including daily loads. As for the instantaneous water supply loads, the whole value of washbasin system shows 39.5 [L/min], and the values for hot-water service rooms in summer and winter show 93.4 [L/min] and 86.0 [L/min], respectively. The values are slightly larger in summer. As for the hourly loads, the failure factor 50% value in washbasin system shows 908 [L/min]. The values for hot-water service rooms in summer and winter show 1,726 [L/hour] and 1,486 [L/hour], respectively.

Table 6 Calculation results of water supply loads in each system

		Washbasin			Hot-water service room	
		Male	Female	Whole	Summer	Winter
Instantaeous water supply loads [L/min] Average value of 10 seconds	F. factor 0.2%	21.6	29.8	39.5	93.4	86.0
Hourly water supply loads [L/hour]	Maximum	406	583	989	2,029	1,841
	F. factor 5%	391	575	951	1,887	1,708
	F. factor 50%	366	536	908	1,726	1,486
Daily water supply loads [m^3/day]	Maximum	3.1	2.4	5.4	8.6	9.6
	F. factor 5%	3.1	2.3	5.4	8.5	9.5
	F. factor 50%	3.0	2.3	5.3	8.0	8.9

When comparing these calculated values with the values according to the following formula used as a conventional calculation method, the following can be said.

Instantaneous load [L/min] = Average expected volume [L/hour] / 60 x (3~4)

The estimated load for the whole washbasin system is slightly smaller than the calculated value by the formula mentioned above. However, the estimated load for the hot-water service rooms is roughly equivalent to the calculated value.

As for the estimated daily loads, the total load of washbasin system and hot-water service rooms is 13.3 ~ 14.2 [m^3/day]. The measurement data by BEMS show about 13.8 ~ 19.8 [m^3/day]. Since the measurement values include the consumption for cleaning system for office and water spraying system for planting, it seems that the results of simulation are showing reasonable values to represent the actual situation.

5 Estimation of tap water consumption for the company cafeteria

5.1 Setting up simulation models for the company cafeteria

When we use the simulation program: MSWC, it is necessary to grasp the frequency of water usage every hour in each system throughout the day. In case of commercial kitchen, it is difficult to grasp the water usage of individual kitchen appliances. Therefore, as with previous paper targeting restaurants [3], this study builds a model that uses water as one unit for the whole kitchen. The frequency of water usage every hour is calculated by BEMS data as follows:

5.1.1 Water consumption in the company cafeteria

The average value of water consumption in the kitchen system calculated from the typical week of each month on weekdays in 2013 is about 21.9 [m^3/day]. The average value per day for each month is in the range of 17.0 to 27.3 [m^3/day]. The number of meals based on the survey results has been 800 to 1,000 meals. If the annual average meal number is 800 meals and the average meal number in July is 900 meals, the water consumption will be 27.4 [L/meal/day] and 26.0

[L/meal/day], respectively. These values are roughly comparable to the investigated values for company cafeterias of office buildings in the past paper: 24.2 ~ 27.0 [L/meal/day].

Figure 9 shows the water consumption per day for the typical month's week. The water consumption on weekdays is roughly 20 ~ 25 [m^3/day]. Figure 10 shows hourly water consumption in the representative week of July. In the 5 days of weekdays, the water consumption of 1~2 [m^3/hour] is seen at the time zone of 6 o'clock, and the peak values of 4 ~ 5 [m^3/hour] are seen at the time zone of 12 o'clock and 13 o'clock of lunch time, and then there is a sharp decline trend.

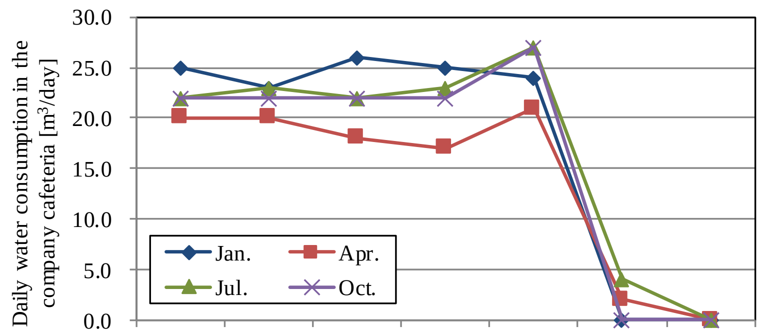


Figure 9 – Measurement results of water consumption per day

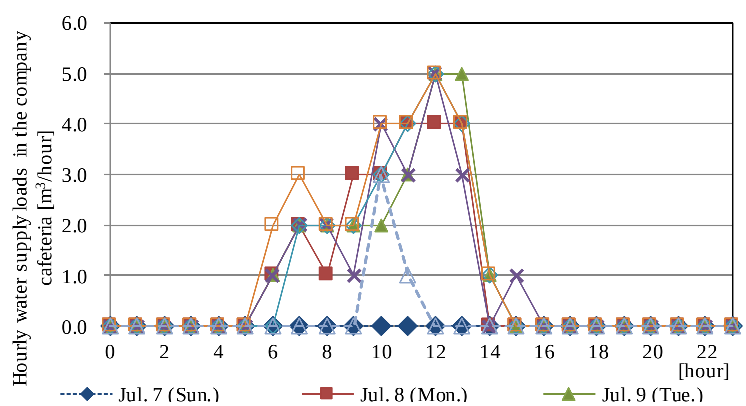


Figure 10 – Measurement results of hourly water consumption

5.1.2 Setting up simulation models

Table 7 shows the simulation models. The average values and distribution of water uses were set from the investigated results in the authors' past research. In this paper, the average discharge flow rates and duration time for the whole kitchen as one unit were set up in three kinds of combination, which consist of 30 [L/min] and 60 seconds: A30, 25 [L/min] and 72 seconds: B25, 20 [L/min] and 90 seconds: C20, as the same amount of water consumption per one frequency.

Table 7 – Simulation models to calculate water supply loads for the cafeteria

		Company cafeteria (T-building)		
		A30	B25	C20
Water volume model	Duration time of water discharge [sec]	60	72	90
	Distribution	Hyp.20	Hyp.20	Hyp.20
	Flow rate [L/min]	30	25	20
	Distribution	Exp.	Exp.	Exp.
Frequency of fixture operation	Frequency per hour	Figure 11		
	Frequency per day (July)	780	780	780
	Frequency per day (Annual)	729.3	729.3	729.3

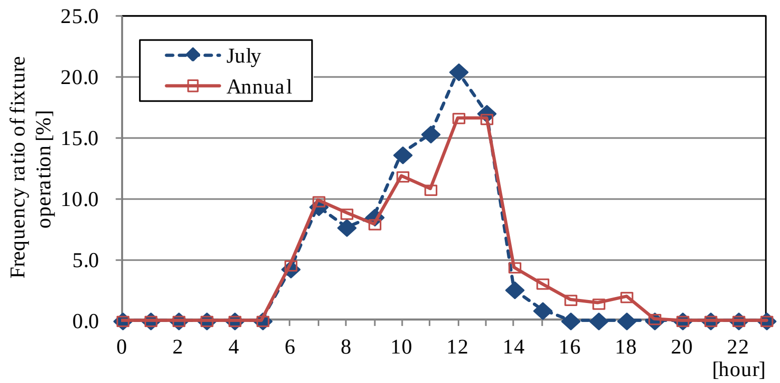


Figure 11 – Simulation models of hourly frequencies of water usage

The hourly frequencies of water usage as one unit were calculated by dividing the water consumption per hour obtained from BEMS data by the water consumption amount per one time of fixture operation. As the two patterns of hourly frequency for simulation, the frequencies were calculated by the average values of weekdays on July and average annual values. Figure 11 shows the model of hourly frequency of water usage as the percentage of total frequency per day.

5.2 Calculation results

5.2.1 Instantaneous water supply loads

Table 8 shows the calculated instantaneous water supply loads at the time zone of 12 o'clock showing the peak as the values of maximum and each failure facto based on the three kinds of simulation models. As for the 5 seconds average value, the results of each failure factor excluding the values of 50% show the maximum, but there is no big difference from the 10 seconds average value. However, as the 60 seconds value is averaged, it becomes smaller than the other values of the 5 seconds and 10 seconds. Among the three kinds of calculation models, the values from maximum to failure factor 10 % for the case of A30 are larger than those of the case of A25 and A20, because the flow rate per time for the case of A30 is larger than those of the other cases. However, these differences become smaller as the value of the failure factor increases.

Table 8 – Statistics of instantaneous water supply loads for the three cases

		Failure factor						
		Maximum	0.1%	0.2%	1.0%	5.0%	10.0%	50.0%
A30	Average value per 5 seconds	486.9	361.3	329.5	269.6	197.8	164.4	68.0
	Average value per 10 seconds	473.6	352.8	326.4	267.3	196.3	162.9	68.1
	Average value per 60 seconds	370.0	314.8	289.5	241.2	181.6	151.8	69.2
B25	Average value per 5 seconds	402.3	334.8	310.3	257.3	187.3	157.1	70.0
	Average value per 10 seconds	394.0	336.8	305.9	254.5	185.9	156.4	70.2
	Average value per 60 seconds	343.8	315.0	293.2	237.8	173.9	149.4	70.7
C20	Average value per 5 seconds	390.8	315.2	292.2	231.9	174.3	148.3	74.7
	Average value per 10 seconds	377.1	313.9	291.3	230.7	173.7	147.7	74.7
	Average value per 60 seconds	332.8	294.1	277.6	215.9	165.8	142.2	75.0

5.2.2 Discussion for the calculation results in comparison with the measurement results

As the hourly and daily water consumption for the company cafeteria have been recorded throughout the year, the estimated water supply loads will be compared with those values and discussed for accuracy.

Figure 12 shows the hourly water supply loads by comparing the simulation results and measurement results. The simulation results show the values of the case A30. The failure factor 50% values on July and annual are almost same with the average values of measurement.

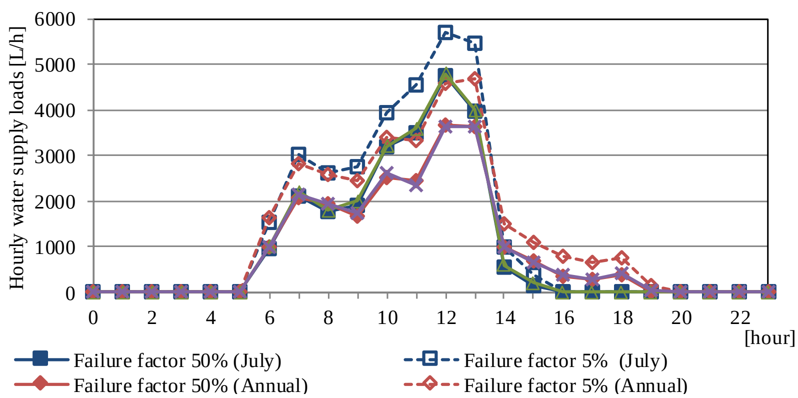


Figure 12 – Comparison of measured values and calculated values for water supply loads per hour

Figure 13 shows the cumulative distributions of water supply loads per day for 100 trials by simulation. The failure factor 50% value by the annual simulation model is 22.3 [m^3/day], which approximates to the measured value of 21.9 [m^3/day].

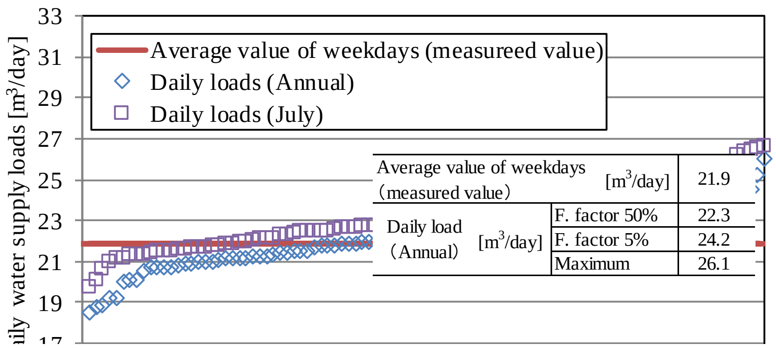


Figure 13 – Cumulative distribution of water supply loads per day by simulation and the average weekday measurement value per day

6 Conclusions

It has been required to estimate the accurate water supply loads for water supply system with high energy saving. The authors have proposed the dynamic calculation method for the hot and cold water supply loads that can estimate from instantaneous flow rates to hourly and daily water consumption by using MSWC program.

In this paper, the tap water supply loads of washbasin in the restrooms, hot-water service rooms and company cafeteria in T-building were clarified by simulation technique. From these results, the following contents will be said:

When we grasp the instantaneous flow rates for design of the diameter of water supply pipes, pumping capacity of water supply systems, etc., it is important to consider the time interval to average the values of instantaneous flow rates. In case of the flushing system in toilet, it would be better to analyze the calculated results with shorter average time rather than with the 60 seconds average values. The instantaneous water supply loads depend on the characteristics of fixture usage such as the duration time of water discharge and flow rate per one time.

For setting up simulation models, the authors tried to use BEMS data in T-building. From the analysis of simulation results, it would be suggested that using BEMS data is a useful method for preparing the calculation models for various buildings applications. The authors have been studying to set up simulation models from the hourly data.

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9 Presentation of Author

Dr. Saburo Murakawa is the Emeritus Professor of Hiroshima University. His special fields are building and city environment engineering, plumbing engineering and environmental psychology for water utilization area. He is now trying to spread the new dynamic calculation method for cold and hot water consumption in buildings using MSWC program.

C5 - Software for Calculation of Potable Water

Manuel Lautz

Manuel.lautz@dendrit.de

(1)Division manager, Dendrit Haustechnik-Software GmbH, Germany

Abstract

Introduction and aims: The designing of pipe networks for potable Water is getting more and more difficult and many laws and regulatories have to be mentioned to design a optimized network. The aim of the Dendrit Company is to reduce the complexity of calculation with software and visualize the results for better networks.

Method: The graphical interface enables the user to gain a maximum of transparency in a schematic view. Lots of drawing tools help to generate a basis for network calculation. Predefined Manufacturers and Products reduce the time to get calculations results, which could be visualized, analyzed and/or simulated. Fully integrated Calculation of Productdatas and Pressuredrops.

Results: Calculation of Network dimensions, Supporting Calculation of Loops, Integrated Reports of Hydraulics and equation of Bernouli, graphical Analyses of Hygiene, Report and Lists from Bill of Material with all accessories.

Keywords

Software; Calculation, Circulation, Water Hygiene, Simulation, Analyses, Bill of Material

1 Potable water system

The quality of potable water is affected significantly by the constructional design of the installation of potable water, from the selection of pipe materials, technical execution, dimensioning of the piping system in the building and also by the operational management. In case of identified problems in the potable water system, during the operation, the responsible persons must expect approval for the planning and dimension of the whole potable water system.

2 Software-solution for Calculation

Determining the required pipe diameter of the supply and circulation pipework of a potable water system must be demonstrated by a pipe network calculation, based on the technical rules of the potable water installation.
The result of a Dendrit STUDIO calculation provides not only the dimensioning of all components of a potable water system considering the rules of technology, but also an extensive documentation of the results in tabular form as well as in graphics as well as analysis of the operating conditions to be expected in the piping system and on the tapping points.

Any potable cold and hot water pipe network with a branching structure for the vertical or horizontal distribution of a building with upper and lower distribution or in combination can be represented and calculated. A network could be divided in pressure levels by pressure-boosting installations and or pressure reducer. The installation of storeys could be equipped and calculated with stub piping, serial piping, loop piping or with the innovative flow splitter loop piping.

Determining the pipe diameter of supply pipes and the dimensioning of the built-in valves, devices and pumps etc. based on a hydraulic model, considering of the relevant standards, worksheets and guidelines.

The pressure loss in the pipes are differentiated calculated considering the temperature-dependent properties of the water. That means that the calculation divides between pressure loss in straight pipes and fittings. The calculation of pressure losses in single resistances is performed using the coefficients. The coefficients were provided by the manufacturers and measured according to worksheet W 575.

All manufacturer specifications are integrated in Dendrit STUDIO. For product neutral tenders the reference pipe systems of DIN 1988-300 and industrial partners are included. Pressure losses in water meters, filters, water treatment plants etc. are calculated from manufacturer data or reference data.

3 Loop pipes

The pressure losses in loop pipes are calculated with a modified method of the Hardy Cross method, for calculating loop pipes and meshed networks, additionally allowing calculation of the peak flow in the loop pipes respective legs. This enables forming bigger loop pipes for the supply of several building units or public showers. This means that a loop pipe doesn’t provide only one building unit as suggested in the technical rules. To ensure a equal flow in the loop pipe, the calculation uses the constant diameter.

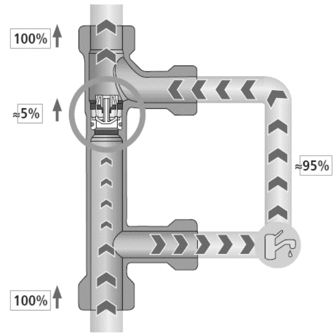

Figure 1 - Flow splitter

Connecting loop pipes to flow splitters will result in an intensive exchange of potable water (cold) at lowered temperatures in the storey pipes. The comparison of temperature and flow rate measured data originating from flow splitter installations with data from similar conventional systems indicates a significantly more intense water exchange which also is more equally distributed throughout the day. The intensive and equal water exchange is attributed to the fact that a water tapping at any point forces a flow in all loop pipes located before said point (induction).

Compared to the current installation standard (series), the average water exchange rate per day for flow splitter installations is up to 40 times higher. Of the stagnation phases occurring during the observation period, more than 90% are shorter than 30 minutes. Stagnation phases, which lasted longer than 2 hours, were not detected during the entire measurement period in the investigated flow splitter installations. A significantly lower level of temperature results from exchanging water evenly distributed throughout the day for the flow splitter installations compared to the current installation standards.

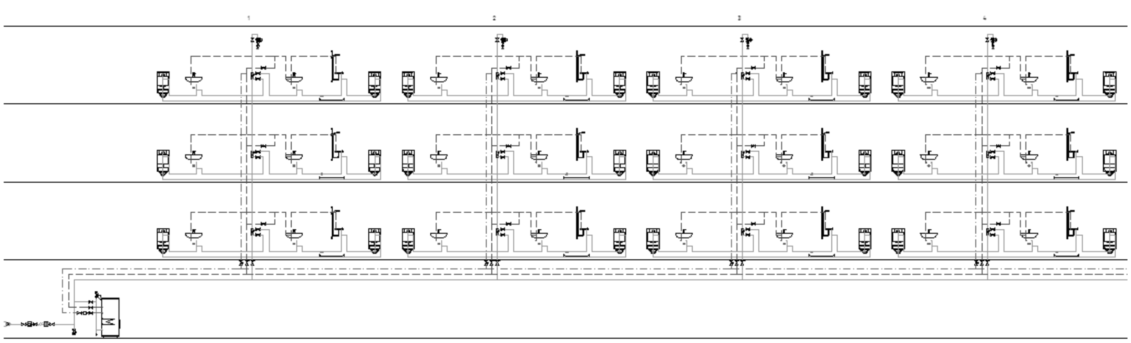

Figure 2 – Drawing example

4 Reporting of flow paths

After the hydraulic calculation, it is possible to highlight the flow path by clicking on the tapping point. The lists of resolves with the included legs with the specifications could be shown.

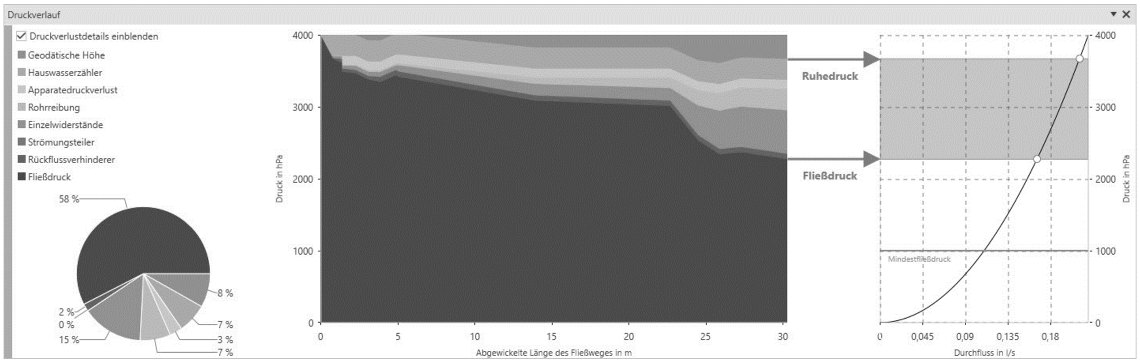

Figure 3 – Pressure chart

The pie chart shows the sum of the pressure components in the flow path calculated for the end of the flow path. The sums of the pressure components correspond to the minimum supply pressure at every calculation point, as a graphical representation of equation of Bernoulli. At the end of the flow path, the nominal flow pressure at peak flow must be between the minimum flow pressure and the static pressure of 5000 hPa to regard of noise reduction efforts at the tap.

To ensure the control of the hygiene and comfort requirements of the DVGW- worksheet W 551 and the VDI-guideline 6003 at the tapping point, the flow pressure, the static pressure and the flow rates at the tapping points are used at the beginning of the planning process. The operating range for the tapping points are highlighted in the characteristic curve of the valve.

In order to avoid serious malfunctions, it is necessary to know two tapping profiles as early as possible in the planning process. The first is the tapping profile of potable water hot to know the time to flush the not circulating water at the tapping point for comfort reasons. The second is the tapping profile of potable water cold for flushing the stagnation water with a temperature ≥25°C.

By knowing these it is possible to check the rule of 30 seconds and also the comfort requirements in the tapping profile chart.

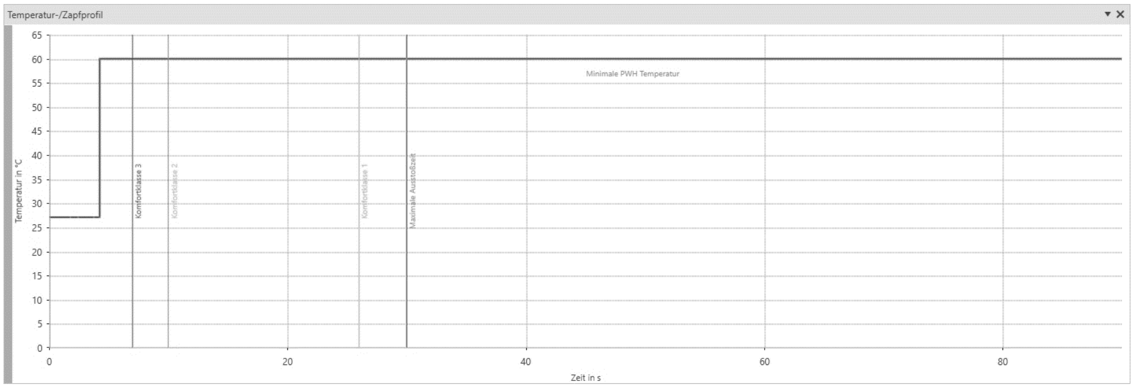

Figure 4 – Tapping profile chart

5 Calculation of Circulation

To ensure the hygienic requirements of the potable water, the temperature the potable water hot in the tank and the piping system became an important meaning. By using a suitable system of circulated pipes, it is necessary that the temperature of distribution pipes and risers doesn't sink under 55 °C. Only storey feeds and individual feeds with a volume less than 3litre allowed without a circulation pipe.

In constructions of residential housing the circulation of potable water hot includes only the distribution pipes and risers. In these systems, it is possible to realize circulation systems with downwards and upwards assembly point of the circulation or a system with Inliner-circulation could be realized.

In the healthcare sector the planning construction, operation of potable water systems must be complied to the German „Richtlinie für Krankenhaushygiene und Infektionsprävention" of the Robert Koch Institut. The aim is, that the circulation of potable water hot pipes is installed in the storey feeds up to the tapping point as near as possible.

A potable hot circulated water system to the tapping points could be calculated with conventional or reduced materials and energy by using potable hot water loop pipes with flow splitter in vertical and horizontal loop pipes. The heat losses of the circulated pipes which are affected are calculated differentiated. To ensure the calculated circulation volume flow in the operation phase, each connection of any circulation to the potable hot water pipes need at least one regulating valve needs. These method causing additional pressure loss to provide the so called hydraulic balancing.

To ensure this hydraulic equilibrium state, the circulation system is classified and adjusted. By a combination of static and thermostatic valves for circulation in multiple adjustment layers.

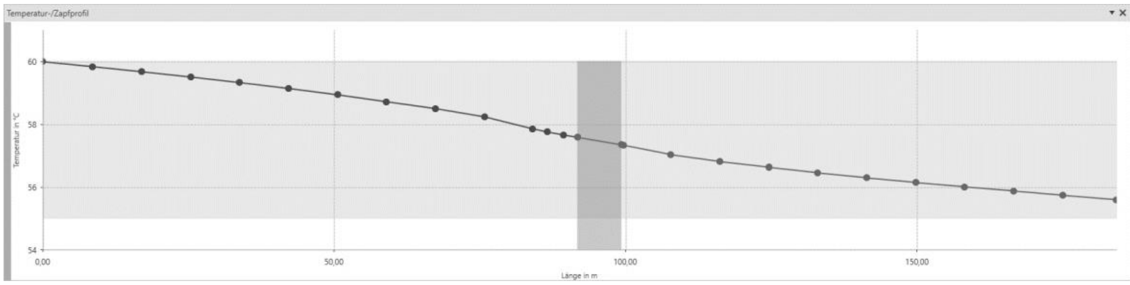

Figure 5 - Tapping profile chart flow path

6 Simulation of Circulation

With a pipe network calculation, according to DIN 1988-300, for the calculation of circulation systems the target of an ideal volume flow distribution is achieved. In the circulation system, it should be ensured that the temperatures of the potable hot water is above required 55 ° C, energy can be kept with a minimal amount of energy. A theoretical operating point in the characteristic curve of the pump and also theoretical operating points for the regulating valves are determined of the results of the calculation of pipe network.

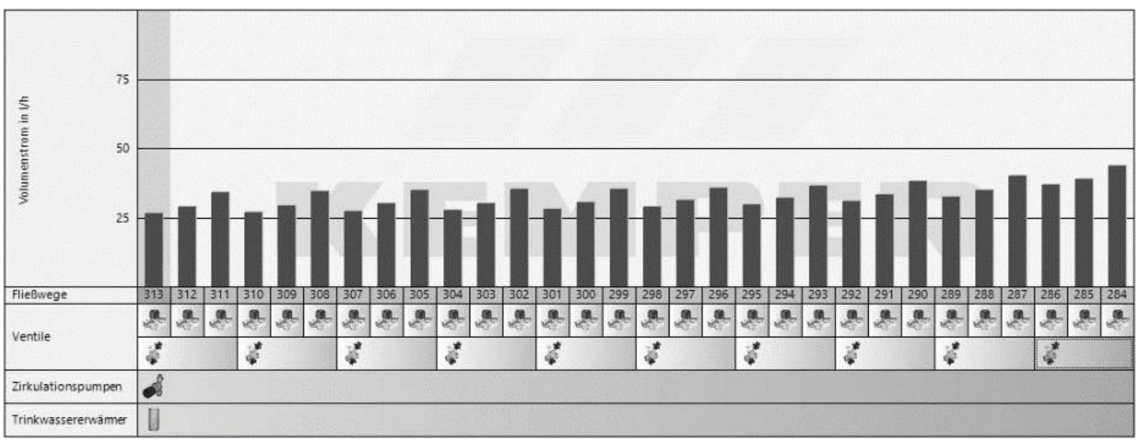

Figure 6 - Simulation

The idealized operating points could already be found in new planning both with the circulation pumps available in the market as well as with real regulating technology only can be achieved approximately. It is therefore useful for new planning to show the effects of these variations on the operation of the circulation system in a simulation tool, considering the real hydraulic and thermal conditions. During the reconstruction of circulation systems, the simulation of the interaction between built-in circulating pump and the real pipe network is essential.

That means that inter alia it is possible to show the impact of modified pump technology and/or the conversion of the pipe network and/or improvement of pipe insulation and the always required retrofitting of regulation technology on the pipe network operation could be represented realistically.

7 Simulation of Flushing technology

To avoid the stagnation of potable water cold, in weak times at the tapping point, automated water exchanges and flushing measures are required. Water exchanges and flushing measures are also required when potable water systems are used only periodically with vacancy on weekends or holidays and stagnation phases over several days or weeks.

The heat absorbed by the potable cold water can no longer be removed when stagnant and cause a temperature increase to the ambient temperature. If there exist an ambient temperatures >25 °C in the installation system, it will create a condition for the growth of bacteria in the warmed pipes.

A required water exchange could be achieved only through flushing measures in such cases. In contrast to conventional systems where water exchange measures locally at each tapping point or in any sanitary block must be made, only some centrally located flushing valves sufficient in a flow splitter system. Central flushing devices allow a time-, volume - or temperature-controlled flow of temperature-critical parts of the pipeline. A flushing measure starts with a given time or with an exceeded temperature limit.

The simulation for the scheduled established processes in the potable water system, provides all necessary setting parameters, so that the greatest possible effect to improve the hygienic potable water relevant boundary conditions could be achieved with the lowest possible flush volume.

Manual flushing is also supported by the simulation as well as the automatic flushing by the Kemper hygiene system KHS.

Also, a mixture of systems in the simulated flushing plan is possible. This means a combination with end flushing devices (Hygieneflushing HS2 / C-Technology) and cascaded flushings (AB-Technology) is possible.

Figure 7 – Flushing Simulation

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9 Author

Manuel Lautz is Division Manager at Dendrit Haustechniksoftware GmbH. In his function he is responsible for the strategic and operative management of the company.
In his business Experience he was responsible for CAD/CAE-Products and optimization of planning and design processes.

C6 - A proposed new UK framework for the sizing of domestic hot and cold water systems for medium-large scale residential buildings

L. Jack (1), S. Patidar and S. A. Wickramasinghe (2)

l.b.jack@hw.ac.uk
s.patidar@hw.ac.uk
saw31@hw.ac.uk

1. Executive Team, Heriot Watt University, Putrajaya, Malaysia
2. School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, Scotland

Abstract

There now exists relatively widespread concern across the building services and public health engineering communities that the loading units approach used for the sizing of domestic hot and cold water systems is no longer fit for purpose. In addition to the known variance and diverging results calculated using relevant codified documents, anecdotal evidence also suggests significant over-sizing of pipes; an aspect of design that impacts directly upon system performance, space-take, energy consumption and potentially water quality parameters.
This paper summarises the report from Phase 1 of the LUNA (Loading Units Normalisation Assessment) project, which recommended that a new framework for the sizing of domestic hot and cold water systems for medium-large scale residential buildings be adopted in the UK[13]. Both case study and measured data are summarised, where datasets were compared to establish the differences between estimated and 'actual' values of flow. The paper also presents a preliminary analysis of the lower threshold for the definition of mid-small size residential dwellings, below which the method adopted is mapped to selected design flow rates.

Keywords

Water supply, sizing methods, Loading Units, water conservation

1 Introduction

This paper addresses the issue of problems with the current practices used in the sizing of domestic hot and cold water for residential buildings. This topic has been addressed widely in many CIBW062 symposia and has been discussed at length, but new methods proposed internationally do not necessarily converge, meaning that nations such as the UK, for whom the discussion about the longer-term suitability or otherwise of the Loading Units method does not provide a ready alternative. Historically, it can be seen that, generally, most codes have drawn on the early work of Hunter[1] but over time, have gradually moved away from this approach. Geographically, the picture is patchy. Some nations have moved completely away from the Loading Unit method based on Hunter's work, whereas others retain the fundamentals of this method of assessment.
The need for alternatives arises from the fact that the traditional method used to specify the simultaneous flow in water supply systems is underpinned by a probability based statistical method that estimates probable demand based on historical average flow rates coupled with data on frequency and duration of use of commonly used sanitary appliances. There is growing concern within both the building services and public health engineering communities within the UK that because of the way in which appliance type, design and usage patterns have changed, this method now results in a major over-estimation of the design flow. This cannot be regarded as a theoretical problem that simply provides a sensible margin of safety. Over-estimation of the design flow is likely to lead to the oversizing of booster pumps and also that of pipework at central plant and throughout the 'spine' of the buildings' supply network, adversely affecting installation cost, construction sustainability, space-take, energy consumption, operational costs and potentially also water quality parameters.

In tackling this issue from a UK perspective, the first challenge was to understand the landscape and to review the various methods used with a view to providing advice on the type of re-worked model that might best suit the UK sector. This was summarised as a fundamental but critical decision as to whether the current Loading Units method should be retained (with Loading Unit values re-worked) or whether a more sophisticated statistical model would provide a better estimate of the simultaneous flow loading. Subsequent work, now ongoing, will determine detailed model parameters. The first part of this work is addressed herein and was carried out with the support of the LUNA group; a group comprising CIBSE (the Chartered Institution of building Services Engineers), CIPHE (the Chartered Institute of Plumbing and Heating Engineering, SoPHE (the Society of Public Health Engineering) and industry representation. This aspect involved a review of relevant European and international standards where relevancy was defined as meaning that the standard provides a theoretical model that merited investigation and comparison within the context of the scope of work being undertaken. In other words, the review was not, nor was it intended to be, a comprehensive review of codified documents. Selected codes were then categorised by their statistical framework and case studies of mid-large scale residential buildings used to determine design flow rates for each. In order to determine a true comparison, these figures were also compared with as-installed data sourced from a verified field dataset. In parallel, the authors also undertook an assessment of the statistical validity of the shortlisted methods.

2 UK Design standards

One of the most challenging issues for design engineers in the UK is that the codified documents yield significantly varying results in their determination of simultaneous design flow. Some of these figures also diverge as the number of installed appliances increases, meaning that for larger or high-rise buildings, this variance is yet more problematic. The type of buildings for which this concern arises is generally universal however, in smaller scale buildings, such as individual dwellings, the impact may be neglected. The focus of the work reported herein and in the full LUNA report[13] is hence on mid-large scale buildings and in particular, residential buildings where the usage patterns make the issue of oversizing more problematic; an aspect of operational performance that is confirmed by both anecdotal evidence and by (albeit limited) data collection.

Table 1 provides information on the standards typically used in the UK.

Table 1 Standards typically used in the UK

Code	Country
BS EN 806 [2]	UK
BS 8558 (BS 6700) [3,4]	UK
CIBSE Guide G [5]	UK
CIPHE/IoP [6]	UK

Further investigation of these codes confirms that all are based on the use of a probability method (originating from the work of Hunter in 1940[1]). Hunter's method uses a Binomial probability distribution theory to estimate the expected peak flow, based on:

a) n number of appliances/fixtures of a particular type/kind;
b) t average duration of operation; and
c) T average duration of successive operation.

and estimates the probability, p, that r out of a total of n appliances of a particular type will be found operating *simultaneously* at any arbitrary chosen instant. Importantly, it estimates the 99th percentile of the simultaneous water demand during a busy period, believed to be the origin of the 1% exceedance referred to in most UK codes.

It is worth noting that BS EN 806[2] is the UK version of the harmonised European Standard and should be applied in conjunction with complementary guidance presented in BS 8558:2015[3] (the replacement for BS 6700:2006+A1:2009[4]). Furthermore, the advice given in BS 8558[3] is that the BS EN 806[2] sizing method should be used for residential applications. The inclusion of BS8558[3] (as well as reference to the now-withdrawn BS6700[4]) was retained as the authors believe it provides a useful comparison for those who are more familiar with what is commonly referred to as the 'traditional' method of pipe sizing; the structure of which has been 'carried over' to BS8558[3] for non-residential dwellings. This method was previously used in the then BS6700[4], although was widely recognised as over-sizing pipes. Interestingly, the Loading Unit values used by BS 8558[3] are the same as when they were first introduced into the UK when BS CoP 310[7] was published in 1965. Importantly, it is worth stating too that in BS EN 806[2], the total flow rate is assumed as being derived from the sum of both hot and cold Loading Unit values, whereas in BS8558[3], the impact of simply adding hot and cold water Loading Unit is recognised and the standard advises that for flow-limited mixed-water outlets, only one Loading Unit value should be used in the assessment of the combined demand. The CIPHE/IOP Design guide has, for some time, been recognised as providing the industry standard and also offers the designer a choice of low, medium and high frequency of use, with 'low' use recommended for '*dwellings and other buildings where appliances are used by a single person, or a small group of people, as a private facility'*.

3 Extending the list of comparators beyond the UK

Table 2 shown below provides information on the extended list of codified documents used to establish comparisons between the simultaneous flow values calculated for the case study buildings. It is worth pointing out that this list was compiled on the basis of those codes deemed to be of relevance due to their suitability of approach to pipe sizing, their geographic and cultural applicability and their accessibility.

Table 2 Standards typically used in the UK

Code	Country	Statistical Method
BS EN 806 [2]	UK	Probability
BS 8558 (BS 6700) [3,4]	UK	Probability
CIPHE/IoP [6]	UK	Probability
ISSO - 55 (Code) [8]	Netherlands	Empirical
SANS 10252-1 [9]	South Africa	Empirical
DIN 1988-300 [10]	Germany	Empirical
DS 439 [11]	Denmark	Empirical
SNiP 2.04.01-85 [12]	Russia	Empirical

It is perhaps no coincidence that the codes used outside the UK rely on the use of an empirical statistical framework. Empirical modelling approaches (sometimes referred to as 'deterministic' approaches) generally rely on formulae, charts and tables established through the exploration of mathematical and statistical relationships and for the purposes of sizing pipework are typically based on the use of power law or square root models.

Whilst it is not the intention of this paper to document all of the methods in detail, it is worth noting that some methods retain a count of appliances, whereas others are based on a summation of apartment types linked to occupancy profile. In most, but not all, cases, there is flexibility of model application to suit different types of building. In other words, not all empirical models are restricted in their application to residential use. Further detail is available on the methods used by all of the standards and their statistical basis in previous publications[13,14].

4 Case Study application

Sample drawings for as-installed systems were supplied by the LUNA team for the purposes of comparison. With reference to table 3, it can be seen that these ranged in size, with the number of apartments spanning 9, 101, 165 and 289 for (anonymised) case studies A, G, I and M respectively. With the exception of case study A, by definition, the assessment of design flow for these buildings was complex and demanded a degree of interpretation; both of national standards and with reference to the in-situ loading placed on the system. Assumptions were made based on the basis of ensuing optimum comparability.

Table 3 Case study buildings provided by the LUNA team

Case study reference	No. of Apartments	Details
A	9	1 and 2 bedroom apartments
G	101	1 and 2 bedroom apartments
I	165	1,2 and 3 bedroom apartments
M	289	1,2 and 3 bedroom apartments

In recognition of the limitations of the scope of the case studies noted above, and the fact that resultant data, while providing reasonable estimates, remains theoretical, additional case study buildings were analysed. Furthermore, for two specific installations, in-situ data for which conditional permission for use was granted were provided via the work done by Tindall and Pendle[15] and by their collaborator and LUNA project team member Aquatec Pressmain. This offered both primary and secondary data, the former gathered from two Local Authority multi-storey residential buildings (case studies H and F) and the latter, as shown in Table 6, provided directly by Aquqtec Pressmain. With regard to the primary data, it is worth noting that this was gathered over a week-long period of time, with details as shown in Table 5. The secondary data not only increases the sample size but also confirms the validity of the primary dataset[13,15].

Table 4 Secondary dataset details

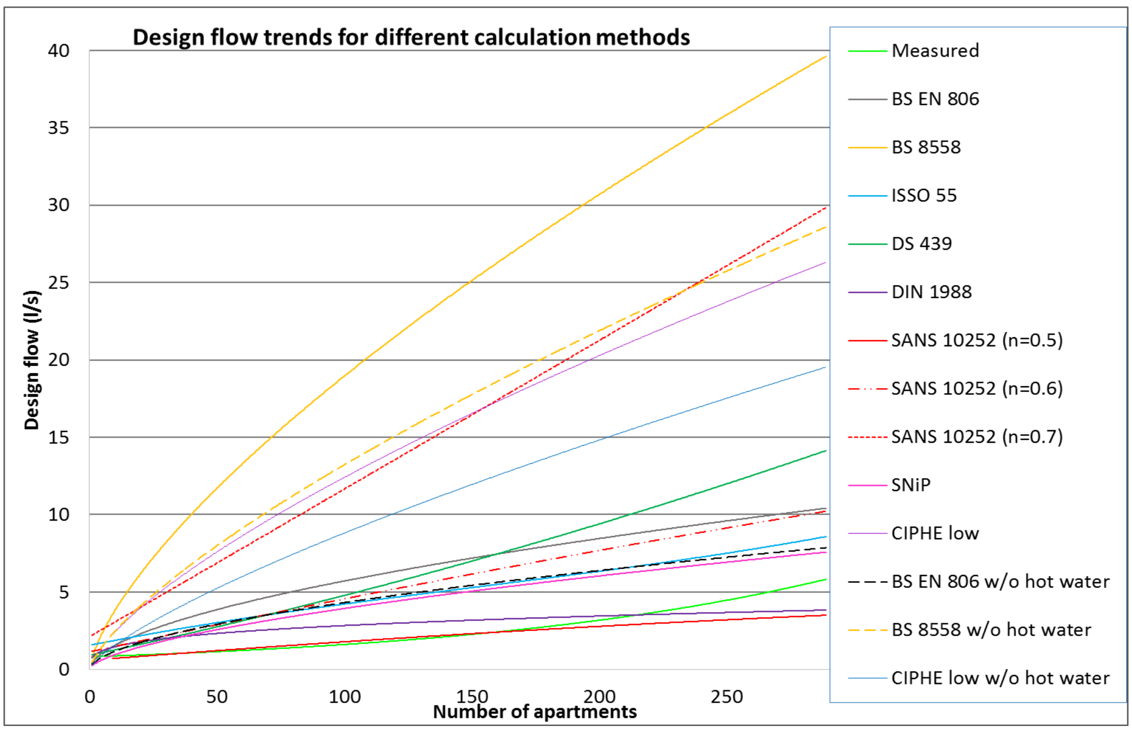
Case Study	Height	Configuration	Build Date	Condition	Comments
H	26-storey	125 2-bedroom	1966	Refurbished	Over 55s only
F	17-storey	60 2-bedroom 30 1-bedroom	1961	Refurbished	Mixed occupants

Table 5 Secondary dataset details showing peak flow (source: Aquatech Pressmain)

Case study	Period of flow measurement	Occupancy	Comments
B	For 5 days 07/05/2009 (14:15) Thursday- 12/05/2009(12:42) Tuesday	Only 18 flats appear occupied (concluded from water meter readings for each apartment)	Built to provide 2.7l/s at 3.4 bar Refers as maximum flow. The described original appliance list - 362 LU according to CIPHE 'low' usage was later changed to 308LU. (No information available on how appliances were changed. Hence the calculated values show clear oversizing.) Average of 292 litres/flat/day water used.
C	For 7 days 24/04/2009 Friday- 01/05/2009 Friday		Built to provide 4 l/s at 4.5bar Refers as maximum flow. Average of 241 litre/flat/day water used
D	For 5 days 10/09/2009 Tuesday- 14/09/2009 Saturday		Pump set sized to supply 0.82+0.82l/s at 4 bar Refers as maximum flow. Average of 200 litre/flat/day water used
E	For 7days 17/03/2008 Monday- 24/03/2008 Monday		Refers as maximum flow. Consultant required 5.8l/s at 8.2bar. 297 litre/flat/day water used
J	For 7 days 12/06/2008 Thursady- 19/06/2008 Thursday		Refers as maximum flow. Average of 85 litre/flat/day water used
K	7 days 4/06/2009 Thursday – 10/06/2009 Wednesday		Refers as maximum flow. Built to provide 12 l/s at 5 bar Wednesday Average of 286 litre/flat/day water used
L	8 days 26/11/2008 Wednesday- 3/12/2008 Wednesday		Refers as maximum flow. 3 pumps that can produce 20l/s at 8 bar had been installed Average of 215 litre/flat/day water used

5 Outcomes

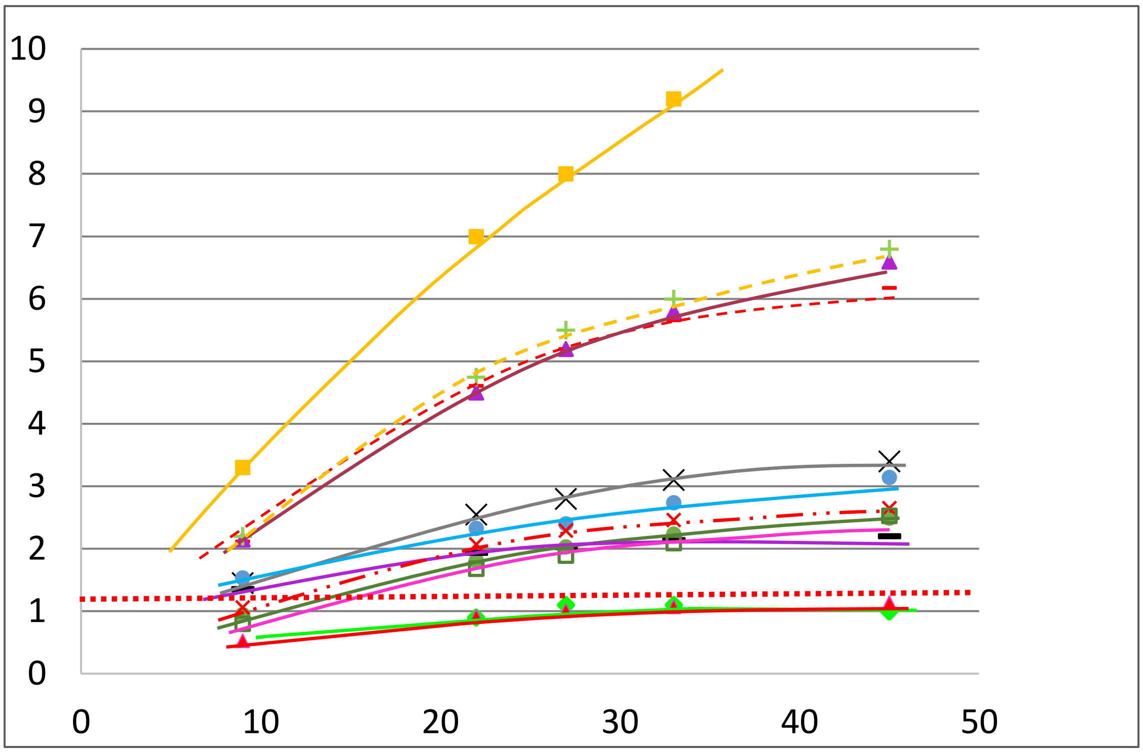
The calculated design flow rates from the range of standards noted in Table 2 are shown in Graph 1. It is worth noting that power-based trend-lines are indicative only, and that further information on the detail behind these results can be found in the LUNA research report[13]. Importantly, it should be noted that this graph omits the highest SANS 10252 dataset. Furthermore, BS EN 806, BS 8558 and CIPHE 'low use' data for which hot loading units have not been included in the calculation *are* presented however, these are provided for comparative purposes only, and should be regarded as purely indicative. The inclusion of these curves should not be interpreted as suggesting an alternative design approach, as the summation of cold loading units *only* does not represent the true system loading. Other than differences in the style, design and number of appliances fitted, it is worth noting that Case study A represents a high-end apartment scheme and Case study H apartments for residents over 55 years. Furthermore, where justified, outliers have been removed from datasets.



Graph 1 Approximate design flow curves for different calculation methods[13]

It is not the intention of this paper to discuss these results in detail. For this, readers are instead referred to the LUNA report[13]. However it can be seen from the results presented in Graph 1 and from the outcomes detailed in the LUNA report that the estimation of design flow compared with measured data, set alongside a review of statistical validity of the models used in relevant codes, suggest that an empirical model is best suited to the sizing of pipework and pump systems for mid-large size residential buildings. This conclusion is based on the assumption that development of a fully stochastic model, potentially integrating fuzzy logic,

although able to present the most accurate representation of loading, lies outwith the timescale and resources available to the LUNA team.
There is naturally a level of uncertainty within the approach outlined here; partly due to the limited availability of measured data; an aspect that will be addressed in phase 2 of this work. Alternative, and to an extent, more sophisticated approaches are of course possible. Oliveira *et al*[16] suggests the use of fuzzy logic embedded within a Monte Carlo simulation scheme, the SIMDEUM stochastic model is well-documented[17, 18] and in the United States, an improved method has recently been developed to address the issue of over-sizing using Hunter's method and is based on the normal approximation of the binomial distribution proposed by Robert Wistort in 1994[19].



Graph 2 Design flow for apartment size <50

Finally, it is worth noting the outcomes for data at the lower end of the scale; in other words for buildings with fewer than 50 apartments, Graph 2. This can be seen to be variable in nature; understandably so, given the underpinning statistical methods used to estimate simultaneous flows. This graph shows that by allocating a threshold for the design flow (neglecting reference to BS8558 for reasons stated above); in this case 3, 4 and 5 litres per second, the data yield an indication of the number of apartments for which the codes predict a design flow lower than this threshold. This is illustrated numerically in Table 6.

Table 6 Number of apartments relative to selected maximum design flow

Design flow (l/sec)	Number of apartments
5	25
4	18
3	12

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7 Acknowledgments

We are grateful to Jess Tindall and Jamie Pendle, of Northumbria University and Arup respectively, for their support in sharing primary data and also to Aquatech Pressmain who supplied, and granted permission for use of, the secondary data.
We are also grateful to Martin Shouler and Fabio Coelho of Arup for access to their technical report and list of relevant literature, and to Julia Novitchenko of Arup for assistance with the Russian Standard.

CIPHE would also like to acknowledge the financial support from the following manufacturers/business brands:

- AquaTech Pressmain
- Uponor
- Pegler Yorkshire
- Meibes

8 Presentation of Authors

Professor Lynne Jack is Director of Research for Heriot-Watt University’s Malaysia campus. She is also Director of Heriot-Watt University’s Royal Academy Centre of Excellence in Sustainable Building Design and is CIBSE Vice-President. Her research interests include water conservation, the simulation of air pressure transient propagation in building drainage ventilation systems and the assessment of property drainage system performance when subject to climate change impacts.

Dr Sandhya Patidar is an Assistant Professor within the Institute for Infrastructure and Environment with the School of Energy Geosciences Infrastructure and Society at Heriot watt. Her research interests are in inter-disciplinary applications of mathematical/statistical techniques to the real-world engineering problems, specifically in the areas of climate change, built environment, energy, extreme events, flood-risk, and human behavior.

S. Achala Wickramasinghe is a PhD student in the School of Energy, Geoscience, Infrastructure and Society at Heriot-Watt University. Her research interests include simulation of connected flow-routing within a property for assessing impacts of water conservation on system performance.

C7 - A mathematical model for decision-making of a non-potable water system in residential buildings: decentralized in clusters or individual decentralized?

Dias, C. M., (1), Oliveira L.H (2), Kurokawa, F.A. (3)
1. christinemdias@gmail.com
2. lucia.helena@usp.br
3. fernando.kurokawa@usp.br
(1) Master's degree in Civil Engineering, University of São Paulo, *Escola Politécnica*, Department of Construction Engineering, Brazil
(2) Associate Professor, University of São Paulo, *Escola Politécnica*, Department of Construction Engineering, Brazil
(3) Assistant Professor, University of São Paulo, *Escola Politécnica*, Department of Construction Engineering, Brazil

Abstract

Among the options to restore the balance between supply and demand of water is the use of reclaimed water by deploying non-potable water systems, this being one of most used strategies today. Non-potable water systems can be of the centralized type, when the effluents from buildings are collected and transported to a single treatment site and redistributed to a set of dwelling buildings; or decentralized, when the collecting, transport and treatment of wastewater occurs near the production site. However, there is no consensus in the literature about what the most appropriate method is, since both centralized and decentralized systems have particularities that either do or do not make them attractive in social, economical and environmental terms. In this context, the aim of this article is to formulate a mathematical model for decision making to help find the optimum solution for a condominium with ten buildings. For this study, a bibliographic review was carried out with the purpose of collecting data about the main variables that interfere in the choice of each type of system. From the principles of Integer Programming, a mathematical model is formulated to reveal which type of system has the lowest total cumulative cost, how much the cost is over time, and how many systems need to be installed to meet a specific demand. Thus, based on the information in the literature consulted for this purpose, the decentralized-in-cluster system proved to be more advantageous than the individual decentralized system in terms of installation, maintenance and energy costs, considering a 20-year service life. However, the choice of the most viable system should not only focus on the costs involved, but should also take into account qualitative variables, such as the quality of the non-potable water produced.

Keywords

Non-potable water system; decision-making; decentralized-in-cluster system; decentralized system; integer programming

1 Introduction

The research work related to the use of non-potable water in individual decentralized systems focuses specifically on verifying the quality of the water offered and on the economic feasibility only in the first year of operation. However, other variables must be taken into account at the decision-making moment as to which non-potable-water building system will be employed in dwelling buildings.

The decision-making in the use of non-potable water in building systems must include all the risks involved in its adoption. Not only is it important to take into account the costs of acquiring and implementing the system, but also, and equally important, is the analysis of operating and maintenance expenses.

Oliveira *et al*. (2013) [1] set forth a model, based on the nearest-neighborhood algorithm, the results of which indicated that the centralized non-potable water system is more feasible economically than the decentralized one, but without considering how much the total cost is at the end of a given period of time.

Therefore, the aim of this paper is to formulate a mathematical model for decision making to afford the choice for the optimum solution for a condominium with ten buildings, but from the principles of Integer Programming.

2 Non-potable water systems

A building's water system has two water subsystems: potable and non-potable. Types of non-potable water in residential buildings after treatment include rainwater, wastewater and underground water.

In Germany and the United Kingdom, where scarcity of water is less critical, but environmental conservation is a real concern, institutions aim at researching new technologies to be implemented in buildings that use non-potable water, verifying the implications for health and the environment resulting from their use, and increasing the awareness and acceptance of users of reuse systems in dwelling buildings [2].

Brazil has the greatest undertaking in South America to produce non-potable water for industrial purposes – Aquapolo – which is apt to treat 1,000 liters/second of sewage, thereby saving approximately 2.58 billion liters/ month of drinking water [3]. However, reclaimed water is as yet little utilized in buildings.

2.1 Centralized and decentralized systems

Based on the concept of waste treatment systems, it is possible to establish a parallel with non-potable water systems of different scales. In centralized systems, wastewater from several buildings is collected and conveyed to a single place, and then is treated and distributed to the same or to another building for use. However, in decentralized systems, wastewater from a house or building is collected, treated and reused or disposed in locus or near the generation point [4], [5], [6].

The alternatives for a decentralized treatment are on-site or in clusters. The on-site system (in locus), the entire process of collection, transport, treatment, and reuse of non-potable water occurs in a single dwelling or building. In the scope of this study, the on-site systems are called individual decentralized systems. On the other hand, in-cluster systems, the collection of wastewater takes place in more than one building or community and is directed to an adequate treatment site, to then return to the population as non-potable water [5].

Based on the literature [4], [6], [7], [8], [9], [10], [11], no consensus exists as to which system, whether centralized or decentralized, is more attractive. Each one has particular advantages that must be evaluated considering both direct consequences, such as infrastructure and expenses involved, and indirect consequences in the systems, such as regional characteristics and environmental impacts.

2.2 Variables for decision-making regarding the type of system to be used

Low implementation, operating and maintenance costs are cited by most authors as important attributes when it comes to choosing the best alternative among centralized and decentralized systems. Nevertheless, the study conducted by [4], in Australia, showed that the belief that a non-potable water system represents a low-cost option of supply is a common mistake made today.

Owing to lack of knowledge, the development of building non-potable water systems usually bases feasibility on expenses arising from the construction of the system and treatment of effluents. In this case, it disregards indirect costs, such as acquisition of the plot of land, labor, machinery, infrastructure, operation, maintenance, and paralyzation of the system, which means that the actual cost of non-potable water production is much higher than that forecasted initially [12]. In addition, the investments carried out are entirely related to the standard of water quality, depending on the activities at which they are aimed in buildings [13].

There are four factors that influence the decision-making process concerning decentralization, especially in the case of small communities: costs, flexibility in the use of the territory owing to smaller physical occupation as compared to centralized systems, maintenance, and environmental protection [14]. Thus, the main variables that interfere in the decision-making as to which system to utilize are presented as follows.

2.2.1 Demand and supply

On analyzing the daily capacity of the production of a non-potable water system, one notices a decrease in the cost of a liter of water with an increase of scale of the system, which may lead to increases in the installation and operating costs for individual decentralized systems [4].

2.2.2 Types of treatment

Regardless of whether the system is centralized or decentralized, the protection of public health must be the main focus of the project developed. Therefore, the costs involved in the generation of non-potable water are directly proportional to its final quality.

2.2.3 Implementation, operating and maintenance cost of the system

While the majority of treatment types favor the choice for centralized systems since they involve better-known technologies and offer more control of the inputs received, the cost of carrying out distribution and collection systems favors decentralization, due to the proximity of effluent generation points to the site of treatment and consumption of non-potable water [15]. However, in individual decentralized or decentralized-in-cluster systems, the overall implementation costs of various treatment stations may be higher than the investment in a single centralized unit, which produces higher volume of non-potable water.

As to the operating and maintenance costs regarding chemical products, electric energy, employees, and equipment, [12] divides them into fixed and variable costs. According to the authors, the fixed costs do not depend on the volume of water treated and reused, whereas variable costs are proportional to the amount of effluent generated. For example, the more the demand for non-potable water, the greater the use of energy for the treatment and pumping of the input. It is important to estimate the values spent with operational and preservation services, for they will never be nonexistent throughout the system's lifecycle.

Considering the total resources spent in auxiliary activities of centralized treatment stations, maintenance represents approximately 36% of the total cost of such expenditure [16]. This means that while planning a non-potable water treatment station, it is essential to consider the costs involved in its maintenance, since the cumulative effect of such in few years can surpass the value spent on its construction. Moreover, in the study developed by [17] in 338 wastewater treatment stations in Spain, the authors verified that the maintenance and management costs are the most important factors, which show the differences between stations in terms of efficiency.

2.2.4 System monitoring

The management of non-potable water quality helps reduce the risk of contamination of the users. With this in mind, [12] show that the number of professionals required depends on the type and size of treatment, and on the system's automation, with the costs with labor decreasing as the production of non-potable water increases. Thus, albeit more judicious, the management of a centralized system can be more economical, since the cost of hiring a qualified and permanent team is lower than the overall cost of various outsourced teams for all the individual systems implemented.

2.2.5 Electric energy consumption

A balance carried out in the United Kingdom showed that, in fact, reuse systems afford a reduction in the consumption of drinking water, but lead to somewhat increased energy consumption owing to the utilization of equipment to collect, treat, and distribute water throughout the building system [18]. In centralized systems, some 41 to 44% of expenses correspond to pumping effluents [7], [16].

In Brazil, the majority of buildings have indirect water supply systems, that is, they have lower and upper water storage tanks. Thus, when a non-potable water system is installed, the demand for repression energy is needed both for drinking water and for non-potable water. Consequently, greater volumes of treated and reused water imply greater energy expenditure. However, the consumption of a smaller amount of reclaimed water implies a smaller reduction in the consumption of drinking water, thus rendering reuse little appealing.

This situation was observed in California, in the U.S., where an energy consumption of 10.3 kWh/m^3 was observed in a decentralized system as opposed to a consumption of 1.9 kWh/m^3 in a centralized system for the same volume of treated water. The authors concluded that decentralized systems require seven times more energy to operate than a centralized system [6].

Therefore, regarding the decision for decentralized or centralized systems based on the energy consumption, one verifies advantages and disadvantages in each one of the systems. The overall energy consumption for the treatment of effluents from various decentralized systems can be much higher than that of a centralized system that caters to the same set of buildings.

3 Methodology

In this study, a bibliographical research was conducted with the purpose of collecting data that may characterize and compare individual decentralized systems with decentralized-in-cluster systems. Moreover, based on the information obtained and with the assistance of Integer Programming, it was possible to formulate a mathematical decision-making model, wherein the solution is determined using the LINDO™ software. The general formulation of the model is set forth as follows.

3.1 General formulation of the decision-making model

This model has the purpose of answering which type of system – individual decentralized or decentralized-in-cluster – offers the lowest overall cost and what the value of the total cumulative cost is in the period of analysis, taking as a basis the data in the references consulted.

Considering X_{ij} the decision-making variable that represents the possibility or impossibility of installing a given available system, where i represents the type of system ($i = 1,2,\ldots,n$) e j

is the type of cost relative to that type of system ($j = 1, 2, \dots, m$), a general formulation for a decision-taking model can be given by:

$$\text{(MIN)} \quad Z = \sum_{i=1}^{n} \sum_{j=1}^{m} A_{ij} X_{ij}$$

$$s.a. \quad \begin{cases} \sum_{i=1}^{n} X_{ij} = 1, & j = 1,2, \dots m \\ X_{ij+1} - X_{ij} \leq 0, & i = 1,2, \dots, n \text{ and } j = 1,2, \dots m-1 \\ X_{ij} \in \{0, 1\} & \forall\, i, j \end{cases} \tag{1}$$

where the coefficients A_{ij} of the objective function (Z) represent the costs (implementation, maintenance, operation, etc.) relative to each type of system.

It is important to point out that the values of i and j change according to the number of system types available to the designer and to the costs needed to make the comparison.

In Equation (1), the objective function (Z) is minimized since the aim is to find the lowest total cost, and it is subject to restrictions (s.a.), represented by inequalities.

The m first equations represent mutually exclusive groups of alternatives, i.e., in each equation, only one variable can be equals one, because the model must return as a final result the possibility of there being only one cost, such as an implementation cost, a maintenance cost, an operating cost, and so forth. Thus, the variables that represent other costs must be equals zero.

The $n + m$ inequalities within the brace refer to contingent decisions, i.e., that may or may not occur, but that depend on the results of previous decisions. In this case, whatever the answer to variable X_{11}, consequently variables $X_{12}, X_{13}, \dots, X_{1m}$ will have the same results. The same is true for the other variables of the model.

This model was formulated based on the principles of Integer Programming with variables 0 and 1. Thus, a variable $X_{ij} = 1$ means the possibility of installing one of the n options available, taking into account the necessary costs, whereas a variable $X_{ij} = 0$ represents the impossibility of installation due to the fact that another option has a lower total cumulative cost.

4 Case study

In this section, results for the decision-taking model and considerations made for the solutions found concerning the type of system to be installed in a hypothetical residential condominium with approximately 1,700 dwellers are presented. It must be pointed out that the model was formulated in order to compare the total costs of individual decentralized systems with decentralized-in-cluster systems involving different types of treatment, which may be implemented in this residential condominium. For this case study, the implementation, maintenance and operating costs were taken into account.

4.1 Characteristics of the systems used in the study

The data used for the formulation of the model are based on the characteristics of the systems detailed in [19] and [20]. Moreover, the absent information was adapted from [21]. In Table 1, the costs referring to the populations indicated in each literature source are shown in detail. The values were rounded off to simplify the model setting.

Table 1 Population, costs and energy consumption in each system indicated in the literature in the year of the systems' operation

System	Type of Treatment	Maximum Population Served	Implementation Cost (US$)	Maintenance Cost (US$/year)	Operating Cost (US$/year)
1	Rotating Biological Contactor (RBC) [1]	170 [1]	43,486 [1]	16,780 [1]	0 [1]
2	Physical-Chemical [2]	360 [2]	60,642 [2]	23,824 [2]	656 [2]
3	UASB Reactor with Aerated Submerged Biological Filter [3]	1,719 [3]	305,229 [3]	7,640 [4]	5,809 [4]

Source: elaborated from [19], [20], [21], [22].

It is emphasized that in this study the implementation cost includes expenses with the acquisition of the system and the civil works needed for its installation. The maintenance cost includes the chemical-physical analysis of the non-potable water produced, the replacement of chemical products, the removal of sludge, and the cleaning of equipment, components and tanks. On the other hand, the operating cost comprises the consumption of electrical energy for the treatment of wastewater, as obtained in the data of the literature. Consumptions related to the operation of pumps for the repression of the non-potable water produced were not accounted for.

Moreover, we point out that the expenses related to lubrications, adjustments and replacements of components and accessories, and to the corrective maintenance for the replacement of equipment were not accounted for in the calculation of the maintenance costs. In addition, since no data were found in the literature regarding the actual rate of adjustment of the maintenance costs of different types of treatment of non-potable water, it was considered that the maintenance costs of the three systems of analysis have a symbolic increase of 1% per year.

4.2 Characteristics of the hypothetical residential condominium

Aiming at comparing the decentralized-in-cluster systems and the individual decentralized systems, it was considered that these systems would be implemented in a hypothetical condominium, comprised of ten 14–storey residential buildings with four apartments per floor, and with a capacity to roof an average population of 170 persons, thus totaling at least 1,700 dwellers.

The designer finds the three systems shown in Table 1 available in the market. Thus, according to maximum populations served, the options to distribute the systems in order to cater to the demand of the condominium are the following:

- Option 1: ten units of individual decentralized systems, composed by system 1, and able to supply the demand of 1,700 dwellers;
- Option 2: five units of decentralized-in-cluster systems, consisting of system 2, and able to supply the demand of 1,800 dwellers;
- Option 3: one unit of decentralized-in-cluster system, represented by system 3, and able to supply a demand of 1,719 dwellers.

4.3 Decision-making model

The model formulated for this case aims to answer what the lowest total cumulative cost is among the three options of system distribution available to the designer, with the data obtained in the consulted references serving as a basis.

Thus, taking into account the implementation, maintenance and operating costs, from Equation (1), the following decision-making model is attained for each operation quinquennium of the systems:

$$
\begin{aligned}
\text{(MIN)}\quad Z = {} & A_{11}X_{11} + A_{12}X_{12} + A_{13}X_{13} + A_{21}X_{21} + A_{22}X_{22} \\
& + A_{23}X_{23} + A_{31}X_{31} + A_{32}X_{32} + A_{33}X_{33}
\end{aligned}
$$

$$
s.a.\quad \begin{cases}
X_{11} + X_{21} + X_{31} = 1 \\
X_{12} + X_{22} + X_{32} = 1 \\
X_{13} + X_{23} + X_{33} = 1 \\
X_{12} - X_{11} \le 0 \\
X_{13} - X_{12} \le 0 \\
X_{22} - X_{21} \le 0 \\
X_{23} - X_{22} \le 0 \\
X_{32} - X_{31} \le 0 \\
X_{33} - X_{32} \le 0 \\
X_{ij} \in \{0, 1\}
\end{cases} \qquad (2)
$$

where the coefficients of the objective function correspond to:

- A_{i1} – implementation cost of option i;
- A_{i2} – maintenance cost of option i, cumulative over time;
- A_{i3} – operating cost of option i, cumulative over time.

The coefficients A_{i2}, referring to the maintenance costs cumulative over the time of analysis, are calculated as follows:

$$A_{i2} = C_{i2} + C_{i2}\times(1+t) + \cdots + C_{i2}\times(1+t)^{n-1} \qquad (3)$$

where:

- C_{i2} is the maintenance cost of option i in the frst year of operation, which corresponds to the sum of the maintenance cost of each type of system included in option i;
- t corresponds to the rate of yearly increase in the maintenance cost defined for each option i;
- n is the service life, in years, determined to conduct the analysis.

And the coefficients A_{i3}, which represent the operating costs cumulative over the time of analysis, are calculated according to Equation (4):

$$A_{i3} = C_{i3} + C_{i3}\times(1+s) + \cdots + C_{i3}\times(1+s)^{n-1} \qquad (4)$$

in which:

- A_{i3} is the operating cost of option i in the first year of operation, equals to the sum of the operating cost of each type of system included in option i;
- s corresponds to the rate of annual adjustment in the charge of electric energy. In this research, a rate of 10.35% per year was used for this purpose.
- n is the service life, in years, determined to carry out the analysis.

For this model, total costs were calculated referring to the implementation of each option to meet the demand of the condominium. Regarding options 1 and 2, which have more than one system, the total cost was calculated by multiplying the costs of one system by the amount to be implemented in the condominium.

Table 2 shows the costs of each option for the first year of operation, considering the characteristics of the systems detailed in [19], [20], [21], [22].

Table 2 Costs of each option in the first year of operation

Option	Type of System	Number of Systems	Implementation Cost (US$)	Maintenance Cost (US$/year)	Operating Cost (US$/year)
1	**Individual Decentralized**	**10**	**434,860**	**167,800**	**0**
2	**Decentralized-in-Cluster**	**5**	**303,210**	**119,120**	**3,280**
3	**Decentralized-in-Cluster**	**1**	**305,229**	**7,640**	**5,809**

Source: elaborated from [19], [20], [21], [22].

Considering that the maintenance costs of the systems have an adjustment rate of 1% per year, Table 3 shows the cumulative maintenance costs of each option in each quinquennium of analysis.

Table 3 Cumulative maintenance costs of the options for the quinquenniums of analysis

Option	Cumulative Maintenance Cost (US$)				
	1st year	5th year	10th year	15th year	20th year
1	167,800	855,780	1,753,510	2,693,190	3,674,820
2	119,120	607,512	1,244,804	1,911,876	2,608,728
3	7,640	38,964	79,838	122,622	167,316

Source: elaborated from [19], [20], [21], [22].

As indicated in Item 3.1, the rate of adjustment of the operating cost was regarded as 10.35% a year. Thus, Table 4 shows the summary of the cumulative operating costs of the options at every five years of operation.

Table 4 Cumulative operating costs of the options for the quinquenniums of analysis

Option	Cumulative Operating Cost (US$)				
	1st year	5th year	10th year	15th year	20th year
1	0	0	0	0	0
2	3,280	20,165	53,160	107,150	195,494
3	5,809	35,712	94,149	189,767	346,228

Source: elaborated from [19], [20], [21], [22].

Therefore, based on the data of Tables 2, 3 and 4, the objective function of equation (2) in the twentieth year is given by:

$$\text{(MIN)}\ \ Z = 434{,}860X_{11} + 3{,}674{,}820X_{12} + 0X_{13} + 303{,}210X_{21} + 2{,}608{,}728X_{22} + 195{,}494X_{23} + 305{,}229X_{31} + 167{,}316X_{32} + 346{,}228X_{33} \quad (5)$$

4.4 Results and discussion

With the model formulated, the data were inserted into the software LINDO™, so as to find the solution for each year of operation. Figure 1 displays the solution obtained for the decision-making model considering the twentieth year of operation of the systems:

```
OBJECTIVE FUNCTION VALUE

     1)      818773.0

VARIABLE        VALUE
     X11         0.000000
     X12         0.000000
     X13         0.000000
     X21         0.000000
     X22         0.000000
     X23         0.000000
     X31         1.000000
     X32         1.000000
     X33         1.000000
```

Figure 1 – Results provided by the software LINDO™ for the model formulated

Table 5 displays the synthesis of the results obtained for each quinquennium.

Table 5 Synthesis of the results obtained

Service Life (year)	Objective Function Result (US$)	Option	Type of System	Type of Treatment
01	318,678	3	Decentralized-in-cluster (one system)	UASB Reactor with Aerated Submerged Biological Filter
05	379,905	3	Decentralized-in-cluster (one system)	UASB Reactor with Aerated Submerged Biological Filter
10	479,216	3	Decentralized-in-cluster (one system)	UASB Reactor with Aerated Submerged Biological Filter
15	617,618	3	Decentralized-in-cluster (one system)	UASB Reactor with Aerated Submerged Biological Filter
20	818,773	3	Decentralized-in-cluster (one system)	UASB Reactor with Aerated Submerged Biological Filter

Source: obtained from [19], [20], [21], [22].

As shown in Figure 1 and Table 5, option 3, which consists in the implementation of a decentralized-in-cluster system unit, the principle of treatment of which is the combination of a UASB Reactor with an Aerated Submerged Biological Filter, offered the lowest overall cost during the service life period of the compared options, based on the first information provided in [19], [20], [21], [22].

Figure 2 represents the total cumulative cost of each option throughout the service life considered. It can be seen from this figure, the difference between the total cumulative costs of the three options available. It is clear that even without consuming electric energy, option 1, with 10 individual decentralized systems, has the highest total cost. Moreover, it can be seen that the advantage of option 3, the implementation of a decentralized-in-cluster system unit, is mainly attributed to the fact that its annual maintenance cost is much lower than that of options 1 and 2, as shown in Table 1.

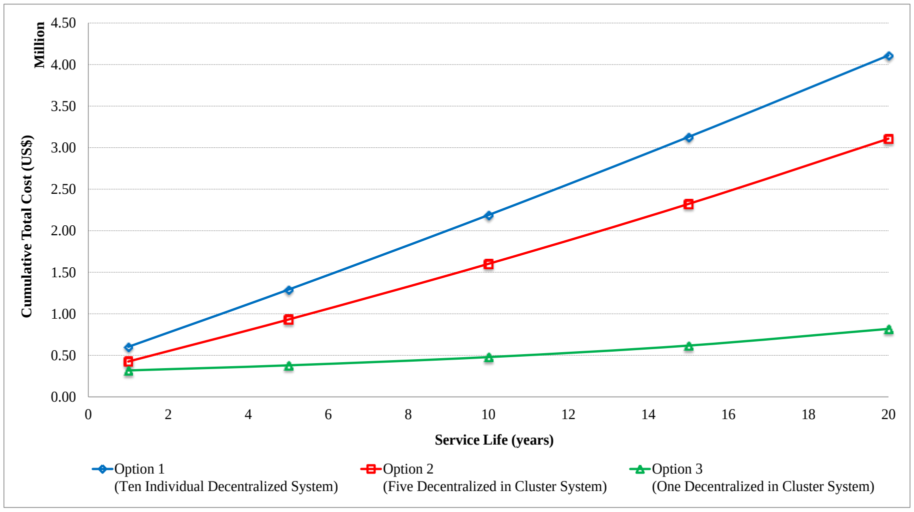

Figure 2 – Total cumulative cost during the service life of the options available for a condominium with 1,700 dwellers

5 Final considerations

The principles of Integer Programming afforded a decision-making mathematical model, which made it possible to indicate which type of system offers the lowest total cumulative cost and what the value of this cost is at the end of a given period of time to cater to a specific demand.

Through the sources consulted, the results obtained pointed out the importance of analyzing cost performance throughout the service life of the systems, as well as the relevance that all the variables inserted into the model have, because the type of treatment or system that seems competitive at first may prove to have a higher total cumulative cost as compared to other options available.

Moreover, we would like to point out that the formulated model can be improved should it consider different maintenance frequencies for each type of treatment, and, also, the influence of a scale effect on maintenance costs, resulting from the increase of population and from the number of systems implemented for each option.

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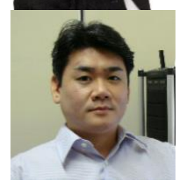
7 Presentation of Authors

Christine Miranda Dias holds a Master's of Civil Engineering from *Escola Politécnica* of the University of São Paulo, Department of Construction Engineering. Her thesis is the issue of models for decision-making of non-potable water in buildings.

Lúcia Helena de Oliveira is an associate professor at the Department of Construction Engineering of *Escola Politécnica* of the University of São Paulo, where she teaches and conducts research work on building services.

Fernando Akira Kurokawa is an assistant professor at Department of Construction Engineering of *Escola Politécnica* of University of São Paulo, where he teaches and conducts researches on CFD simulations and graphical geometry for engineering.



C8 - Use of Storm Water Management Model for on lot drainage

R. N. MATTOS (1), R. P. A. REIS (2), M. S. O. ILHA (3)
1. renato_nmattos@hotmail.com
2. ricardoprado.reis@outlook.com
3. milha@fec.unicamp.br
(1) School of Civil Engineering, Architecture and Building Design, University of Campinas, Sao Paulo, Brazil
(2) School of Civil Engineering of University of Goiás, Goiania, GO, Brazil.
(3) Department of Architecture and Building Construction, School of Civil Engineering, Architecture and Urban Design, University of Campinas, Campinas, SP, Brazil.

Abstract

The increasing waterproofing of the soil contributes to the rise of the surface runoff, and consequently the increment of the floods in the cities. In this context, the management of the storm water on-lot assumes important position, it is necessary to evaluate still in the design phase the impacts of different measures to be adopted in this meaning. There is various software for computational modeling in the Civil Engineering currently and, among them, the Storm Water Management Model (SWMM), which has been used to evaluate the strategies of the management storm water on-lot. For establishing the limits of your applicability on lot drainage, this paper aims to compare the results obtained with the SWMM and the data observed in an experimental installation executed in Campinas, São Paulo, Brazil. Two design rainfalls were used: intensity of 52 mm/h and 192 mm/h with 60 min duration, in a real scenario composed of a roof area of 53 m^2 and a gutter that conducts the flow to an infiltration trench (area of 0,6 x 0,6 m and length of 5,0 m, filled with crushed stone). The hydraulic profiles simulated by SWMM 5.1 were compared with experimental data and the results indicate the adequacy of the use of this software for the case study presented.

Keywords

Infiltration trench, Low Impact Development, LID, SWMM 5.1, storm water infiltration

1 Introduction

The increasing waterproofing of the soil contributes to the increase of the surface runoff, aggravating the flood problem in the cities. Such waterproofing originates from the inefficient management of land use and occupation from the view point of urban drainage, generating areas that change the natural characteristics of the surface prior to occupation. In parallel, the property appreciation contributes significantly to the expansion of built-up areas, with the increase of the horizontal impermeable area and the creation of large vertical planes that act as rain interception surfaces, increasing the contribution of unloaded rainwater in the urban drainage system.

For many years the urban drainage was approached in an ancillary way within the context of the parceling of the soil for urban uses. Urban growth has been accelerated and only in some places the drainage systems has been considered a preponderant factor in urban expansion planning [1].

The hygienist approach adopted in the conventional urban drainage treatment generates numerous large civil buildings that do not always support the requests of the seasonal hydrological effects, making it impossible for the excess flow to be absorbed naturally without causing damages to the population and urban devices. According to [2], besides these factors, the alteration of the use and occupation of the ground and the constant change in the hydrological balance of the urban centers can contribute even more to the events of great pluviometric intensities.

Therefore, the management through decentralized drainage systems: (1) source drainage systems, (2) conventional urban drainage systems, and (3) non-structural management instruments become an alternative technically and environmentally more sustainable and economically feasible, since each part of the drainage system acts to solve the problems related to the excess of surface runoff referring to its area of coverage. Thus, the results obtained through the drainage systems complement each other as integrated management measures of a definitive character.

The implementation of compensatory techniques and LID (*Low Impact Development*) practices are essentially based on storm water detention and retention associated with the infiltration, aiming at the temporal rearrangement and the damping of the outflow of surface runoffs and, eventually, the volume drained. Thus, they reduce the probability of floods and flash floods and allow gains in the quality of rainwater and surface wellhead sources that receive the discharge of urban drainage systems [3].

With the computational advancement, there are currently softwares that aid in the simulation of hydraulic and hydrological performance behavior of drainage systems. Some of these softwares contain hidden calculation processes for users, often presenting only the input interface and the result simply generated. This feature can lead the user to erroneous analyses or errors built into the generated models. In addition, automation and/or programming may hide parameters that are not applicable to different situations from those where the software was developed.

Thus, the objective of this paper was to compare the actual exit hydrographs of an experimental infiltration trench with the output hydrographs obtained through the computational model developed for this same trench using the Storm Water Management Model - SWMM Version 5.1.012 developed by US Environmental Protection Agency - EPA US.

2 Storm Water Management Model

The Storm Water Management Model (SWMM) is a dynamic model that simulates the quantity and quality of surface runoff and drainage systems flow especially in urban areas (Rossman, 2010).

The SWMM represents the behavior of a drainage system and models the environment in which it is implanted through four main modules, which are interrelated:

- atmospheric;
- soil surface;
- groundwater and
- transport.

The atmospheric module, through the object "rain gage", generates the flows incident on the soil surface module described by means of the "sub-catchement" object.

The soil surface module, after receiving input data from the atmospheric module, exports the water flow to the groundwater module through infiltration and propagates the surface runoff and transport of pollutants to the transport module which is represented by objects denominated "nodes and pipelines".

After all the characterization of the environment for the analysis by means of the definition of the objects (nodes, sections, subcatchments and rain gages), the propagation of the incident flows can be evaluated. Once the simulation is done the result is presented in different ways: tables, graphs and reports. All objects can be analyzed separately or together in the various parameters, such as: input hydrographs, water line levels in pipelines and channels, overflow volume, infiltrated volume, drained volume, etc.

The SWMM modeling process requires some parameters, such as: periods of analysis (beginning, interval and end), calculation methods and climatological parameters. Then, the objects must be defined according to the need of each modeling with the definition of the individual parameters of each one of them. Table 1 illustrates such objects.

Table 1 – SWMM input objects.

Hydrology	Hydraulic	Quality	Curves
• Rain gages	• Junctions	• Pollutants	• Control curves
• Subcatchments	• Outfalls	• Land uses	• Diversion curves
• Aquifers	• Dividers		• Pump curves
• Snow packs	• Storage units		• Rating curves
• Unit hydrographs	• Conduits		• Shape curves
• LID Controls	• Pumps		• Storage curves
	• Orifices		• Tidal curves
	• Weirs		
	• Outlets		
	• Transects		
	• Controls		

Source: authors.

The modeling of the LID structures – scope of the present research – is similar and independent of the type of system under study, that is, the water balance is made considering layers and processes related to the flow of water in the soil, as the diagram shown in Figure 1.

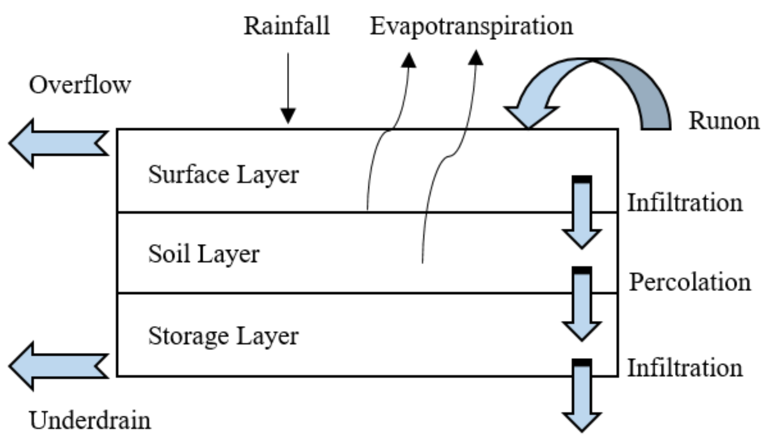


Figure 1 – Modeling of LID strategies in SWMM. Source: authors

3 Infiltration trench modeling: case study

To evaluate the ability to represent the observed conditions in the field of an infiltration trench, SWMM software was used for the hydrological modeling of the system. The experimental infiltration trench was sized for a contribution flow from rain caught by a contribution area equivalent to 53.0 m², in an asbestos-cement roof installed with a slope of 10%. For the storm simulation and flow measurement it was used centrifugal pumps with adjustable flow and high precision water meters were used.

A drilling of 0.80 m depth, 0.60 m wide and 5.0 m long was implemented with only the 0.60 m portion from bottom to top corresponding to the trench filled with gravel n. 1 enveloped with geotextile blanket (Bidim® RT-7). Therefore, the trench has a square section of 0.36 m² and a length of 5.0 m. The remaining portion on the 0.2 m infiltration trench was grounded with sand, Figure 2.

At the top of the infiltration trench, at a height of 0.60 m from the bottom, a drain was made of PVC pipe with drilled DN 100 with approximately 120 holes of 5/16" per linear meter, which has the function of overflowing the excess of water.

The rate of soil infiltration was determined by means of the average values obtained in water drawdown tests according to the criteria of [4]. Three uncoated wells with a diameter of 0.15 m and a depth of 2.50 m were drilled by means of an auger. These wells were filled with water after saturation of the boundary region and subsequently the lowering of water level was measured and translated into infiltration rate.

To generate the output hydrograph of the experimental trench considering the worst case of operation, they were filled and emptied three consecutive times in the interval of 6h: 12h: 6h, before each test. This procedure increased the degree of soil saturation in the environment, creating a critical operating scenario.

Through SWMM, it was generated a model that represents the described conditions and simulates the roof, the trench and the drain, as shown in Figure 2.

Experimental facility

Model used for simulation in the SWMM

Figure 2: Experimental infiltration trench and scheme used for SWMM modeling. Source: authors.

For the simulation, it was considered that the flow generated by the rain after falling on the roof is led by rails and conductors into the infiltration trench and after the water level reaches the maximum height, equal to 0,60 m. The excessive volume was sent to a buried reservoir where water level measurement and overflow volume determination were made, thus allowing the generation of the hydrograph measured *in loco* and the data adopted in the modeling through the SWMM.

For the comparison of hydrographs observed in the field and modeled by SWMM, the data monitored at the exit of the infiltration trench were obtained from two tests with the following project flows: I) discharge flow of 2.75 m³/h (45.90 L/min) with a duration of 30 minutes, equivalent to a rainfall of 52 mm/h; And II) discharge flow of 10,10 m³/h (169,60 L/min) with a duration of 8 minutes, equivalent to a rainfall of 192 mm/h of intensity. Both hydrological events refer to the rainfall data of the city of Campinas, São Paulo, Brazil and were defined by means of the rainfall equation developed by [5]

Due to the short duration of the tests limited by the volume of the reservoir that received the overflow water, the rainfall used in the computational modeling is equivalent to the projection of the events tested in the field for a period of 60 minutes. This consideration does not change the intensity of the design rainfall, only its duration, and was adopted to better represent a hydrograph in its phases of: (1) flow start (ascending stretch of flow curve), peak flow (phase in which the flow rate reached its maximum limit considering the influence of the entire contribution area) and (3) the end of the surface runoff phase.

It is worth to highlight that the longer duration of the design rainfall adopted in the modeling does not determine the reduction of the infiltration rate during the test, since as previously mentioned the measurements have already considered the worst situation in terms of elevation of soil saturation, with percolation occurring when the soil had already reached its field capacity.

From this, precipitations in the form of intensity were inserted in the object "rain gage" during the analysis period of 60 minutes, with a 10-second-interval between each entrance, according to Table 2.

Table 2 – Time series - Simulations I and II.

Simulation I		Simulation II	
Time (h:m:s)	Value (mm/h)	Time (h:m:s)	Value (mm/h)
00:00:00	52	00:00:00	192
00:00:10	52	00:00:10	192
00:00:20	52	00:00:20	192
00:00:30	52	00:00:30	192
00:00:40	52	00:00:40	192
00:00:50	52	00:00:50	192
00:01:00	52	00:01:00	192
...	...	...	...
01:00:00	52	01:00:00	192

Source: authors

Subsequently, the characteristics of the subcatchments were inserted. The important parameters in this case are:

- contribution area;
- flow characteristic width (division of the subcatchments area by the average of the maximum flow path lengths, according to [6]);
- slope;
- percentage of impermeable area;
- Manning coefficient of the impermeable area and
- LID structures adopted in each sub-area.

The LID structures considered in the present case study are:

- in the sub-area that represents the roof: Rooftop Disconnection.
- in the sub-area that represents the trench: Infiltration trench.

Both structures were applied throughout the corresponding sub-area, since the SWMM interprets and calculates the hydrographs of the sub-catchment according to the percentages of use of each inserted plot. Figure 3 shows the SWMM screen with the selection of the structures used.

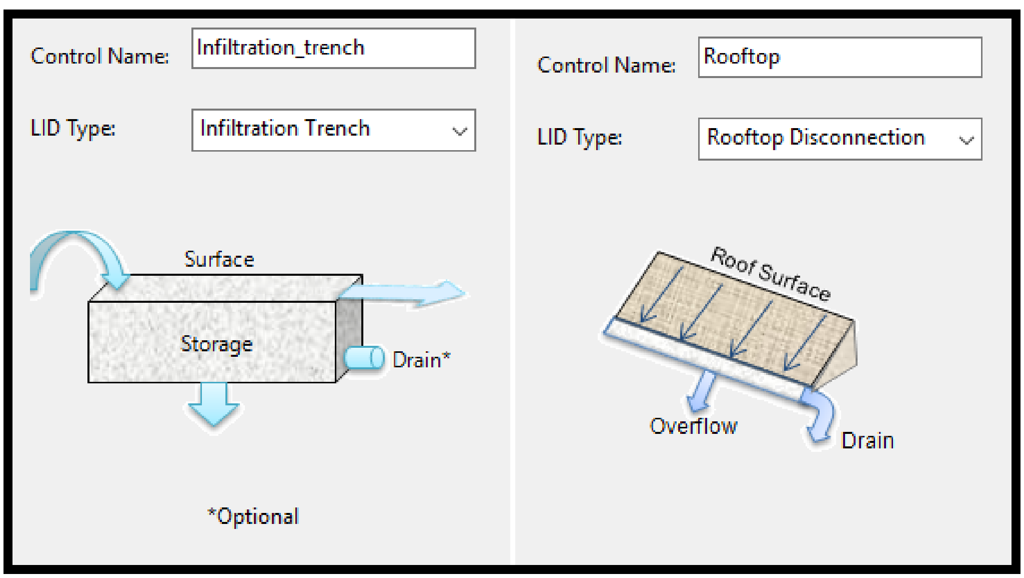


Figure 3- LID structures selected for this study. Source: SWMM 5.1

The simulation of the roof through the LID-Rooftop disconnection structure has as main objective the characterization of the way the flow is concentrated, after generation in the sub-area, in a pipe, thus representing the conductors and rails [6]. The layers considered in the simulation are: surface, with the parameters: Storage Depth, Surface Roughness and Surface Slope; and drain, with the parameter Flow capacity. From this, the SWMM determines the water balance of the structure under study, as shown in Figure 4.

The hydrological balance of this structure is simplified, considering the direct incidence of rainfall on the area, an increase of flow through other areas that go to this structure, the exit through the drain device and the volume exceeded. For the simulation in question, the discharge drain adopted was the one that has its output flow equalized to the inlet flow rate for each rainy event under study, thus ensuring that there is no overflowing of the structure before its full filling.

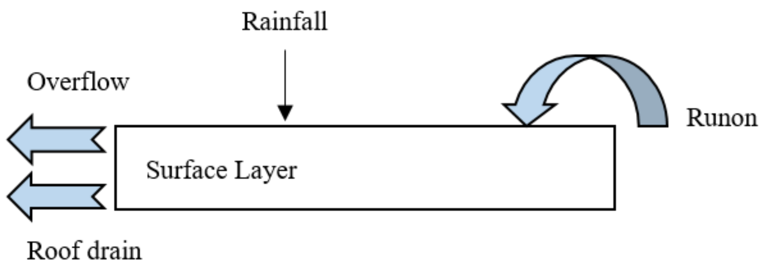


Figure 4 – Conceptual model of the LID structure Rooftop Disconnection. Source: authors

For the trench it was adopted the LID-Infiltration-trench-structure, with the following layers: a) surface, with the parameters Berm height, Vegetation Volume fraction, Surface roughness and Surface slope; b) storage, with parameters Thickness, Void Ratio, Seepage rate and Clogging factor; and c) drain, with the parameters Flow coefficient, flow exponent and Offset height. The water balance of this structure is represented by the SWMM as shown in Figure 5.

The hydrological balance of this LID structure contains elements of greater complexity, such as evapotranspiration. Like rooftop disconnection, there is inlet flow through direct rainfall and the addition of flows from other areas. The output is represented by the drain of extravasation, surface overflow, infiltration and evapotranspiration. As a transport element between the surface layer and the storage layer, there is percolation. In this structure, it was also adopted the drain with flow capable of supplying all the input contribution, thus avoiding the overflow before full filling of the trench.

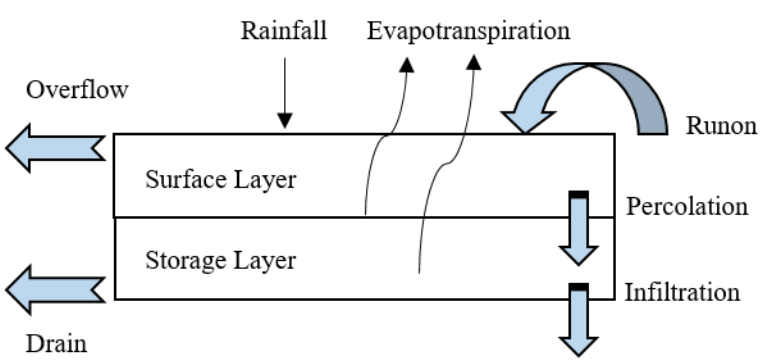


Figure 5 – Conceptual model of the LID structure Infiltration Trench. Source: authors

Tables 3 and 4 show the data of both structures for the two hydrological events considered.

Table 3 – Simulation I

Layer	Parameter	Rooftop Disconnection	Infiltration Trench
Surface	Berm height (mm)	--	0
	Vegetation volume fraction	--	0
	Surface roughness (Manning's *n*)	0.011	0.11
	Surface slope (%)	10	0
	Storage depth (mm)	0	---
Storage	Thickness (mm)	--	600
	Void ratio	--	0.577
	Seepage rate (mm/hr)	--	12.1
	Clogging factor	--	0
Drain	Flow coefficient (mm/h)	--	2759
	Flow exponent	--	0.5
	Offset height (mm)	--	600
Roof Drain	Flow capacity (mm/hr)	2756	---

Source: authors

Table 4 – Simulation II

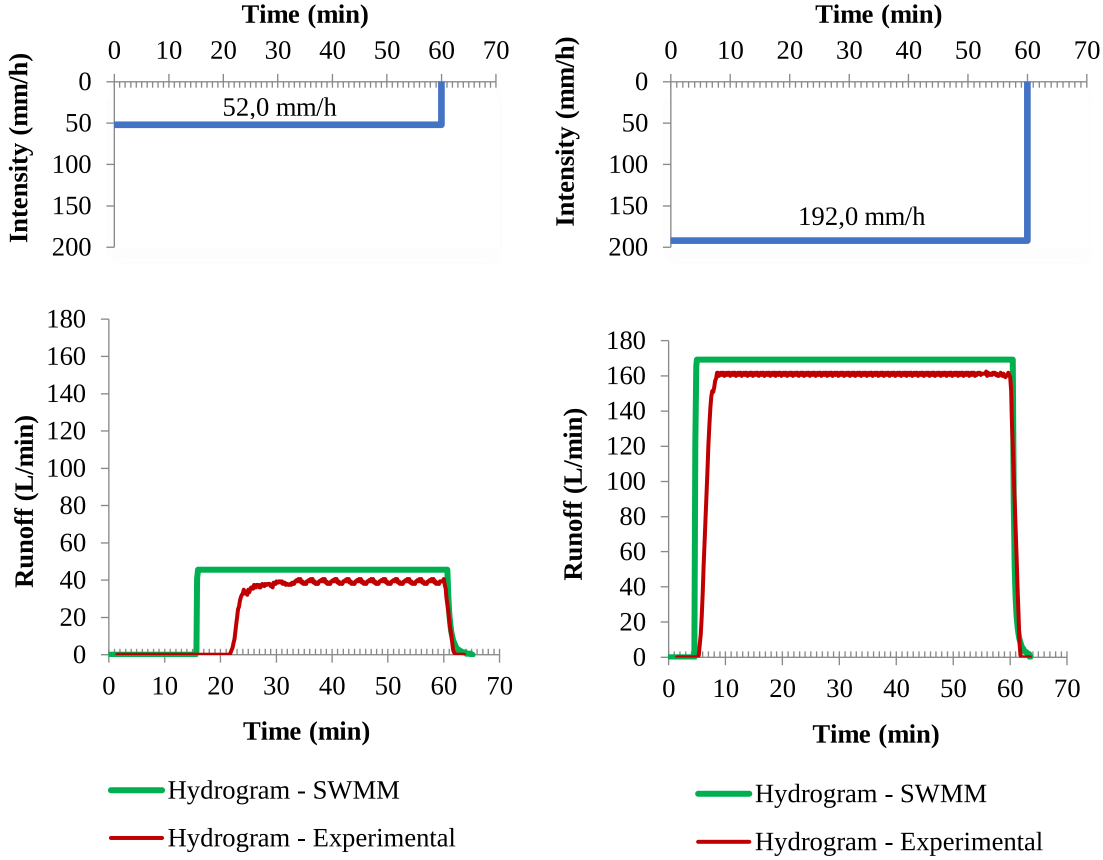
Layer	Parameter	Rooftop Disconnection	Infiltration Trench
Surface	Berm height (mm)	--	0.00
	Vegetation volume fraction	--	0.00
	Surface roughness (Manning's *n*)	0.011	0.11
	Surface slope (%)	10	0.00
	Storage depth (mm)	0	---
Storage	Thickness (mm)	--	600
	Void ratio	--	0.577
	Seepage rate (mm/hr)	--	12.10
	Clogging factor	--	0.00
Drain	Flow coefficient (mm/h)	--	10176
	Flow exponent	--	0.50
	Offset height (mm)	--	600
Roof Drain	Flow capacity (mm/hr)	10176	---

Source: authors

The Green-Ampt model was selected for the simulation since only soil parameters were available: the permeability coefficient, 12.1 mm/h, was determined by means of tests in the experimental installation. The infiltration rate, also used in the hydrological balance of the infiltration trench, refers to the speed of the infiltration rate, that is, the value at which the infiltration rate stabilizes and therefore corresponds to the permeability coefficient.

4 Results and Discussion

Figure 6 presents the experimental hydrographs modeled by the SWMM in the simulations with the two flows considered.



Scenario I – i=52,0mm/h **Scenario II – i=192,0mm/h**

Figure 6: Experimental hydrographs and modeled by SWMM. Rainfall duration projected for 60 min. Source: authors

The constant oscillation in the experimental hydrographs after the beginning of the reading can show factors resulting from the measurements, such as perturbations in the liquid line or the occurrence of expulsion of air from the soil during filling of the emptiness. In the case of the hydrograph generated in the SWMM; this oscillation does not occur because only the water balance between the input and output of the system is considered, which is evidenced by the linear threshold.

It was verified that for both simulations in both hydrographs the flow decay begins after the end of the precipitation, being more abrupt in the experimental model

The exponential decay in the case of the model can be explained by the fact that the SWMM considers that the infiltration occurs only by the bottom layer. In the real cases the infiltration occurs on the entire soil surface where the trench is inserted, that is, bottom and side. Such simplification of the infiltration model causes the decay to occur more slowly.

For Scenario I, the SWMM model indicated a peak flow of 45.60 L/min while the experimental model showed a peak of 45.12 L/min, a difference of 1.05%. However, the beginning of the overflowing in the SWMM model occurred with 940 sec., and in the experimental installation model it was 1310 sec.

In the case of Scenario II, the SWMM model indicated a peak flow of 169.20 L/min, while the experimental model reached 174.04 L/min, representing a difference of 2.76% less than SWMM in relation to the experimental model. The beginning of overflowing in the SWMM model occurred with 280 sec, in the experimental model, this parameter was 320 sec.

As with decay, the anticipation of runoff time (trench overflowing) may have resulted from the infiltration condition only by the trench bottom layer, which limits the representation with greater accuracy of the initial overflowing condition. Despite this, the damping of the flow after the stabilization of the peak flow was very close and could result in data closer to the real.

It is verified that despite the reported differences in beginning time, end time, stability of the water balance and flow peaks, the model has good adherence to the observed data.

The use of technical devices such as interpretations of input data, adjustments and treatment of physical parameters and knowledge of the software design interface is of paramount importance for the generation of this specific result.

5 Conclusion

The infiltration of stormwater into source drainage systems still require a greater focus by the researchers and construction industry, aiming the dissemination of LID practices and the consolidation of calculation parameters. The definition of the regional parameters of each system and public guidelines to encourage them are key factors for the adoption of such systems in a conscious and optimized way.

The complete understanding of the modeling processes must be precondition on the use of Storm Water Management Model - SWMM effectively, avoiding the generation of models that do not represent reality. For that, it is important that input parameters be well defined and refined.

For the development of this research several technical devices were necessary for the software to correctly interpret the input data to produce results as close as possible to reality.

As an example, we can mention the definition of the precipitation time series, where precipitation values were inserted every 10 sec for the program to interpret the data as a continuous rainfall, with duration of 60 min, established premise in the simulation. If these parameters were erroneously interpreted and only an initial and an end value were inserted, it would be considered by the software that there was only precipitation at the beginning and end of the modeling period, generating hydrographs in the wrong way.

In the experimental facility, there is a layer of sand in the final portion of landfill with 0.20 m, which could not be considered in the SWMM model. In this case, one option would be to consider the Bio-Retention structure, which has different characteristics compared with the infiltration trench. Thus, structures that have different construction patterns than those foreseen by the software require adjustments and technical devices for their use.

However, the SWMM showed good efficiency in the sizing processes when compared to the results observed experimentally for the case study developed in this work, constituting an option for the design of this system.

6 Acknowledgments

CNPq - Conselho Nacional de Desenvolvimento Científico e Tecnológico (National Council for Scientific and Technological Development); FAPESP – Fundação de Amparo à Pesquisa do Estado de São Paulo (Foundation for Research Support of the State of Sao Paulo).

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Presentation of the Authors

Renato Nunes de Mattos is Civil Engineer (at the time that this research was conducted, graduate student in the School of Civil Engineering, Architecture and Building Design, University of Campinas, Sao Paulo, Brazil).

Ricardo Prado Abreu Reis is professor at the School of Civil and Environmental Engineering of University of Goiás (at the time that this research was conducted, graduate student in the School of Civil Engineering, Architecture and Building Design, University of Campinas, Sao Paulo, Brazil).

Dr. Marina Sangoi de Oliveira Ilha is professor at the Department of Architecture and Building Construction, School of Civil Engineering, Architecture and Urban Design, University of Campinas, Campinas, SP, Brazil. She is the dean of the School of Civil Engineering, Architecture and Urban Design since 2014 and the head of the Building Services Research Group.

Session D Drainage sanitation and indoor environment pollution control

D1 - A study on the applicability of a hybrid drainage system to commercial building conversions

Yudai Motomura(1), Masayuki Otsuka(2), Shingo Tanabe(3), Kaori Shiraishi(4)

1. m17J3022@kanto-gakuin.ac.jp
2. dmotsuka@kanto-gakuin.ac.jp
3. shingo.tanabe@nikken.jp
4. shiraishi.kaori@nikken.jp

(1) Graduate Student, Graduate School of Engineering, Kanto Gakuin University, Japan
(2) Prof. Dr. Eng., Department of Architecture and Environmental Design, College of Architecture and Environmental Design, Kanto Gakuin University, Japan
(3) Engineering Department, M & E Engineering Division, Mechanical & Electrical Design Section, Mechanical Engineer, NIKKEN SEKKEI LTD, Japan
(4) Engineering Department, M & E Engineering Division, Mechanical & Electrical Design Section, Mechanical Engineer, NIKKEN SEKKEI LTD, Japan

Abstract

The study focuses on the actual applicability of a hybrid drainage system of force-feed-type and gravity-type drainage systems to commercial building conversions, the hybrid drainage system which allows the installation of water supply spaces freely according to the change of use of buildings. During the study, the performance of the hybrid drainage system was verified by designing it and introducing it to an actual building.
The findings of an investigation on said hybrid drainage system were reported at the 42nd International Symposium of CIBW062 held in Slovakia in 2016, the investigation in which the hybrid drainage system was connected to a drainage stack system in a super high-rise building, and the influence of the hybrid drainage system on the performance of the drainage stack system was examined for approximately six months. This report presents further findings of the investigation as well as the findings of an investigation of the influence of noise generated by the force-feed drainage pump, when in operation, on the habitability of the building, thus, verifying the effectiveness of said hybrid drainage system from a comprehensive perspective, and consequently confirms the effectiveness of applying said hybrid drainage system to commercial building conversions.

Keywords

hybrid drainage system, conversion

1 Background and objectives of the study

In Japan, while high-rise office buildings are being built in central cities, construction and design are expected to be flexible to accommodate changes in the use of such buildings in response to the surrounding environmental conditions and diverse tenants' needs. However, when adding water supply spaces or renovating them, it is difficult, with the current gravity-type drainage system, to secure adequate room and pitch to house horizontal drainpipes, and it has been a problem that locations for providing water supply spaces are restricted.

With the intention of addressing the problems, the study proposes a hybrid drainage system, which is a cross between the force-feed-type drainage system using a force-feed-type drainage pump and the commonly used gravity-type drainage system. The study also examines the performance of the hybrid drainage system by actually applying it to the conversion of a super high-rise commercial building to verify the effectiveness of said hybrid drainage system. The report focuses on the following four points:

(1) Planning and overview of the hybrid drainage system for building conversions

(2) Evaluation of the influence of the hybrid drainage system on the drainage performance of the existing drainage stack system

(3) Evaluation of the noise of the force-feed-type drainage pump

(4) Effectiveness of applying the hybrid drainage system

2 Overview of the hybrid drainage system

Fig. 1 shows a conceptual diagram of the hybrid drainage system that is applied following the conversion of the first floor of an office building to accommodate gynaecology clinics with small water supply spaces. In said drainage system, toilet, basin and washing machine booths (1) are installed in predetermined locations, and the wastewater from these fixtures is first taken into a force-feed-type drainage pump (2). The wastewater is then pumped up through a force-feed drainage pipe (3) into a horizontal drainpipe (4) installed in the ceiling and eventually into a drainage stack (5). By this, many water supply spaces can be created in addition to the toilets already installed in the original communal zone.

The previous study[4)] proposed a similar system for apartment housing. This study makes use of the knowledge acquired in the previous study to discuss the applicability of the hybrid system for offices.

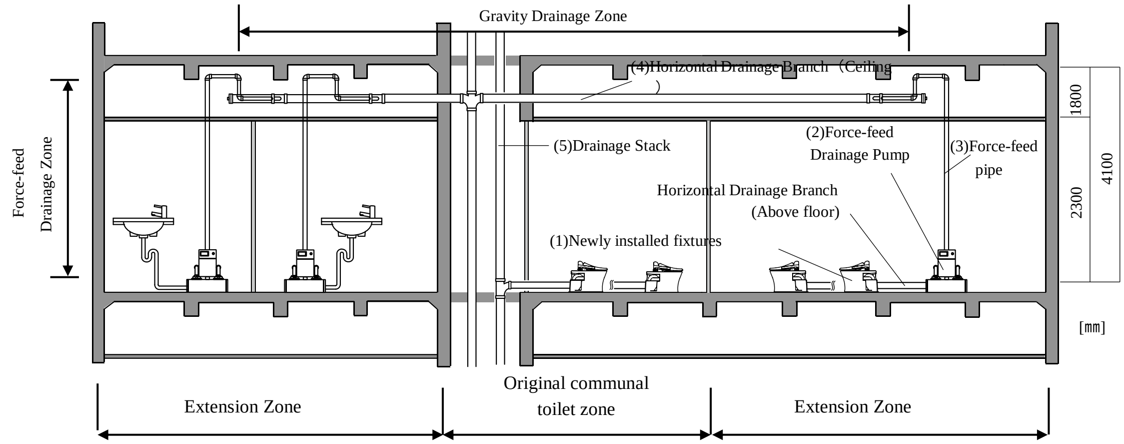


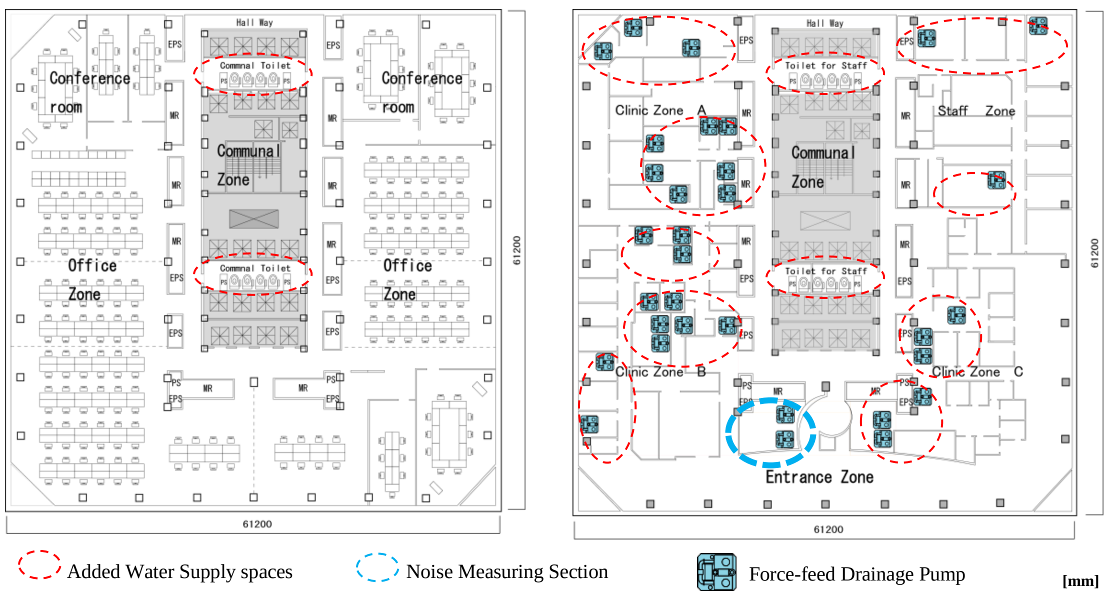
Fig. 1 Conceptual diagram of the force-feed/gravity-type hybrid drainage system

3 Overview of the applied case

Table 1 shows the overview of the building to which the hybrid drainage system was applied. The building has 37 storeys above the ground and is mainly for commercial and office use. The 15th floor was converted. **Fig. 2 (1)** shows the floor plan of the 15th office floor before conversion, **Fig. 2 (2)** shows the floor plan of the gynaecology clinic floor after conversion, and **Fig. 3** shows a schematic diagram of the drainage system. On the converted 15th floor, 34 force-feed pumps of various types are installed (see **Photo 1** for the appearance and **Fig. 4** for the pump capacity curve of each type) and the wastewater from various sanitary fixtures is guided above the floor. The force-feed drainage pumps are respectively connected to force-feed drainage pipes of 25A, 40A, 50A and 65A, according to the pump capacity, which are connected, using anti-backflow joints, to a 100A horizontal drainpipe installed in the ceiling. The wastewater is guided through these pipes and eventually into a 100A drainage stack. The wastewater is then guided through a 100A house drain provided in an offset section on the 8th floor and discharged to the outside together with the wastewater from the other floors. The force-feed drainage pumps are also connected to 20A and 32A vent pipes and the force-feed drainage pipes and the drainage stack are also connected to 50A and 100A vent pipes, respectively. **Fig. 2 (2)** and **Fig. 3** also show a section for measurements that were carried out during the study.

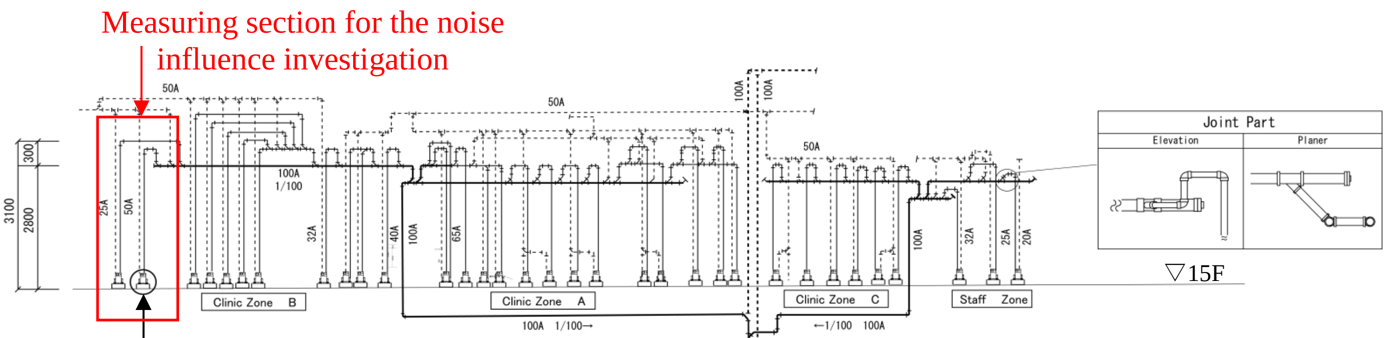
Table 1 Overview of the applied building

Intended use	Commercial facilities / Offices / Hotels, etc			
Area	Building area	15597.79m^2	Floor area	294775.31m^2
Structure	S/SR/SRC			
No.of storeys /Height	No.ofstoreys	37 Floor including 3 basement floors	Height	175.3m
Target Floor intended use	Before	Office	After	Gynaecology Clinic
Target Floor area	3745.44m^2			



(1)Before (Offices) （2） After(Gynaecology Clinic)

Fig. 2 Floor plan of the 15th floor before and after the conversion



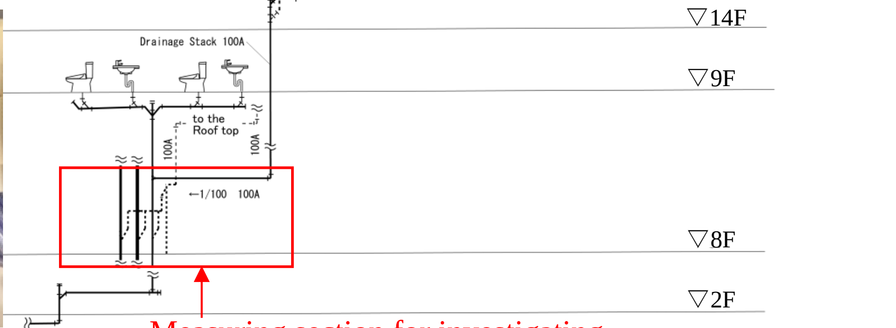


Photo 1 Force-feed drainage pump

Fig. 3 Schematic diagram of the drainage stack system

legend	Force-feed Pump	Specifications		No.of Pumps inlled	legend	Force-feed Pump	Specifications		No.of Pumps inlled
	(Ⅰ)	Type	Sewage/Watewater Drainage System	1		(Ⅱ)	Type	Sewage/Watewater Drainage System	4
		Pump Capacity	175L/min				Pump Capacity	50L/min	
		Tank Capacity	200L				Tank Capacity	20L	
		Head	12m(120kPa)				Head	12m(120kPa)	
	(Ⅲ)	Type	Watewater-only tank-less force-feed Drainage System	25		(Ⅳ)	Type	Sewage/Watewater tank-less Drainage System	4
		Pump Capacity	35L/min				Pump Capacity	35L/min	
		Head	6m(60kPa)				Head	6m(60kPa)	

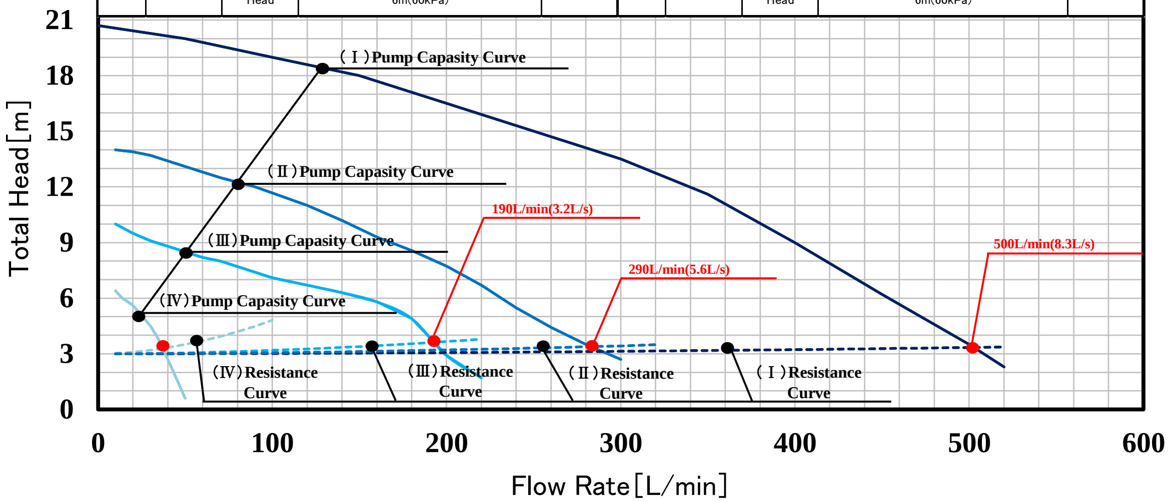


Fig. 4 Force-feed drainage pumps and the pump capacity curves thereof

4 The scope of the investigations to be conducted

The report describes two investigations that were conducted during the study: an 'investigation of influences on the existing drainage stack', by which the influence of wastewater from said drainage system on the existing drainage stack was examined, and an 'investigation of the influence of force-feed drainage pump noise', by which the influence of noise from the force-feed drainage pump on habitability was examined.
The 'investigation of influences on the existing drainage stack' was carried out on the existing drainage stack system (see **Fig. 5**), in which the water level was measured at point Ⓗ of the house drain by using an ultrasonic water level sensor (see **Photo 3**) and the in-pipe pressure was measured at point Ⓟ, where the joint for full-water testing is located, along the drainage stack by using a pressure sensor (see **Photo 4**). Incidentally, the investigation was carried out on an actual building for approximately one year between 24 September 2015 and 27 December 2016, and the sampling interval was set to 1[sec].

Photo 4 In-pipe pressure variation measuring point

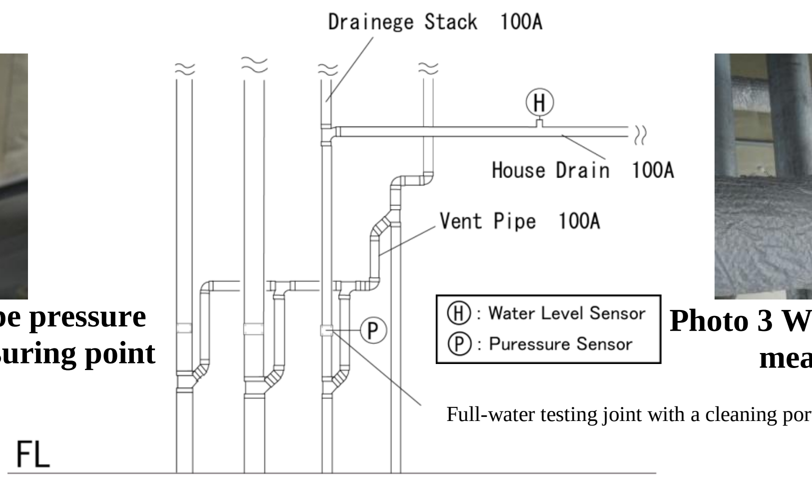



Photo 3 Water level variation measuring point

Fig. 5 Measuring points for the investigation of influences on the existing drainage stack

The 'investigation of the influence of force-feed drainage pump noise' was carried out to see how the noise from the force-feed drainage pump housed in the pump booth would affect the toilet booth and entrance areas (see **Fig. 6**) by simultaneously measuring the noise level with a noise meter (see **Photo 5**) at point ① and the noise level at points ② to ⑧ (point ⑧ is outside the pump booth), respectively, with another noise meter. As well as measuring noise levels, a water pressure sensor (see **Photo 6**) was attached to the force-feed drainage pipe (see **Fig. 7**) to measure the variation of the water pressure in said pipe so that the behaviour of the force-feed drainage pump could be identified. Incidentally, the noise measurement and water pressure measurement were carried out using the force-feed drainage pump for handling wastewater from the male toilets.

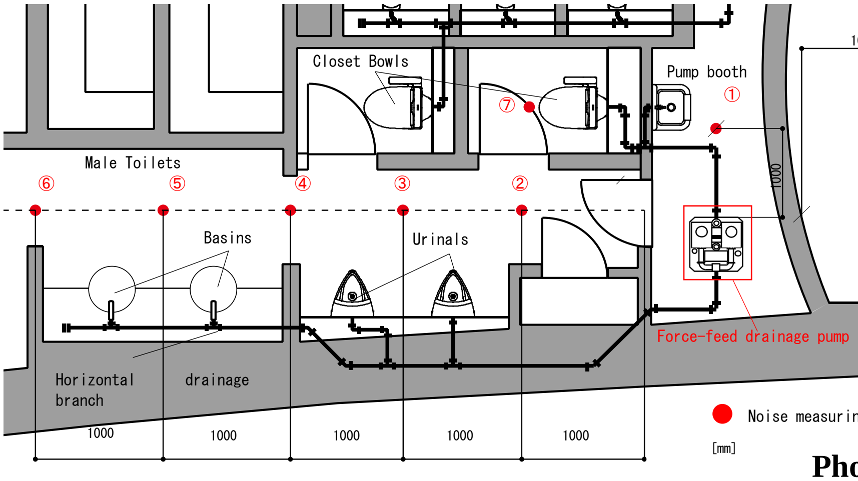


Fig. 6 Noise level measuring points - plan view

Photo 5 Noise level measuring point (Point ①)

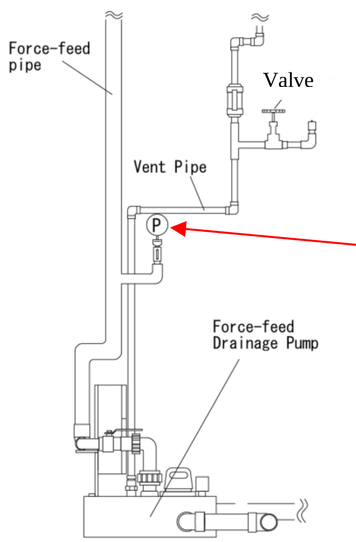


Fig. 7 The outline of the pump for measurements

Photo 6 Water pressure measuring point

5 Consideration of influences on the existing drainage stack system

In the experiment described in the previous report[2)], a horizontal drainpipe model was set up using the same diameter and material as a real horizontal drainpipe, and the drainage load flow rate was measured with a flowmeter attached to the intake port of the model, while the drainage load flow rate was also estimated by applying a Manning's equation to a water level measurement. It was subsequently confirmed that there was a correlation between the actual measured drainage load flow rate and the estimated drainage load flow rate. Therefore, in this report, similarly to the previous report, the influence of the drainage load flow rate calculated from an actual water level measurement by using a relational expression is discussed.

The water level was measured at point H of the house drain in the 8th floor offset section (see **Fig. 3**), and, as described before, the drainage load flow rate was estimated from the measured water level by applying a relational expression. However, when looking at the waveform of measured values closely, it is evident that some measurements reflect the case where wastewater, from a washing machine for example, contains detergent foam. In that case, as in the previous report, the detergent foam was disregarded and only the actual wastewater was taken into observation.
Fig. 8 shows the transition of the daily maximum drainage load flow rate calculated from the variation of water level. The diagram also shows the allowable flow rates for 75A and 100A house drains in accordance with SHASE-S206. The maximum value is approximately 2.5[L/s], which is approximately 44% of 5.6[L/s], the allowable flow rate for 100A (pipe gradient 1/100) horizontal drainpipes in accordance with SHASE-S206. Therefore, it is considered that the hybrid drainage system is adaptable to drainage stacks and offsets having the same diameter under the current design, thus, not requiring diameter expansion, in other words, the hybrid drainage system can be introduced while using the existing drainage stack system.

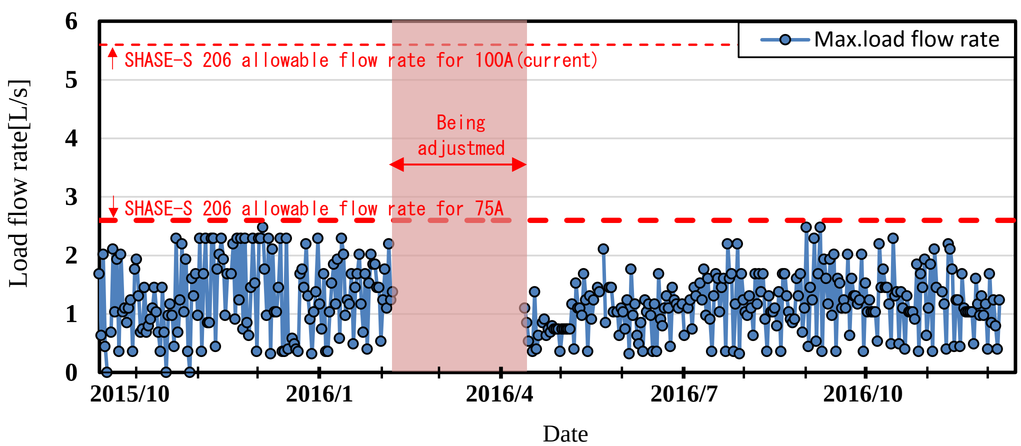


Fig. 8 The transition of the daily maximum drainage load flow rate (24 Sep. 2015 to 25 Dec. 2016)

Fig. 9 shows the number of times of generating drainage loads on a weekday and a Saturday that were selected as typical days. According to **Fig. 9**, most of the load flow rates are less than 1.0[L/s]; on the weekday, approximately 80% of the drainage load flow rates are roughly 0.5[L/s], and on the Saturday, approximately 90% of the load flow rates are about 0.5[L/s] even at the highest. Moreover, only 1% of the drainage loads were generated at 1.5-2.5[L/s] during each day. This suggests that because the flow rate of pumped wastewater decreases by the time the wastewater flows in the house drain and flows down a long distance, the influence of the wastewater on the drainage performance of the drainage stack decreases.

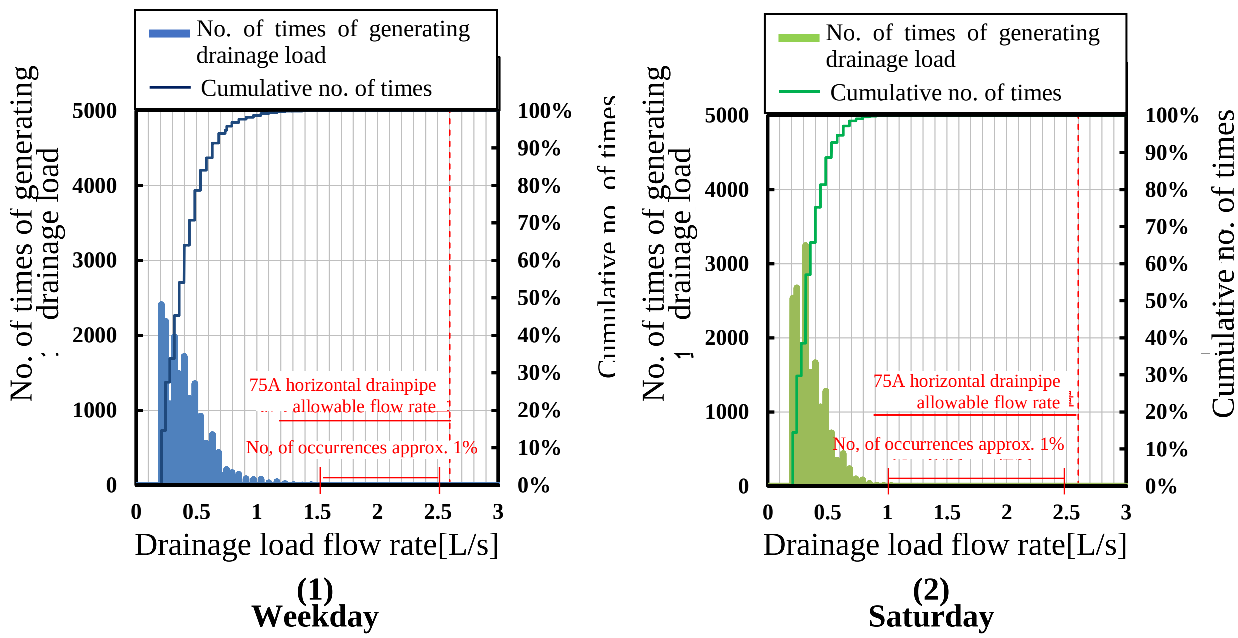


Fig. 9 The number of times of generating drainage loads on a weekday and Saturday

Fig. 10 shows the transition of the average of the maximum and minimum daily in-pipe pressure values taken at point P along the drainage stack (see **Fig. 3**) during the experiment period. According to **Fig. 10**, the maximum in-pipe pressure value on the negative pressure side is approximately -300[Pa], and the maximum in-pipe pressure value on the positive pressure side is approximately 180[Pa]. The variation of the in-pipe pressure is in a range which is roughly 75% of ±400[Pa], the reference range specified SHASE-S218, and therefore, it is considered that the hybrid drainage system can be operated safely.
In addition, a large number of values close to the minimum values are recorded in October, and it is thought that this was caused by the increased number of times of discharging wastewater along with the increased number of clinic users during the month.

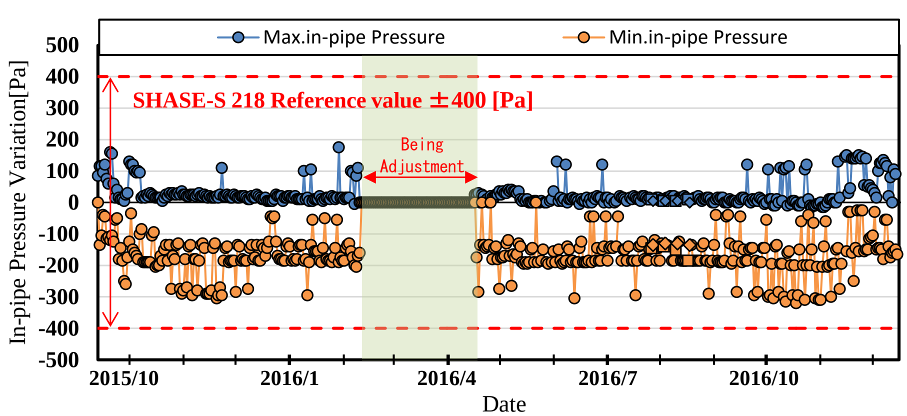


Fig. 10 The transition of the maximum and minimum values of daily in-pipe pressure
(24 Sep. 2015 to 25 Dec. 2016)

6 Consideration of the influence of noise generated by the force-feed drainage pump

Fig. 11 shows the comparison between the noise level of the pump in operation, which was measured at point ①(see **Fig. 6**), and the water pressure in the force-feed drainage pipe, which was measured at point P (see **Fig. 7**). According to the waveform of the pump noise, it is right to classify the pump noise into four groups depending on the operation stage; (1) the noise generated at startup, (2) the noise generated during motor operation, (3) the impact noise generated at shutdown, and (4) the background noise after shutdown.
Moreover, the level of noise generated at startup was 65.9[dB(A)] and the level of impact noise generated at shutdown was 69.5[dB(A)]. Therefore, these two noise levels are greater than the level of noise generated during motor operation and the level of background noise.

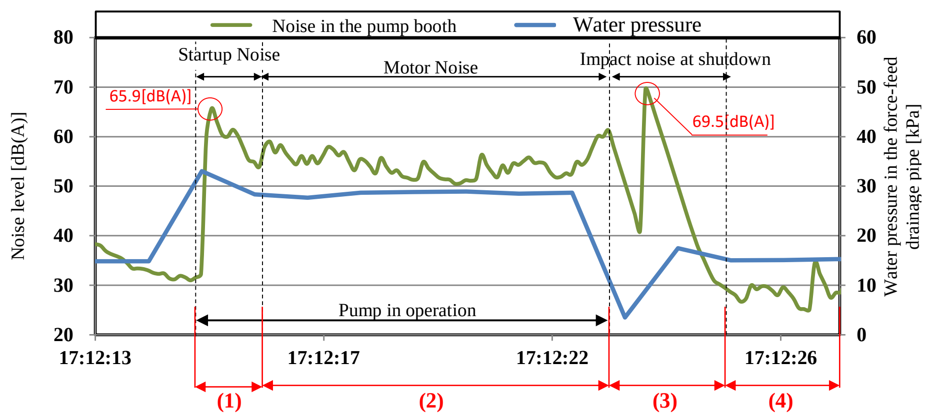
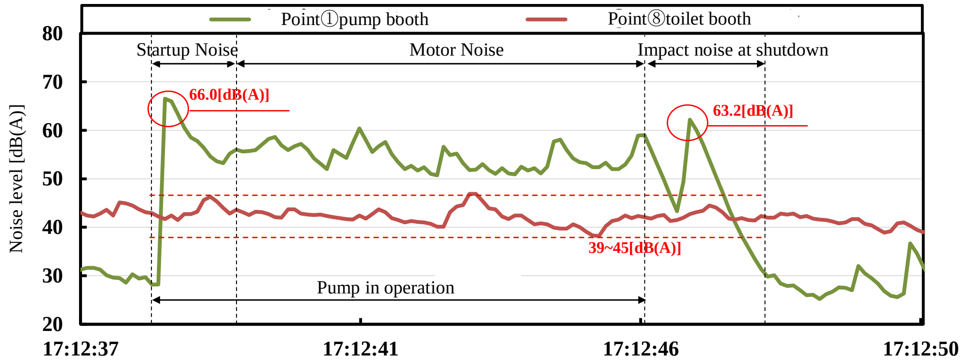
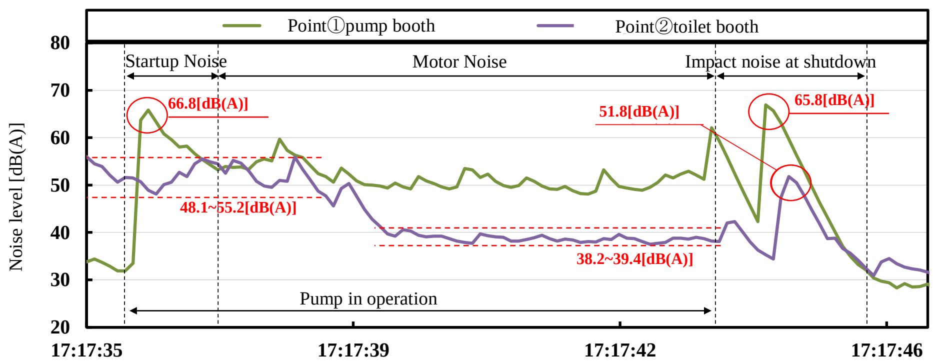


Fig. 11 The noise level measured at point ① during pump operation and the water pressure in the force-feed drainage pipe

Fig. 12 shows typical noise levels measured at points①, ②and ⑧during pump operation. According to **Fig. 12 (1)**, the noise level measured at point ⑧(the entrance) varies with time between 39[dB(A)] and 45[dB(A)]. Because the variations of the previously mentioned noise levels measured at startup and shutdown , which were predicted to have a significant influence, cannot be confirmed, and because no significant variation of noise level through the stages of the start, middle and end of operation is observed, it is right to assume that there is little influence caused by the pump noise.
According to **Fig. 12 (2)**, the impact noise level generated at shutdown is approximately 52[dB(A)], and because there is no significant change supposedly caused by the variation of noise generated before startup, at startup, and during motor operation, it is right to assume that the influence of the noise generated in the toilet booth is dominant. Therefore, although the impact noise generated at shutdown can have a little influence on the rooms surrounding the pump booth, though depending on the room location, it is right to assume that on the whole, the influence of the noise generated at startup or during motor operation is small.



(1) Noise levels at point ① and point ⑧



(2) Noise levels at point ① and point ②

Fig. 12 Noise levels measured at point ① and points ② and ⑧ during pump operation

Fig. 13 compares the averages of noise levels measured at the measuring points and at the pump operation stages, respectively. According to **Fig. 13**, the peak noise level measured at startup and the peak impact noise level measured at shutdown are both in the approximate range of 50-53[dB(A)]. In the entrance (at point ⑧), the noise of the pump in operation was measured approximately 50[dB(A)], and is approximately 10[dB(A)] lower than 60[dB(A)], which is the level of noise generated by general conversation. At point ②in the toilet booth, the level of impact noise at shutdown made no difference with or without BGM. However, the levels of noise measured during motor operation and at startup are 3-5[dB(A)] greater with BGM than without BGM. Therefore, it is considered that the influence of the noise generated while the force-feed drainage pump is in operation and at startup of the pump is small. The maximum level of impact noise at shutdown is approximately 53[dB(A)], and this is lower than the maximum noise level of 80[dB(A)] measured when flushing a gravity-type toilet in the experiment described in the previous report5). Therefore, it is right to assume that the influence of the impact noise is small.

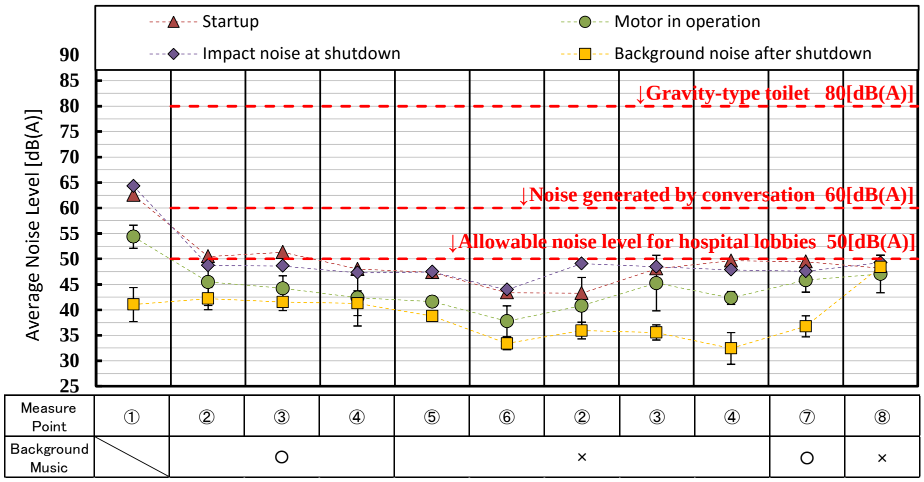


Fig. 13 Comparison of the averages of noise levels measured at the measuring points and at the pump operation stages

7 Conclusion

The study proposed a hybrid drainage system adaptable to building conversions, which uses the force-feed type and gravity-type drainage systems. The verification experiment described in the previous report was extended for another eight months and was carried out on the actual building for a total of 16 months while considering the findings from the previous experiment. An investigation was also carried out to identify the influence of the noise of a force-feed drainage pump when in operation. According to the findings acquired from the verification experiment and noise investigation, it was confirmed that the hybrid drainage system could be operated without interfering with the drainage performance. In addition, it was found that the noise level of the pump was more or less the same as the allowable noise level for hospital lobbies. Therefore, the effectiveness of said hybrid system was verified. The findings acquired from the experiment and investigation are as follows.

(1) The variation of drainage load is in a range that is approximately 44% of the allowable range for 100A house drains in accordance with SHASE-S206, and it is possible to reduce the pipe diameter.
(2) The occurrence where the drainage load reaches a maximum value is rare.
(3) The variation of the pressure in the drainage stack is in a range that is approximately 75% of the reference range specified by SHASE-S218.
(4) The noise level generated by the force-feed drainage pump was measured to be approximately 70[dB(A)] in the pump booth and the pump noise level measured around the pump booth was very similar to the reference value of 50[dB(A)].
(5) Subsequent to the above findings, the effectiveness of adapting said hybrid drainage system to building conversions has been verified.

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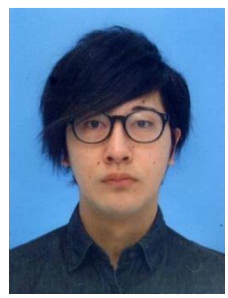
9 Presentations of Authors

Yudai Motomura is a master of the Otsuka Laboratory, Kanto Gakuin University. He is a member of AIJ (Architecture Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His latest interests is to acquire knowledge about the hybrid drainage system that uses both force feed type and gravity type drainage methods.



Masayuki Otsuka is a professor at Department of Architecture and Environmental Design, Kanto Gakuin University. He is a member of AIJ (Architecture Institute of Japan) and SHASE (the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His latest interest is the development of a hybrid drainage system that uses both force feed type and gravity type drainage methods compatible with commercial building conversions.

Shingo Tanabe works in the Department of Environment & MEP Engineering of NIKKEN SEKKEI LTD. Among his studies, He made an achievement particularly in the development of a natural ventilation system applicable to large buildings. He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, academic director). Currently, he has been engaged in ZEB and Life Cycle design.

Kaori Shiraishi works in the Department of Environment & MEP Engineering of NIKKEN SEKKEI LTD, and mechanical design of various sizes and uses such as offices, hospitals, city halls and the like. She is design not only new buildings but also conversion from office to clinic. In addition analyze energy in office buildings and verify the performance after building operation.

D2 - Air pressure transient generation, propagation and alleviation in tall buildings

M. Gormley (1), D.A. Kelly (2)
1. m.gormley@hw.ac.uk
2. d.a.kelly@hw.ac.uk
(1) & (2) School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, Scotland, UK

Abstract

Air pressure transients are inevitable in any fluid transportation system. This is no less the case in building drainage systems (BDS) where flows are due to random discharges from appliances leading to unsteady flow conditions throughout the system. In addition to the random nature of discharges there are other contributing factors to the magnitude and duration of air pressure transients generated within a BDS. Since the mechanism for air pressure transient generation is due to the fundamental Joukowski equation relating pressure rise to fluid density, fluid velocity and local acoustic velocity, then air/water traction forces, flow rate, pipe diameter and pipe length are all logically significant. Of increasing concern amongst design engineers is the loading of the main vertical stack in tall buildings, and in particular, those over 50 floors. There is now an increasing body of evidence which suggests that current methods and technologies are unable to cope with the excessive magnitude of air pressure surges possible in tall buildings. With the growth in the number of tall buildings around the world the need for a means to understand and cope with these challenges has never been greater. Current alleviation devices are designed to protect water trap seals against air pressure transients in the region of 100 mm water gauge (approximately 1000 Pa) with an associated air volume of around 4 litres. In tall buildings, it is not uncommon for a system to experience air pressure transients in excess of 1500 mm water gauge (15000 Pa) due to surcharges in the main sewer. An evaluation of air pressure transient generation and propagation is presented together with an innovative solution to alleviate such pressure surges in tall buildings.

Keywords

Air pressure transients. Building drainage, alleviation and suppression, tall buildings.

1 Introduction

Any fluid carrying system will be subject to local pressure rises in the form of transient pressures or surges due to the inevitable changes in flow conditions experienced by the system.(Swaffield, 2010) The instances of pressure rise in building drainage systems (BDS) is more common since all flows are as a result of random discharges of unsteady flows from sanitary fixtures such as WCs, sinks, baths and showers. Another significant factor in relation to BDS is the fact that the system is designed to expel waste water from a building, yet the vulnerability of the system depends on its ability to cope with the significant airflows induced as a result of the shear force between the water falling in the main stack and an entrained central air core. This shear force sets up airflows with an attendant air pressure regime. It is these air pressure fluctuations which designers try to avoid in the design stage (Swaffield, 2010).

The ingress of malodourous air into a building may be bothersome and unpleasant, however there is a far more dangerous aspect to this breach in seal. Recent work has shown that the turbulence in building drainage system water flows is sufficient to aerosolise bacteria which can then be carried on BDS airflows and emerge into the building by trap seal breaches caused by excessive air pressure transients (Gormley *et al* 2017, Gormley *et al* 2013, Gormley *et* al, 2011, Hung *et al* 2004).

The invention of the first ever positive air pressure transient attenuator designed specifically for use in building drainage systems in 2001 (Swaffield *et al* , 2005[a,b]), provided a significant new design option to engineers and architects faced with limiting the low amplitude air pressure transients likely to be found in these systems. This device was designed to cope with low amplitude pressure transients with a peak positive pressure up to approximately 100 mm wg (1kPa), with options for increasing this by adding two or more devices in series. It should be remembered that most water trap seals are 50 mm deep (with WCs 75mm deep) and so these water trap seals are vulnerable to any pressure transient in excess of 75 mm. These low amplitude air pressure transients are generated from momentary occlusions to the passage of air caused by a confluence of water flows within the building drainage system or temporary surcharge in the main sewer. In general, these events are fleeting, however they can create low amplitude air pressure transients of sufficient magnitude to cause breaches in the trap seal.

There is growing evidence of the occurrence of very large air pressure surges in super high rise buildings, defined here as over 50 storeys tall. (Swaffielld, 2010). One specific case in a high rise housing block in Hong Kong recorded positive pressure transients sufficient to blow water out of a WC pan some 2 metres into the air in the bathroom (Swaffield, 2010). Further anecdotal evidence gathered by the authors refer to pressures sufficient to lift manhole covers adjacent to buildings. Unlike low amplitude air pressure transients, these large air pressure waves are usually generated at the BDS/sewer interface. Other likely causes are offsets in the main vertical stacks, which should be avoided in the design.

The aim of this research was to develop the necessary understanding of air pressure surges within the building drainage system of tall buildings in order to develop a practical solution to alleviate such pressures which would be suitable for installation within a building.

2 Methodology

The methodology employed focuses on two main investigative techniques: numerical simulation of an ideal attenuator and establishing operational parameters for the physical model and the construction of a full scale model

1. Airnet simulation of various configurations
2. Full scale tests on a representative 160 m (44 floor) test rig

2.1 Theoretical device

A theoretical device was developed, simulated and appraised using AIRNET,a method of characteristics based finite difference (FD) model which was developed at Heriot-Watt University initially by the late Professor Swaffield and is under continued development. This model simulates whole system responses to air pressure and water flow in a building drainage system (Swaffield, 2010).

A pressure transient alleviation device must be able to provide an alternative route along which a significant portion of the pressure wave can propagate away from the areas of the system to be protected. In effect, this key attribute disperses and attenuates the propagating pressure wave.

Note that for the case of the ideal attenuator the coefficient of refection can be ignored: modelling the exit branch as very long (infinitely long) means that there will be no reflection from the branch termination. This is useful in assessing the attenuating effect of exit dimensions only. Any reflection would occur at a time determined by the pipe period of the branch, given as

$$pp = 2L/c \qquad (1)$$

Where,
pp = pipe period
L = distance to the termination, reflecting exit
c = wave speed.

The inclusion of a branch creates a junction along the vertical stack where the proportion of the propagating pressure wave, which is transmitted beyond the junction, is determined by the cross sectional area of the pipes creating the junction and the wave propagation speed within them. Furthermore, the greater the cross sectional area of the branch, the smaller the proportion of the pressure wave transmitted. Figure 1 illustrates the relationship between branch to stack area ratio, the number of junctions traversed, and the resultant proportion of the propagating pressure transient transmitted. The branch length is assumed to be sufficiently long (greater than the pipe period of the whole system) as to allow any reflections from branch terminations to be ignored. Therefore, for a branch to stack area ratio of 1.0, after traversing 10 such junctions, the transmitted pressure wave drops to just 2% of its original magnitude, a reduction of 98%.

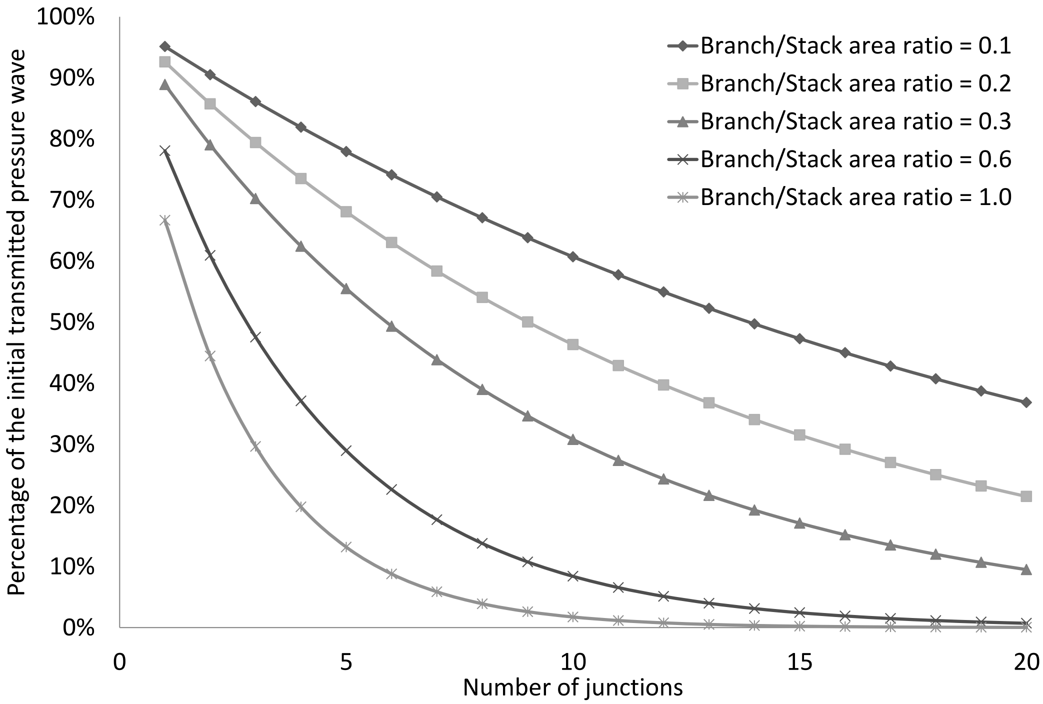


Figure 1: The relationship between branch to stack area ratio, number of junctions traversed, and the resultant proporation of transmitted pressure wave

The numerical model, AIRNET, was used to verify the assumed operation of the theoretical device. Figure 2 shows the simulated system. It has an 85m vertical stack with a diameter of 150mm. The ideal attenuation device was represented by ten 150mm diameter branches each 100m long and spaced 0.2m apart giving an overall device length of 3.3m. The length of the pipes are required to avoid any unnecessary reflections during the test run. An exit cross sectional area equivalent to 11.4% of a 3.3m stack section to which they are connected was modelled. Connected above the device are four 100mm diameter branches, each 2m in length, at 20m intervals.

The pressure wave is generated 3m below the device at the base of the vertical stack by a simulated piston with a diameter of 1.2m and a length of 0.5m, giving a piston volume of 565 litres. The piston dimensions were determined by trial and error with the aim of producing a pressure wave with a magnitude of around 2000mm Water Gauge (20kPa peak). The pressure wave is generated by moving the piston 0.228m in 0.384 seconds.

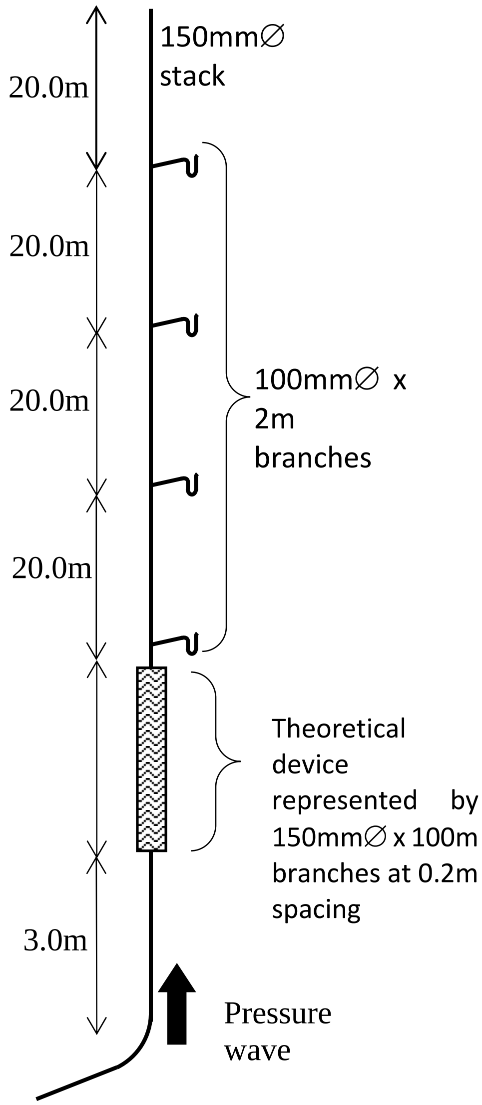


Figure 2: The system used to test the attenuating principles of the Inline Attenuator, based on junction transmission, using AIRNET

Figure 3 shows the pressure response of the system with and without the branch exits. Without the ten branches, the pressure wave reaches a peak of 2201.54mm Water Gauge. With the ten branches are connected, the peak pressure drops to 267.09mm Water Gauge, representing a drop of 88% to just 12% of the original wave.

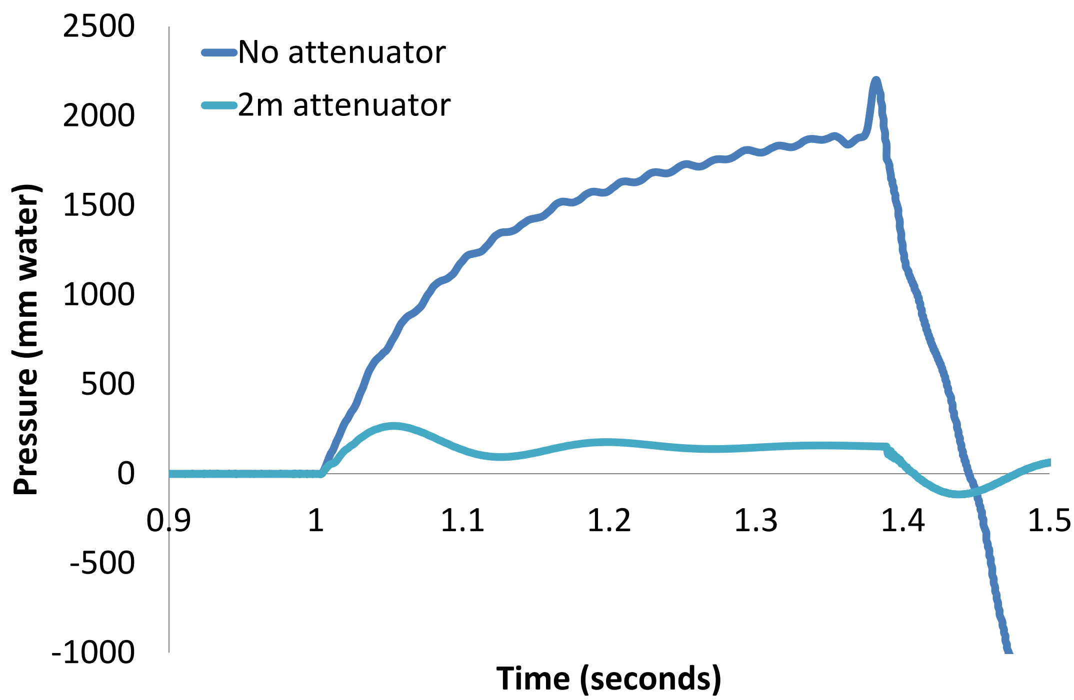


Figure 3: AIRNET simulated pressure response of the system shown in Figure 2 showing the attenuating effect of the ten branches

These initial simulations confirm the hypothesis that the propagating pressure wave can be attenuated by providing an alternative route along which it can travel. The representation of this alternative route as a series of long branches provides an exit area within the system which facilitates the dispersal of the propagating pressure wave.

2.4 Full-scale test rig investigations: installation

As it was impractical to erect a 50-storey vertical stack, the test rig was designed as a simple looped system on the horizontal plane using HPPE pipe. Electrofusion fittings were used for easy and fast assembly, and also for their high pressure rating. All pipework and fittings were rated to 10Bar as, although the tests would not use pressures of this magnitude, the compressor used to create the pressure wave had a maximum working pressure of 10Bar. The test rig consisted of looped sections of HPPE pipe, with a nominal diameter of 160mm and a wall thickness of 9.5mm giving an internal diameter of 141mm.. The total length of the pipe was just over 160m from the first pressure transducer, constructed in an inward loop with long radius bends (800mm radius). The pipe was fixed to free standing supports using rubber lined pipe clamps, spaced at regular intervals. This is shown in Figure 4.

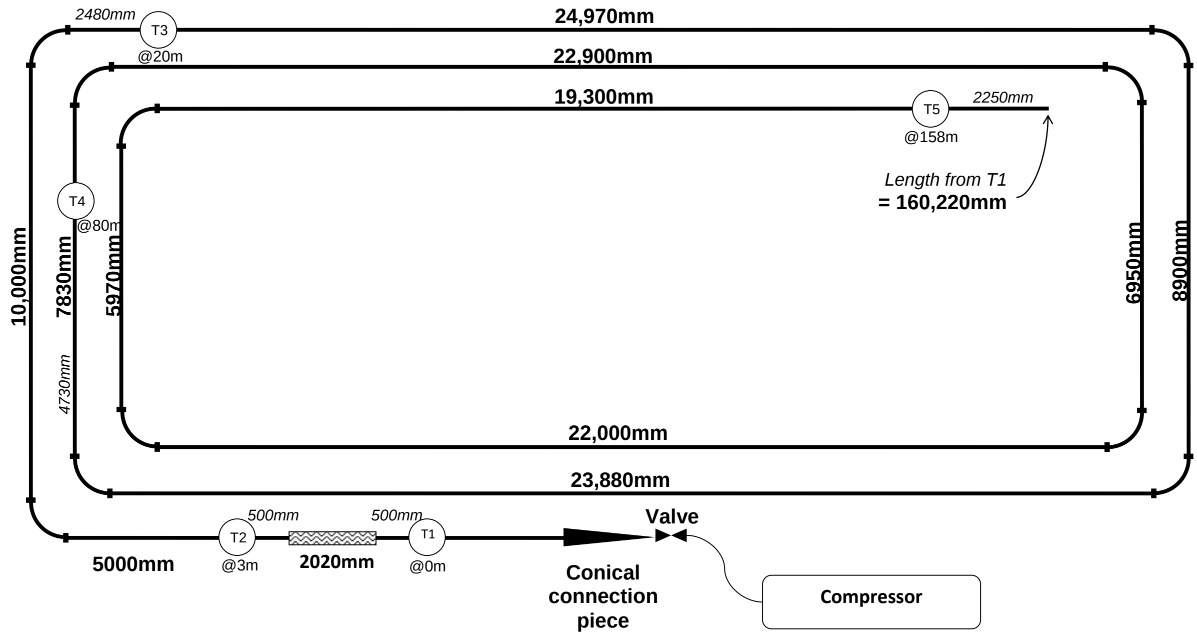


Figure 4: Full-scale test rig

An industrial duty air compressor (Clarke SE45C270) with a 270 litre horizontal air receiver and rated to a maximum working pressure of 10Bar was connected at the simulated stack base. A proportional control valve located just upstream of the compressor was used to generate the desired transient event. From the results of the simulation study, the valve was controlled to have an opening time of 0.5 seconds (see figure 5), a variable fully-open duration in order to allow control over the final test pressure, and a slow closing time of 5 seconds to avoid generating unwanted transients on closing. To provide a smooth transition from the valve into the test rig, a conical connection piece was manufactured to replicate the tapered pipe designed during the full scale test-rig simulation work. The details of the conical connection piece can be seen in Figure 6.

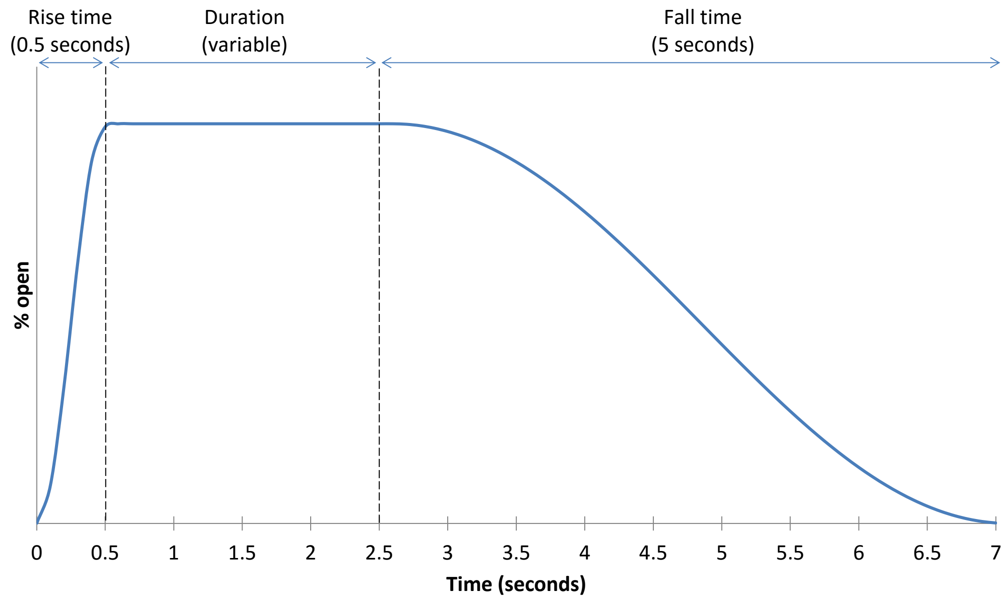


Figure 5: Valve control diagram

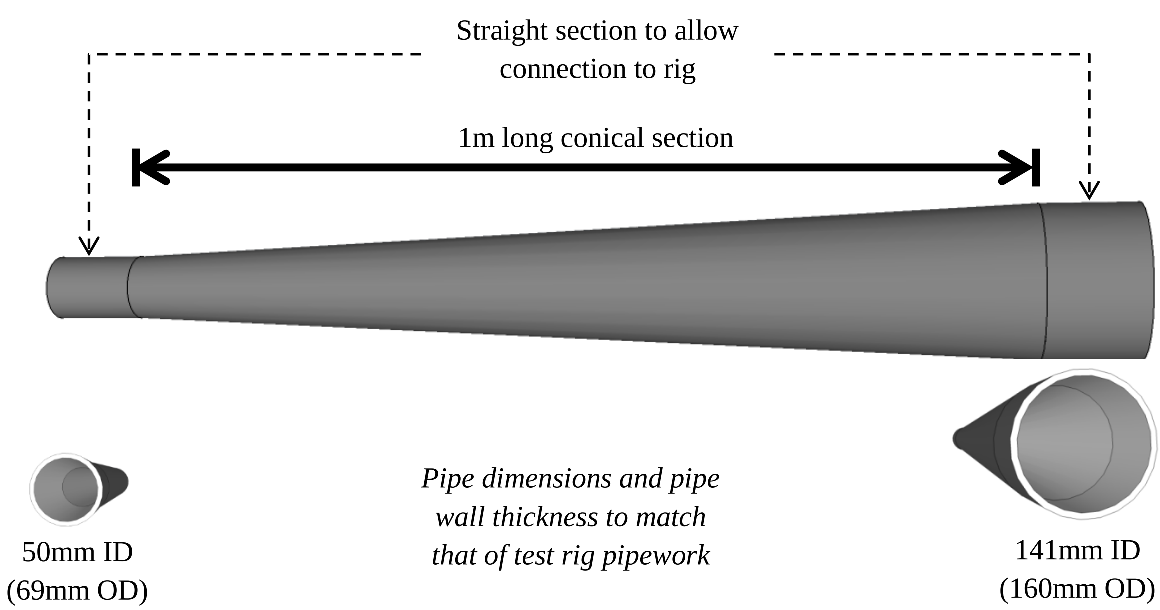


Figure 6: Conical connection piece used to deliver the pressure wave to the test rig.

3 Results

Investigation of device opening area

Figure 7 shows the pressure response to the applied pressure wave, recorded at pressure sensor T1 (Figure 4). The effect of opening area was tested for comparison with the results from the laboratory investigations. With no device fitted , the maximum pressure peak can be seen to reach almost 2500mmWG. With just a 0.21% opening area , the maximum peak pressure recorded at T1 reduces to 511.5mmWG (79.2% reduction). Increasing the opening area had the corresponding effect of reducing the maximum peak pressure recorded within the system, although, as the opening area was increased in small increments (from 0.21% to 2.12%) the recorded reduction in maximum peak pressure was also small: 0.85% opening area (4 slots open) provided an 80.3% reduction; 1.27% opening area (6 slots open) provided an 80.8% reduction; 1.70% opening area (8 slots open) provided an 82.3% reduction; and the 2.12% opening area (all 10 slots open) provided an 88.1% reduction.

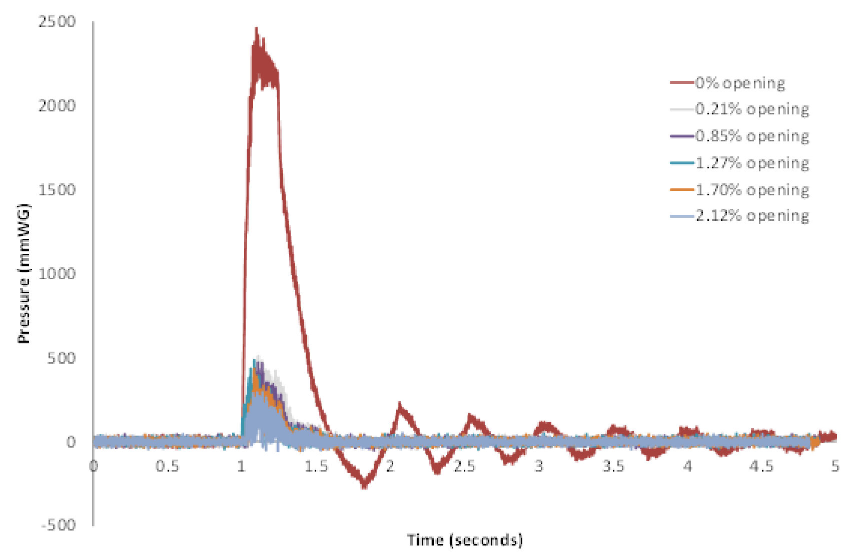


Figure 7: Measured pressure response from the test rig at pressure transducer T1 demonstrating the attenuating effect of different opening areas within the pipe surface

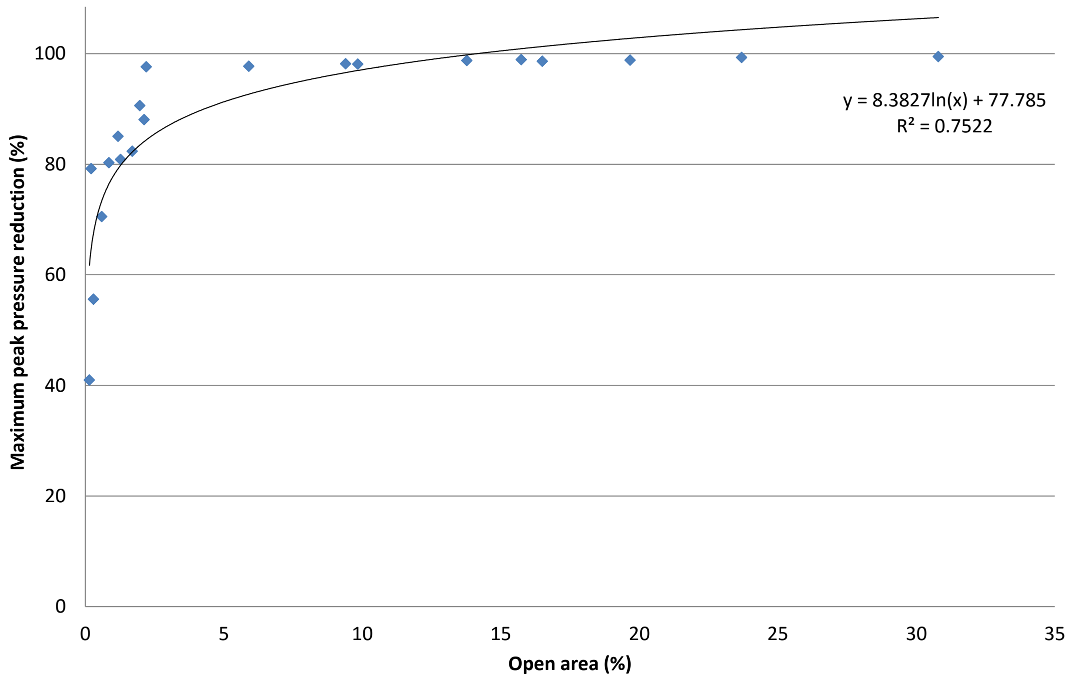


Figure 8: Device evaluation on full-scale test rig

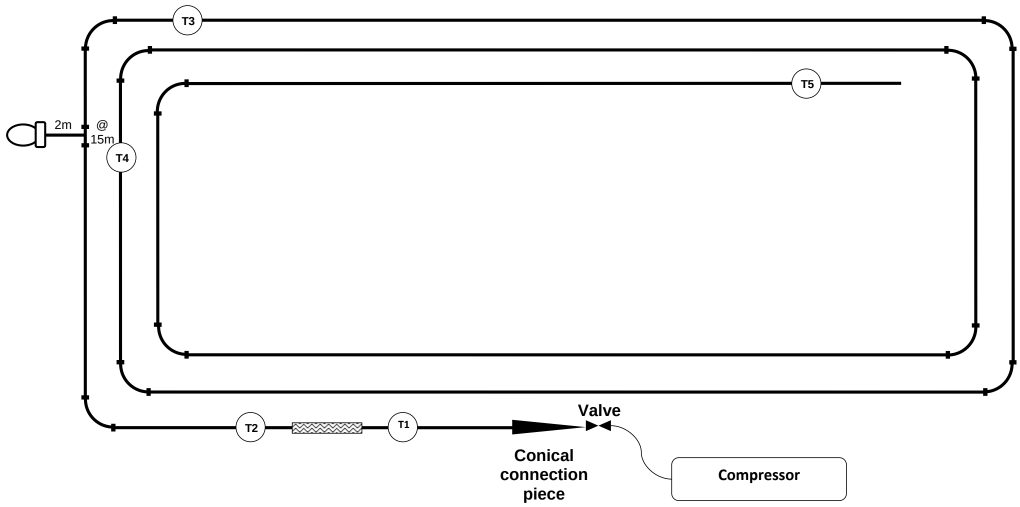


Figure 9: Full-scale test rig showing branch and WC connection.

While the first set of tests on the full size test-rig were based on the simple laboratory prototype, providing the propagating pressure wave with a route out of the system direct to atmosphere, it is of course necessary to provide a containment method whereby the air is kept within the drainage system. This is achieved by providing an additional volume with adequate capacity to absorb the propagating pressure wave. The containment volume was provided by creating a collapsible cylinder which was secured at either end of the line of slots. The collapsible cylinder was designed to give a maximum diameter of 500mm when fully inflated, providing an additional volume of 311 litres compared to the 23 litre volume of the pipe alone, an increase of almost 14 times. The system, which now includes a flexible conduit wall, also benefits from the attenuating effect of reduction in wave speed.

In addition to testing the pre-production device prototype for its ability to reduce the maximum peak pressure of an applied pressure wave, the direct effect on trap retention was tested by installing a WC onto the test rig. The WC was connected to the test rig via a 2m long 100mm diameter branch located 15 m (equivalent to 5 floors) from pressure sensor T1, see Figure 9 above. In order to avoid damaging the WC, the magnitude of the applied pressure wave was reduced slightly from the initial tests.

Figure 10 shows the pressure response to the applied pressure wave for the system with and without the device connected. Without the device the maximum peak pressure recorded was 1368mmWG. While the inclusion of the WC branch creates a junction within the system which has the effect of dividing the wave into reflected and transmitted components, the proportion of the wave transmitted into the WC branch would be 80% of the propagating wave. Therefore, it can be assumed that a pressure wave of just under 1100mmWG is transmitted into the WC branch. Figure 10 shows the recorded pressures before and after the installation of the device. A pressure wave of this magnitude completely blew out the water trap of the WC, resulting in full loss (see Figure 11) . In inclusion of the device reduced the maximum peak pressure to just 162mmWG, representing a reduction of 88%. Assuming 80% transmission into the WC branch, it can be assumed that a pressure wave of just under 130mmWG is transmitted. Although, still higher than recommended, instead of completely losing the trap the trap water was pushed into the WC bowl with sufficient water returning to provide an operational trap seal, and importantly the wave speed had been reduced with attendant reductions in volume of air which minimized the impact on the WC.

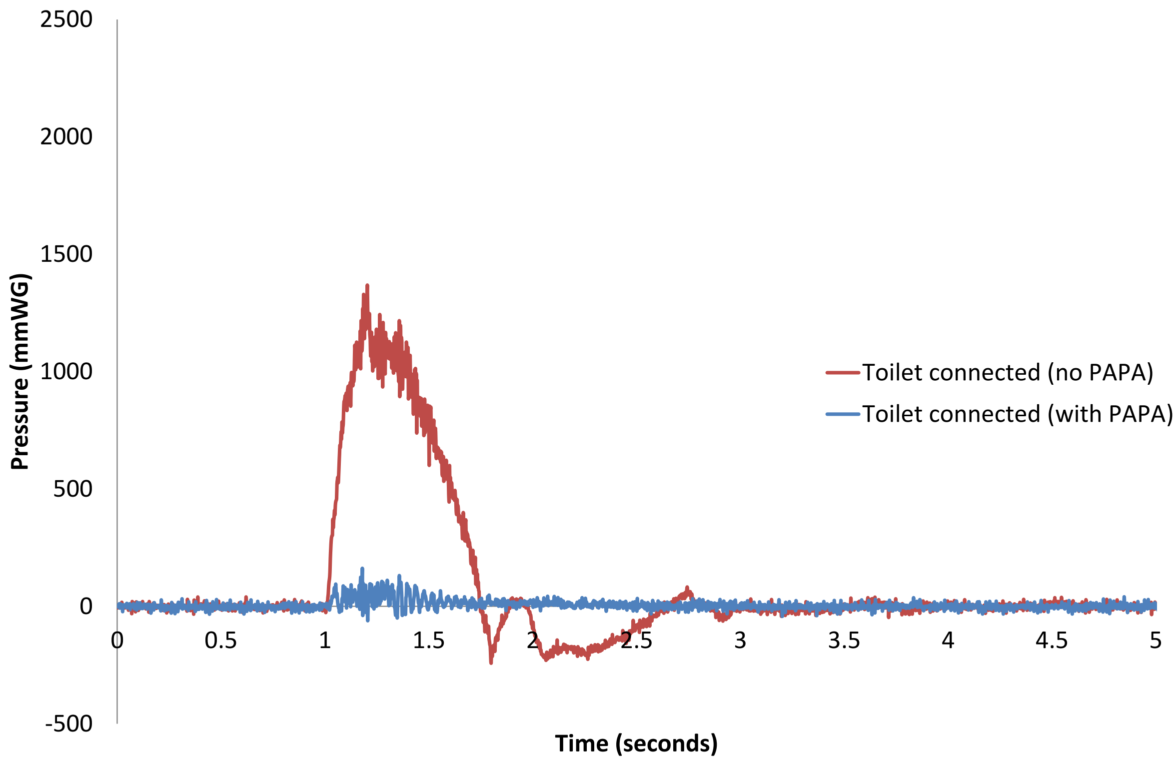


Figure 10: Comparison of the measured pressure response from the test rig with a toilet fitted 15m from pressure transducer T1 with and without a contained Inline PAPA fitted.

Figure 11: The effect of large pressure surge on a WC situated 3 floors from base of stack with no alleviation.

4 Conclusions

This work has shown that it is possible to suppress large air pressure transients in building drainage systems. This is particularly important in tall buildings where anecdotally the problems associated with pressure surge are much worse.
The use of numerical modelling has proven invaluable in taking the idea of a theoretical device from a sketch to a pre-production prototype in the laboratory.
The methodology used in this work has shown that it is possible to evaluate tall buildings in a controlled laboratory setting.

The research confirms that a device, located inline with the drainage stack is effective at suppressing air pressure transients of 1500 mm wg magnitude. The device has also been shown to limit negative pressure transients in the same system.

5 Acknowledgments

We would like to acknowledge the assistance of STUDOR for funding this research. We would also like to acknowledge the input and support of the School of Energy, Geoscience, Infrastructure and Society at Heriot-Watt University.

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7 Authors

Dr. Michael Gormley is Director of Research at the School of Energy, Geophysics, Infrastructure and Society at Heriot-Watt University in Edinburgh, Scotland. He has been active in research on pressure transient generation, propagation and alleviation since joining Heriot-Watt University in 2000. His recent work has focussed on pressure transients in tall buildings.

Dr. David Kelly is a lecturer in Architectural Engineering at the School of Energy, Geophysics, Infrastructure and Society at Heriot-Watt University in Edinburgh, Scotland. He has been involved in Draihage research since 2005. His current work involves water conservation and management, and pressure transient propagation in building drainage systems.

D3 - Maintaining the Functionality of a Plumbing System

K. Yagasaki (1), T. Nishikawa (2)
1. dm16061@ns.kogakuin.ac.jp
2. t-nskw@cc.kogakuin.ac.jp
(1) Graduate student, Kogakuin Univ., Japan
(2) Prof., School of Architecture, Kogakuin Univ., Dr. Eng., Japan

Abstract

A large-scale earthquake damages not only building structures but also building equipment that act as lifelines in high-rise buildings. For example, seismic damage to the plumbing system of a building causes loss of water supply and drainage, which leads to the temporary shut-down of other building equipment, thus making the use of the building impossible. More importantly, the plumbing system, which is necessary for the maintenance of human life and health, should remain functional or should be made functional at the earliest if it is damaged in the event of a large-scale earthquake.
In this study, with the purpose of maintaining the functionality and restoring a plumbing system at the time of earthquakes, we evaluated the aseismic performance of a plumbing system in a building by using a numerical analysis. The results of the numerical analysis indicated that the lifting pipe and water supply pipe connected to the elevated tank installed on the roof were fragile in the evaluated building. These results are consistent with the damage caused by past large-scale earthquakes, include that caused by the 2016 Kumamoto earthquake, and clarified a future task which necessity of aseismic measures.

Keywords

Lifeline; Plumbing system; Numerical analysis; Aseismic performance.

1 Introduction

During past earthquakes, the damage inflicted to building structures due to earthquake ground motion was insignificant. However, the building equipment was significantly damaged because of the earthquake ground motion, thereby indicating that the aseismic performance of the building equipment was poor. In general, the plumbing system of a building comprises water supply and drainage facilities, which play important roles from the viewpoint of maintaining human life and health. Hence, the plumbing system differs from ordinary building services and utilities, as the functionality should be maintained for immediate service even in the aftermath of an earthquake. High-magnitude earthquakes can be expected in metropolitan areas where high-rise buildings are located. Therefore, it is necessary to ascertain the seismic risk and improve the aseismic performance of plumbing systems, particularly those of high-rise buildings.

The objective of this study is to ascertain the seismic risk of building equipment by evaluating the aseismic performance of a plumbing system of a high-rise building, which should be continuously operational. First, in this study, the extent of seismic damage due to the 2016 Kumamoto earthquake was analyzed. Subsequently, the aseismic performance of the plumbing system of the Kogakuin University, Shinjuku campus building, was evaluated using numerical analysis as a case study.

2 Damage inflicted to Building Equipment due to the 2016 Kumamoto Earthquake

The 2016 Kumamoto earthquake occurred in April 2016. The earthquake was characterized by many aftershocks that occurred over a long period compared to previous direct-type earthquakes. Figure 1 shows the damage reports of building equipment, including those of the plumbing systems, air conditioning systems, and electrical installations. The plumbing systems sustained the second greatest damage because of the 2016 Kumamoto earthquake, second only to air conditioners. The air conditioning systems were the most frequently damaged equipment based on the number of damaged cases studied. However, with regard to plumbing systems with high functional importance, the damage was tabulated with respect to the parts. The total damage percentage of the piping system to the plumbing system is approximately 58%. In the plumbing systems, the pipes sustained most of the damage, highlighting the fragility of the water-supply system. In addition, it was reported that significant movement of the piping installed in the roof floor was one of the reasons that led to the damage in the tanks. Thus, the aseismic performance of a plumbing system with water supply and drainage facilities should be improved.

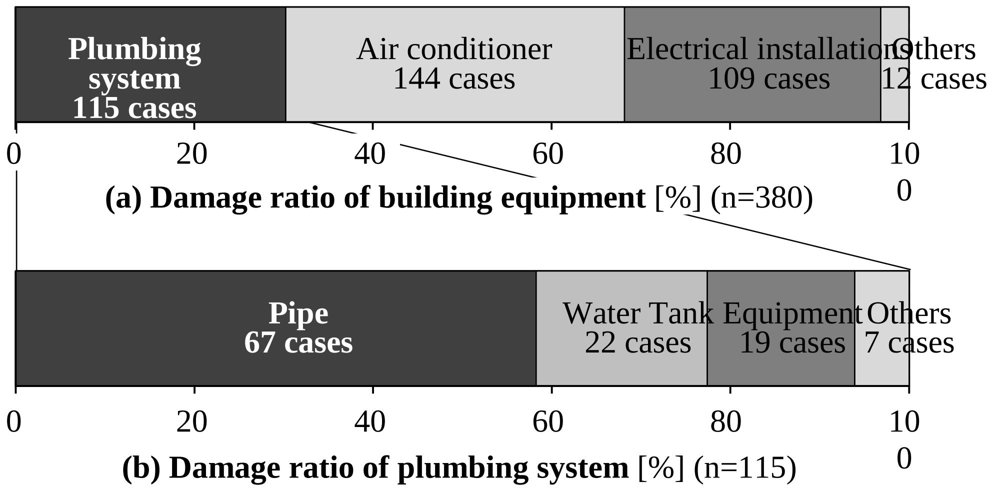


Figure 1 - Damage ratio in the 2016 Kumamoto earthquake[1)]

3 Overview of Aseismic-Performance Evaluation of the Plumbing System

3.1 Overview of the Evaluated Building

Figure 2 shows the schematic of the plumbing system and details of the input wave. The evaluated building is a high-rise building with 29 floors above the ground and 6 floors below. The water supply system used was the gravity tank system. The water was supplied to the receiver tank installed in the 6th basement to pump water up to the three gravity tanks installed on the 8th and 20th floors and the roof floor. The water was then supplied to the plumbing fixture installed on each floor. The waste water on the ground floor was drained by gravity and that in the basement was pumped using a sump pump after being collected in the sump pit. The evaluated building was supplied with potable and non-potable water to the upper (18–28F), middle (7–17F), and lower floors (B6–6F).

3.2 Model development of Plumbing System and Details of Input Seismic Wave

In this study, the aseismic performance of the plumbing system was examined using a pipe-stress analysis software (AutoPIPE, Bentley Systems, Inc.). The numerical analysis model* of the plumbing system of the evaluated building was developed by confirming the shape, dimension, material, joining condition, and support condition via as-built drawing and on-site measurement. However, it is difficult to develop the support part with the U-bolt in the numerical analysis model. Hence, the following two numerical analysis models were developed, interpolated, and evaluated: a pin moveable joint that does not constrain the displacement in the tube axis direction (case A) and a pin that restrains the displacement in the tube axis direction (case B).

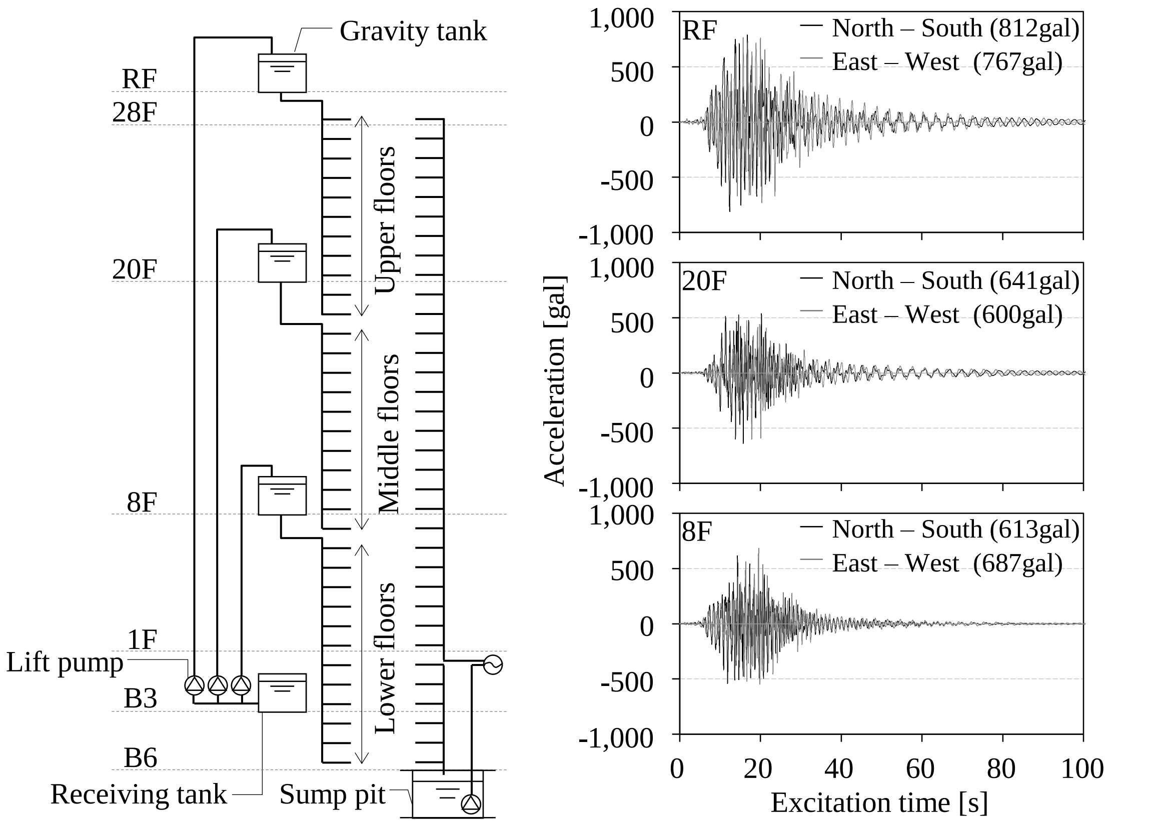


Figure 2 – Plumbing system schematic and input wave

The input wave was a random wave that hit the evaluated building during the Tokyo inland earthquake. The maximum acceleration of the wave of the Tokyo inland earthquake, which is higher than that of a typical observed wave, is used to model the design of the high-rise building. In the proposed numerical-analysis model, the response acceleration of the floor at the time of the earthquake immediately following the capital in the evaluated building was inputted. Subsequently, the allowable stress-intensity ratio of the plumbing systems of the evaluated building was calculated. The allowable stress-intensity ratio is the ratio of the stress calculated in each member to the allowable stress.

4 Result of Aseismic-Performance Evaluation of the Plumbing

4.1 Results of Water Supply Piping system

4.1.1 Result of Upper Floors

Figure 3 shows the stress distribution of the upper floors of the water supply piping in the evaluated building obtained from the numerical-analysis results based on case A. The stress distribution shows the maximum stress obtained from the numerical analysis. A maximum allowable stress-intensity ratio of 2.23 was obtained for the bent part of the roof floor (①). This corresponds to a stress of 448 N/mm^2, which is higher than the allowable stress (201 N/mm^2) of the stainless steel pipe. The maximum allowable stress-intensity ratio was obtained for the horizontal pipe, which is connected from the gravity tank installed on the west side to the pipe shaft on the east side in the evaluated building.

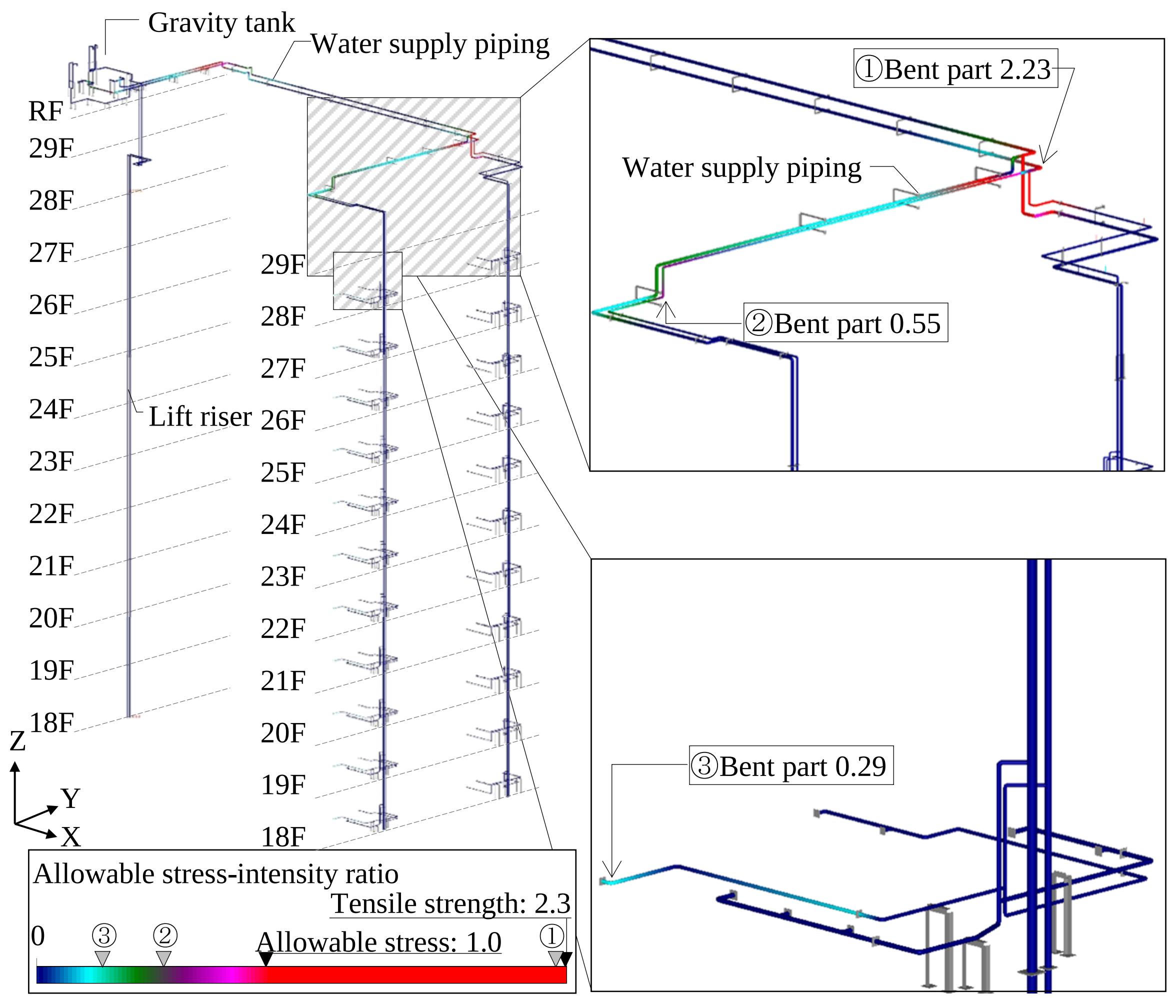


Figure 3 – Stress distribution of the water supply piping（Upper floors, case A）

For the pipe connected to the plumbing fixtures from the pipe shaft, the maximum allowable stress-intensity ratio is 0.29 (③). This corresponds to a stress of 22 N/mm^2, which is lower than the allowable stress (75 N/mm^2) of the carbon steel pipes. Because the support interval of the pipe connected to the plumbing fixtures from the pipe shaft is shorter than that of the pipe in the roof floor, the allowable stress-intensity ratio of the pipe connected to the plumbing fixtures from the pipe shaft is low.

Figure 4 shows the stress distribution of the water supply piping of the evaluated building obtained from the numerical analysis results based on case B. A maximum allowable stress-intensity ratio of 0.43 was observed for the bent part of the roof floor (②). This corresponds

to a stress of 86 N/mm^2, which is lower than the allowable stress (201 N/mm^2) of the stainless steel pipe. The parts of occurrence of the maximum allowable stress-intensity ratio calculated based on cases A and B are different because the displacement in the axial direction of the pipe is fixed.
For the pipe connected to the plumbing fixtures from the pipe shaft, the maximum allowable stress-intensity ratio is the same as the result obtained based on case A.

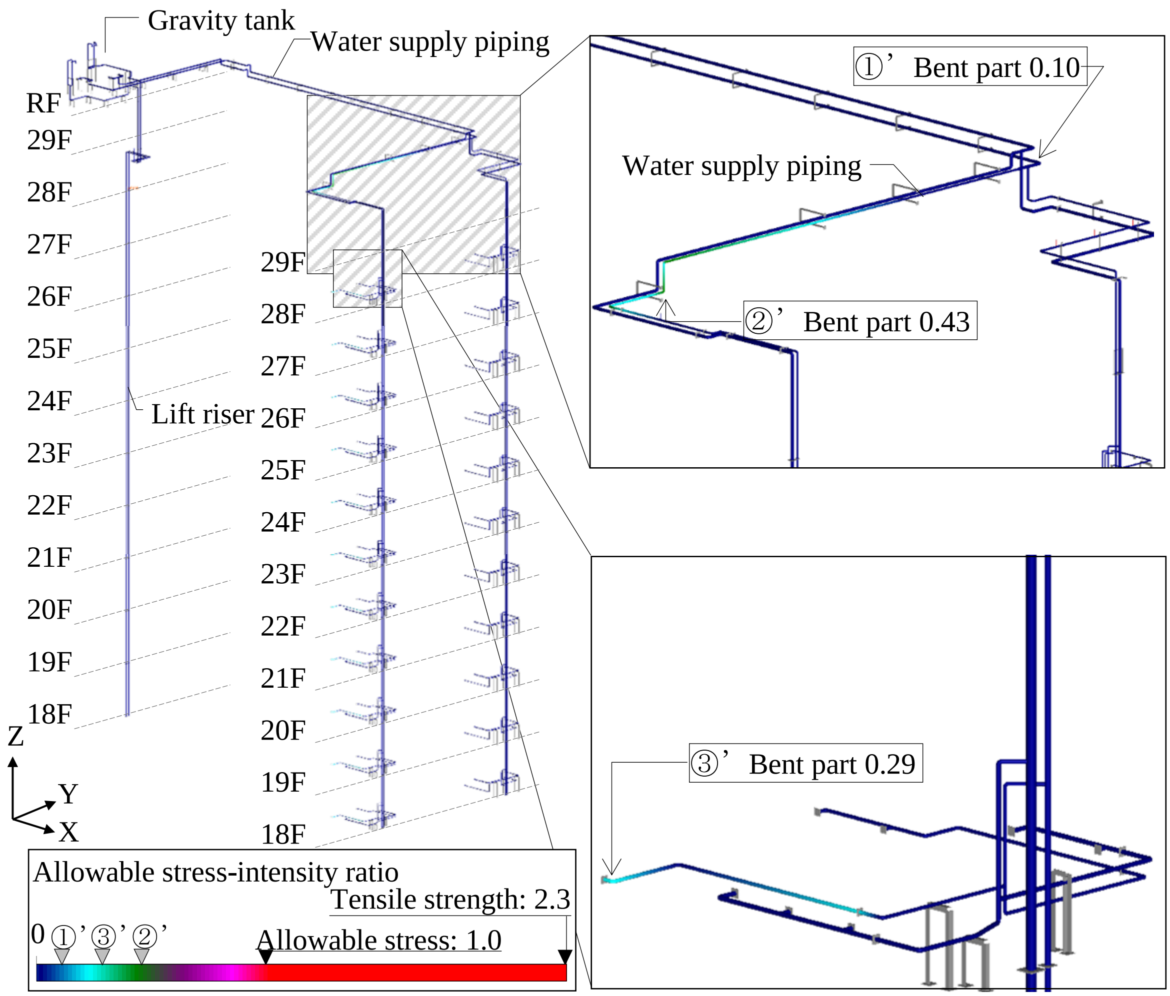


Figure 4 – Stress distribution of the water supply piping（Upper floors, case B）

4.1.2 Result of Middle and Lower Floors

Figure 5 shows the stress distribution of the middle and lower floors of the water supply piping of the evaluated building obtained from the numerical analysis results based on case A. Similar results were obtained for the middle and lower floors, which have similar piping routes. The stress distribution shows the results of the middle floor. The results of the lower floor are shown in the legend. With regard to the middle floors, a maximum allowable stress-intensity ratio of 0.50 was observed for the straight pipe part located on the 20th floor (④). This corresponds to

a stress of 111 N/mm^2, which is lower than the allowable stress (223 N/mm^2) of the stainless steel pipe. With regard to the lower floors, a maximum allowable stress-intensity ratio of 0.42 was observed for the straight pipe part located on the 8th floor (⑥). This corresponds to a stress of 94 N/mm^2, which is lower than the allowable stress (223 N/mm^2) of the stainless steel pipe. Evidently, the maximum allowable stress-intensity ratio of the lower floors is lower than that of the middle floors, which is the difference in the input wave.
For the pipe connected to the plumbing fixtures from the pipe shaft, the maximum allowable stress-intensity ratio of the middle and lower floors is the same as that of the upper floors.

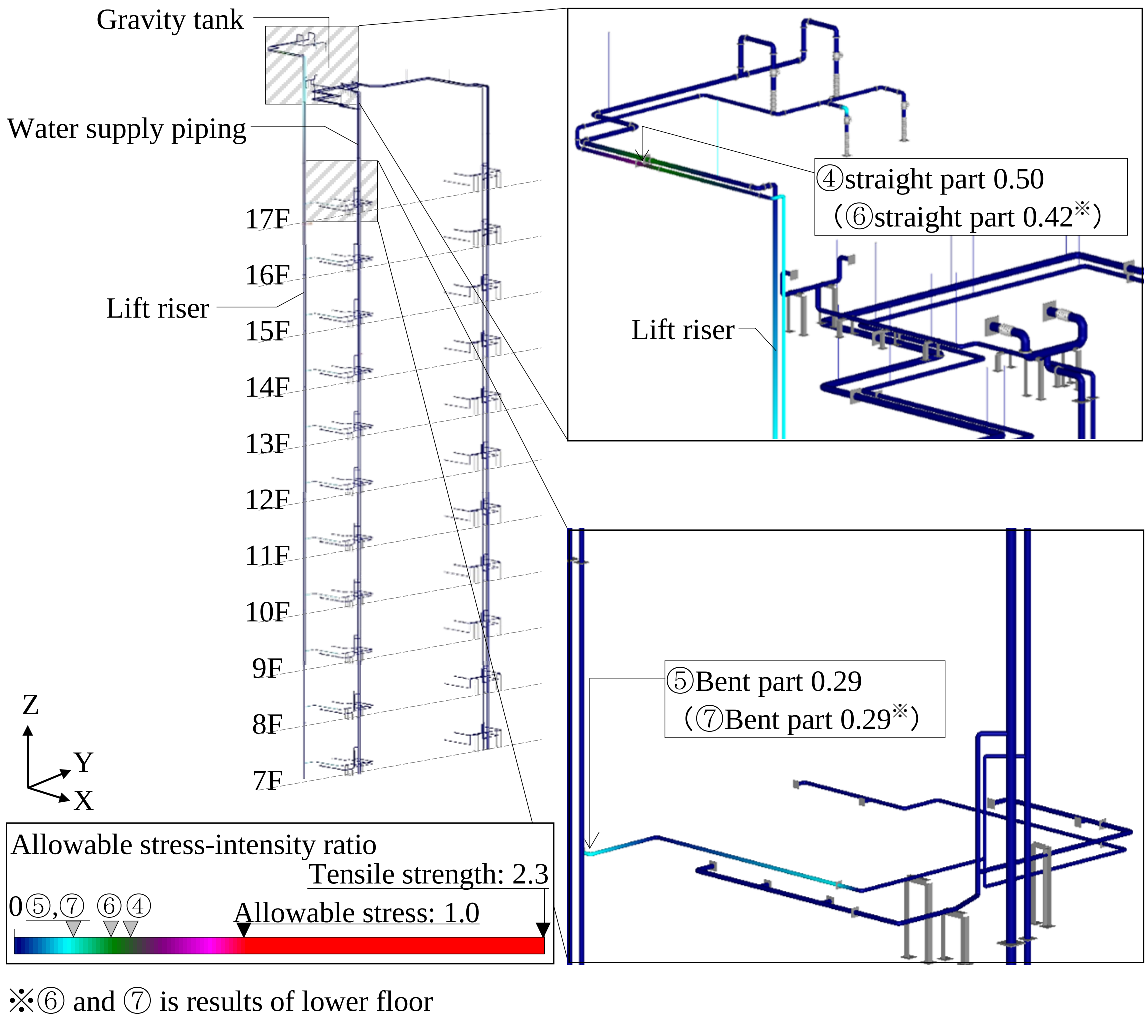


Figure 5 – Stress distribution of the water supply piping
(Middle floors and Lower floors, case A)

Figure 6 shows the stress distribution of the middle and lower floors of the water supply piping of the evaluated building obtained from the numerical analysis results based on case B. With regard to the middle floors, a maximum allowable stress-intensity ratio of 0.49 was observed for the straight pipe part located on the 20th floor (④’). This corresponds to a stress of 109 N/mm^2, which is lower than the allowable stress (223 N/mm^2) of the stainless steel pipe. With regard to the lower floors, a maximum allowable stress-intensity ratio of 0.41 was observed for the straight pipe part located on the 8th floor (⑥’). This corresponds to a stress of 91 N/mm^2, which is lower than the allowable stress (223 N/mm^2) of the stainless steel pipe. Few pipes were supported by U-bolts, and the difference between the results of cases A and B was slight. For the pipe connected to the plumbing fixtures from the pipe shaft, the maximum allowable stress-intensity ratio of the middle and lower floors is the same as that of the upper floor.

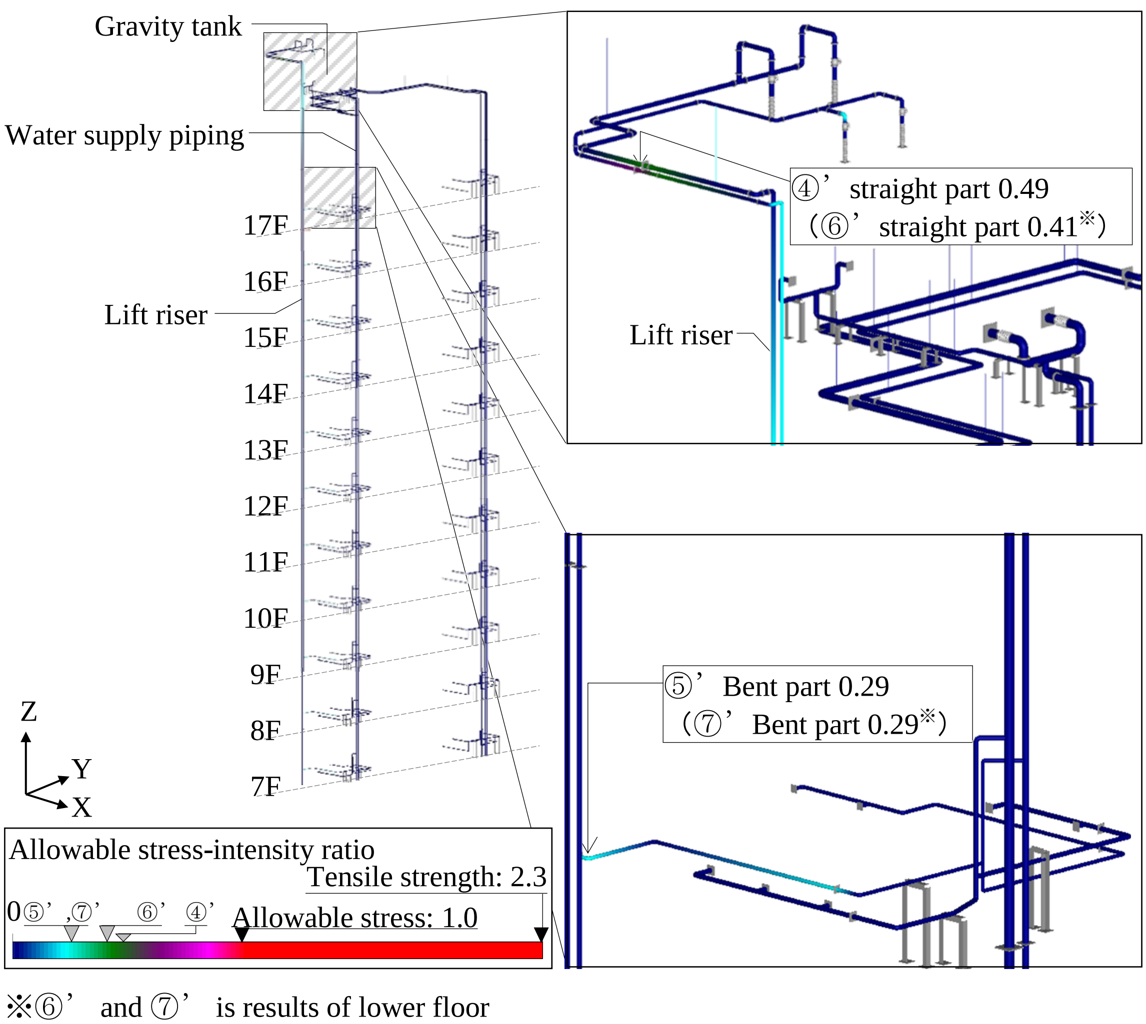


Figure 6 – Stress distribution of the water supply piping
(Middle floors and Lower floors, case B)

4.2 Result of Drain Piping

Figure 7 shows the stress distribution of the drain piping of the evaluated building. The maximum allowable stress-intensity ratio was 0.20 based on both cases A and B, which was obtained for the horizontal piping of the plumbing fixtures connected to the pipe shaft. This corresponds to a stress of 15 N/mm^2, which is lower than the allowable stress (75 N/mm^2) of the stainless steel pipe.

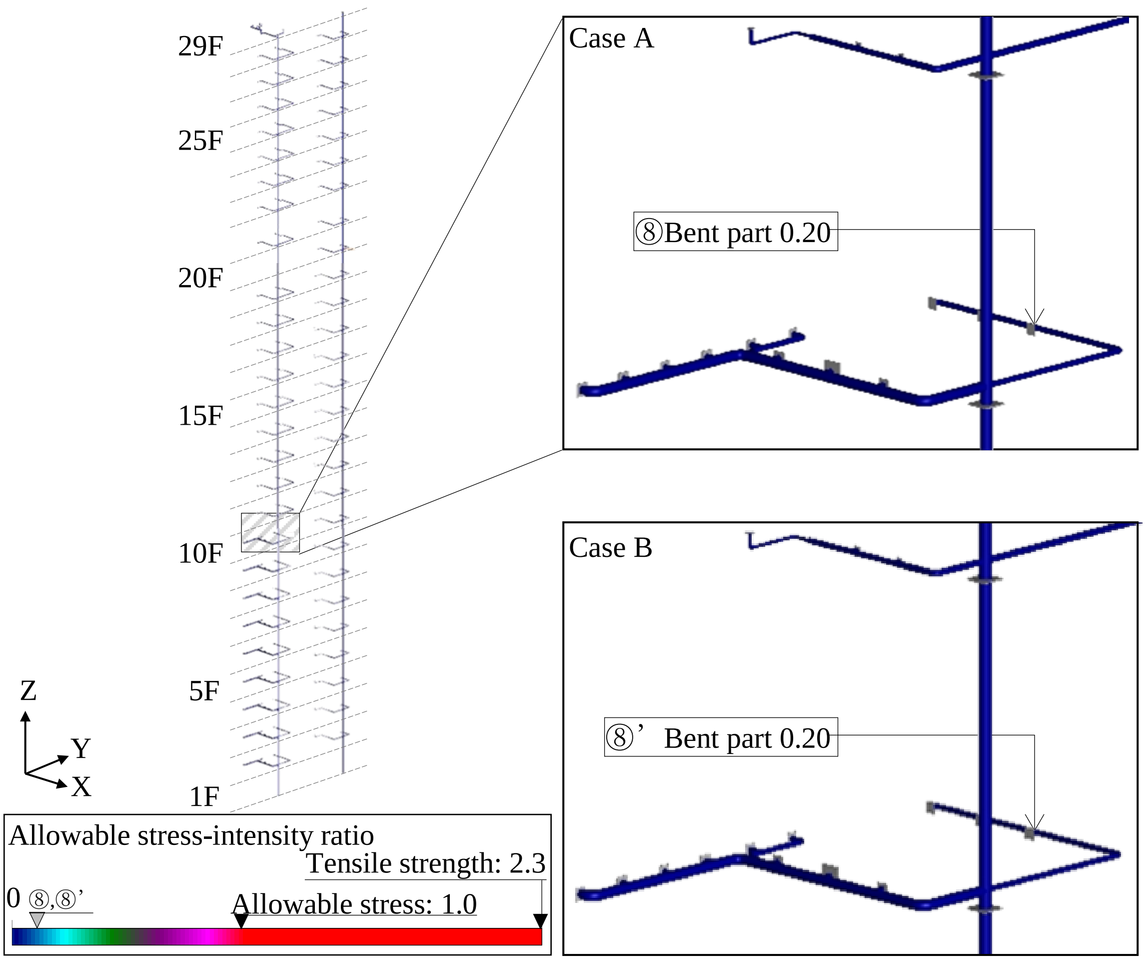


Figure 7 – Stress distribution of the drain piping（cases A and B）

5 Seismic Risk of Plumbing System

Figure 8 shows the maximum allowable stress-intensity ratio of the plumbing system of the evaluated building on each floor. Based on the results up to the previous chapter, the maximum allowable stress-intensity ratio for each floor was calculated in the event of the Tokyo inland earthquake. The maximum allowable stress-intensity ratios are higher at the roof floor and the 20th and 8th floors, where the gravity tank was installed, in the range of 0.43–2.23, 0.49–0.50, and 0.41–0.42, respectively. However, the pipe connected from the pipe shaft to the plumbing fixtures has a lower allowable stress-intensity ratio than the pipe connected to the pipe shaft from the gravity tank.

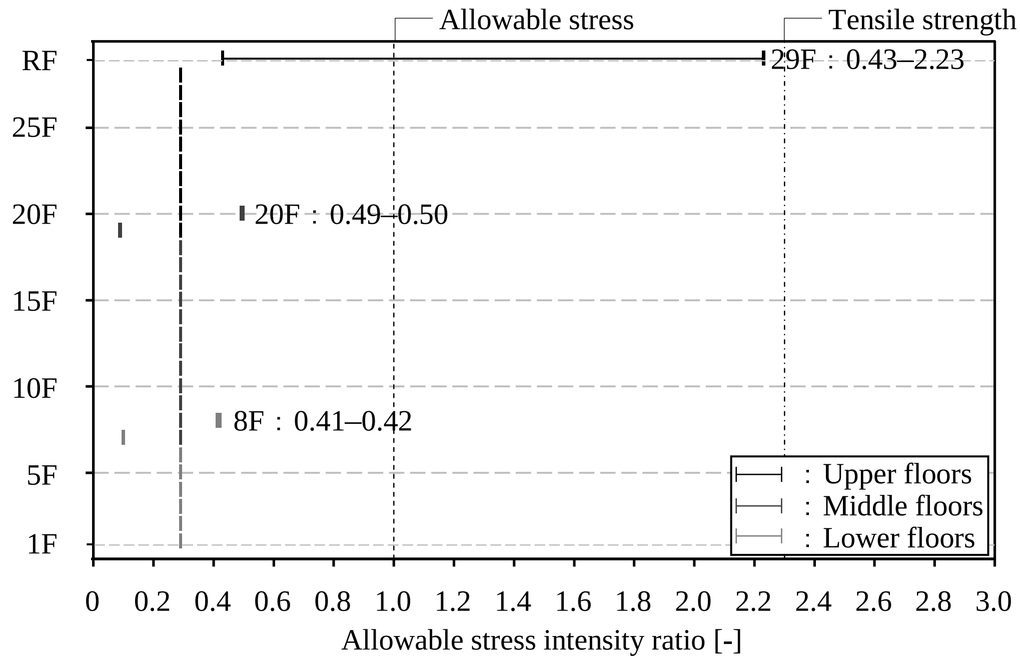


Figure 8 – The maximum allowable stress-intensity ratio of plumbing system in the evaluated building on each floor

6 Conclusion

This study was conducted to evaluate the aseismic performance of the plumbing system of the Kogakuin University, Shinjuku campus building using numerical analysis.
The maximum allowable stress-intensity ratio of the plumbing system varied in the range of 0.43–2.23 for the bent part of the horizontal water supply piping located on the upper floors. Moreover, the pipe connected from the pipe shaft to the plumbing fixtures has a lower allowable stress-intensity ratio than the pipe connected to the pipe shaft from the gravity tank. This is because the pipe connecting the pipe shaft from the gravity tank has a large support interval of the horizontal pipe.

7 Acknowledgments

The work was supported by Japan Society for the Promotion of Science KAKENHI Grant Number JP16H02375. The authors would like to thank Prof. Yoshiaki Hisada and Prof. Tetsuo Yamashita of Kogakuin University. The authors would like to thank Mr. Kohei Kanno for working with us to prepare the manuscript.

8 Note

* Figure 9 and Table 1 show the boundary condition of each element in the piping. In addition, the fixed point of piping by the U band was created two different calculated model based on boundary conditions. Details are shown in Table 2.

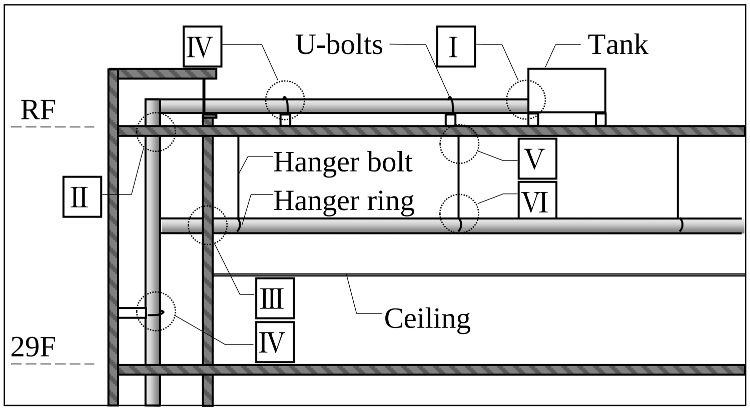
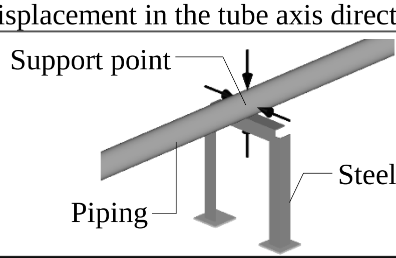
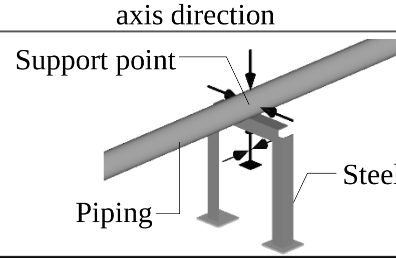


Figure 9 - Model outline of piping in numerical analysis

Table 1 - Contact conditions of each element in the horizontal piping

Each element		Boundary conditions	
		Case A	**Case B**
Ⅰ	Tank・pump - piping	Rigid joint	
Ⅱ	upper and lower floor slabs - piping	Rigid joint	
Ⅲ	piping - smoke control zone compartments penetration	Rigid joint	
Ⅳ	Fixed point of piping（U-bolts）	Pin moveable joint	Pin joint
Ⅴ	The slab of upper floor and hanger bolts	Rigid joint	
Ⅵ	Hanger ring	Pin joint	

Table 2 – Boundary condition of part of fixed point of vertical piping（U-bolts）

Case A	**Case B**
Pin moveable joint	Pin joint
A pin moveable joint that does not constrain the displacement in the tube axis direction	A pin that restrains the displacement in the tube axis direction
	

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10 Presentation of Authors

Keisuke Yagasaki is a graduate student of the Nishikawa laboratory, Graduate Student, Kogakuin Univ. He is a member of AIJ (Architecture Institute of Japan) and SHASE (The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His current study on Earthquake Disaster Mitigation in building equipment.

Toyohiro NISHIKAWA is the Assoc.Prof.,School of Architecture,Kogakuin Univ.,Dr. Eng.He is a member of AIJ (Architectural Institute of Japan) and SHASE (The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His current research interests are of the heat of building equipment, air, waste, earthquake disaster prevention.

D4 - Numerical Analysis of Induced Siphonage in P Trap

K. Sakaue (1), K. Fujimura (2), T. Mitsunaga(3)

1. sakaue@isc.meiji.ac.jp
2. kazuya.fujimura@mj-sekkei.com
3. mitunaga-t@yamashitasekkei.co.jp

(1) Dept. of Architecture, School of Science and Technology, Meiji University, Japan
(2) Mechanical Engineering Department, Mitsubishi Jisho Sekkei Inc., Japan
(3) Mechanical Systems Design Development, Yamashita Sekkei Inc., Japan

Abstract

Seal water in trap plays a crucial role in preventing foul-smelling toxic gas in drainage pipes from entering indoors. Induced siphonage is the most important of the phenomena associated with seal break and seal loss. This phenomenon occurs when seal water level changes rapidly in response to air pressure fluctuations in drain and gets lost. Though there have been several studies on numeric analyses and motion equations of seal water fluctuation, none of them addressed the issue of seal water fluctuation analysis in response to air pressure fluctuation in drain.
In this study the authors derived a motion equation for induced siphonage in P trap with same diameter, and examined the validity of the equation by analyzing seal water fluctuation using EXCEL VBA based on the force of vibration in drain.

Keywords

induced siphonage; trap; drainage system; simulation

1 Introduction

Water is used in a number of ways in buildings. Its main use involves appliances for water usage such as sanitary fixtures. Water, together with wastes, is discharged through drainage pipe into the sewer or septic tanks. The drainage pipe is usually filled with foul-smelling toxic drainage gas, and if such gas enters indoors through drain outlets of sanitary fixture, it may contaminate air and cause health damage. In order to prevent this from happening, fixture drainage pipes are equipped with traps, which contain seal water. Seal water plays an important role to stop drainage gas from entering the room. However, seal water may be lost for many reasons leading to a condition called seal break. Induced siphonage is one of the most important seal break phenomena. In induced siphonage, air pressure inside drainage pipe fluctuates when discharge is made, and seal water also starts to fluctuate in response to pressure fluctuation precipitating seal loss and seal break. To prevent seal break due to this phenomenon, various precautions such as an addition of vent pipes and the use of appropriate diameter pips are stipulated in the design method. The design method is based on a proportional relation that regards the causal relationship of discharge flow rate and air pressure fluctuations to seal loss as a static phenomenon. However, their relationship must be understood as a dynamic phenomenon as pressure and seal water fluctuate constantly in reality. Though there have been several studies [1–3] published on numeric analyses and motion equation of dynamic seal water behaviours, not a single one of them analyzed seal water fluctuations as a response phenomenon of pressure fluctuation in pipe.

In this study the authors derived a motion equation for seal water fluctuations in response to pressure fluctuations in P trap, and analyzed the validity of the equation based on pressure and seal water fluctuation data collected from a discharge experiment conducted in a 15-story experimental tower.

2 Motion equation for seal water fluctuation

Induced siphonage can be considered as a single degree freedom forced vibration phenomenon created by the force of pressure in drain. Following the conventional procedures of vibration analysis, first we derived a motion equation of free vibration and then that of forced vibration.

2.1 Free vibration

The law of conservation of momentum can be applied to seal water vibration on the premise that the sum of inertia, damping force and power of resistance is constant. As shown in Figure 1, the falling mass of water that amounts to the water levels between the trap legs constitutes the power of resistance. The equation (1) represents the motion equation for seal water fluctuations where the water level is y and damping coefficient is c. The damping coefficient c is determined from the equation (3) with critical damping coefficient cc and damping ratio ζ. The damping ratio ζ is obtained from logarithmic decrement σ in the equation (4).

The damping ratio ζ is obtained from water level fluctuation patterns in the seal water free vibration experiment. For example, Figure 2 shows the water level for free vibrations of P trap (trap with the same diameter) with 30 mm diameter. Based on the wave patterns, the logarithmic decrement is calculated to be σ=0.139. The critical damping coefficient is cc＝2.26. Therefore, damping coefficient ζ=0.0222 and damping coefficient c＝0.0502 can be obtained from the equations (3) and (4). Natural frequency f is obtained from equation (5), which, in the case of P trap, is 1.96 Hz. Natural frequency obtained from the water level fluctuation patterns (ALd2＝0.0919kg, ρAL＝13.9N/m) in Figure 2 is 1.94 Hz, which roughly matches the result of the calculation.

$$\rho A L d^2y/dt^2 + c\,dy/dt + 2\rho A g\, y = 0 \qquad (1)$$
$$c_c = 2((\rho A L)\cdot(2\rho A g))^{1/2} \qquad (2)$$
$$c = \zeta \cdot c_c \qquad (3)$$
$$\zeta = \sigma/2\pi \qquad (4)$$
$$f = ((2\rho A g)/(\rho A L)/(2\pi))^{1/2} \qquad (5)$$

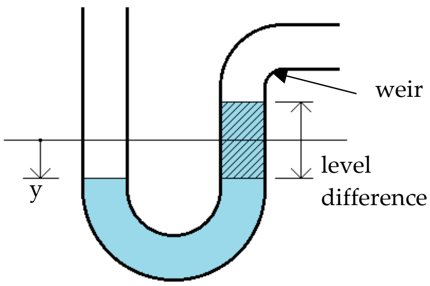

Figure 1 Model of seal water fluctuation

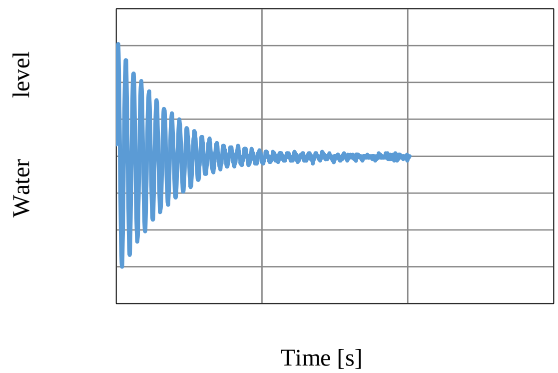

Figure 2 Free vibration wave of seal water (experiment)

2.1 Motion equation for forced vibration

Fluctuations of seal water in trap is a forced vibration phenomenon that changes in response to air pressure fluctuations caused by discharged water, and can be expressed in equation (6).

$$y = \rho A L d^2y/dt^2 + c\,dy/dt + 2\rho A g\, y - AP = 0 \qquad (6)$$

3 Numerical analysis of motion equation

Seal loss occurs when the top of seal water in the outlet leg overflows the weir of a trap. When this happens, the mass of seal water is reduced and it must be dealt with as an unsteady phenomenon (transient phenomenon). As a general solution cannot be obtained for an unsteady phenomenon, the numerical calculation method must be applied. We applied the Runge-Kutta method as a numerical calculation method, and used EXCEL VBA. The damping coefficient c of 0.076 obtained from the preliminary experiment was applied and seal water fluctuation was simulated using air pressure fluctuations data from the experiment.

3.1 Time-step

Time-step plays an important role in attaining accuracy in analysis. Therefore, appropriate time-step must be established based on the free vibration wave patterns of seal water. Table 1 shows the results of analysis at time-steps ts＝0.01,0.05,0.075,0.1s, logarithmic decrement σ, and damping ratio ζ obtained from the equation (6). As ζ when ts＝0.25 was the closest to the experimental results, ts＝0.025 was used in subsequent calculation.

Table 1 Logarithmic decrement σ and damping ratio ζ according time-step

Parameter	Simulation					Experiment
Time step t_s [s]	0.01	0.025	0.05	0.075	0.1	
logarithmic decrement σ [-]	0.0476	0.139	0.182	0.230	0.375	0.139
damping ratio ζ [-]	0.00758	0.0218	0.0290	0.0366	0.0568	0.222

3.2 Seal loss rate

Seal loss occurs when water level in the outlet leg flows over the dip. The loss rate depends on how large the water level fluctuations are. As it is difficult to simulate the actual water level conditions, we estimated as follows: γ＝0.001 when ymax<8mm; γ＝0.1 when 8mm≦ymax ＜15; and γ＝0.8 when ymax≦1.

4 Discharge experiment on induced siphonage

We constructed a stack vent drainage system with special drainage fittings in a 16-story experimental tower and conducted a discharge experiment to obtain data on fluctuations of pressures in drain and seal water in actual drainage situation.
The experimental drainage system is shown in Figure 3. Stacks with 100 A diameters and horizontal branches with 50 A diameters were used in the experiment. PVC traps were placed on the 9th floor. Constant discharges (1.5, 4.5 L/s) and fixture discharge (1 WC and 3WC) were made. Constant discharges were made from the floors 14 and 15, fixture discharges form the floors 13 ~ 15. Average flow rate of fixture discharge from WC qd was 2.2L/s.

Table 2 Shape parameters of P trap

diameter	Cross-sectional rea	Seal depth	volume
0.03m	$7.1 \text{x} 10^{-4} m^3$	0.05m	150 mL

5 Validation of results

5.1 Pressure fluctuation in drain and seal water fluctuation

The experimental drainage system is shown in Figure 3. Stacks with 100A diameters and horizontal branches with 50A diameters were used in the experiment. PVC traps were placed on the 9th floor. Constant discharges (1.5, 4.5 L/s) and fixture discharge (1 WC and 3WC) were made. Constant discharges were made from the floors 14 and 15, fixture discharges form the floors 13 ~ 15. Average flow rate of fixture discharge from WC qd was 2.2L/s.

Experimental results of air pressure fluctuations (Pa) in drain, and experimental and simulated results of seal water fluctuation (mm) with constant discharge of 1.5 L/s and 4.5zL/s, and fixture discharge with 1 WC and 3WC are shown in Figure 4. Maximum and minimum values of air pressure and seal water level, and seal loss of those discharge are shown in Table 3.

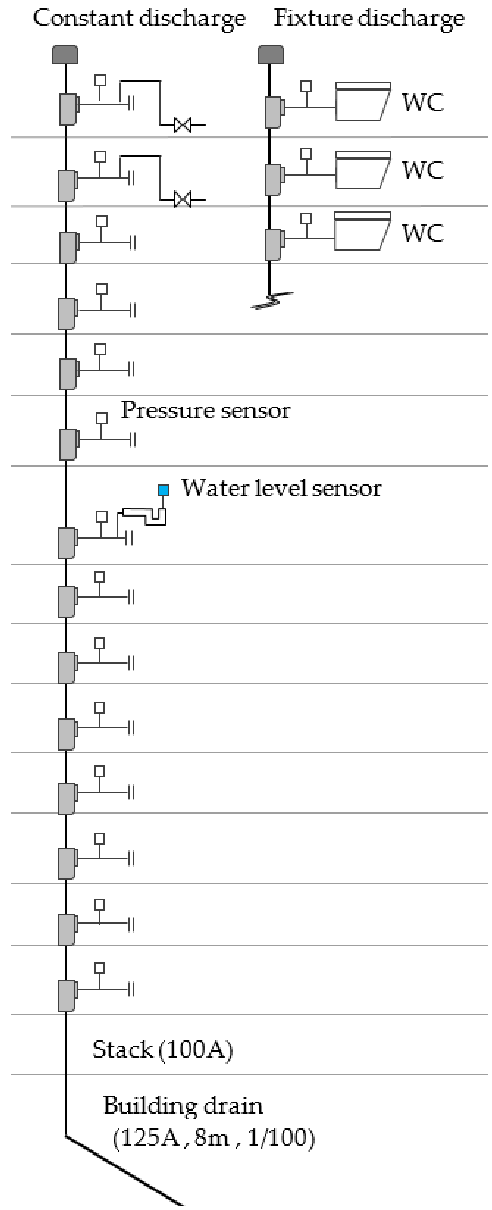

Figure 3 Outline of experimental drainage system

Air Pressure fluctuations in drain with fixture discharge moved from the negative to positive range while those with constant discharge stayed in the negative range. The reason for the increase in the case of fixture discharge is that air in drain was compressed by initial large loads of large discharge. Experimental and simulated results of seal water fluctuation indicated the similar trend in response to fluctuation of air pressure in drain. While air pressure in drain returns to zero after discharge is completed, seal water level continues to show minute vibration due to oscillation of water surface. In simulation, there was no seal water level fluctuation as the movement of water surface was not computed. As a whole, maximum and minimum air pressure and water level in simulation were approximately 10% smaller than those in experiment expect constant discharge of 1.5L/s and fixture discharge with 3WC. However, maximum seal water level with constant discharge of 4.5 L/s only showed larger values than maximum negative pressure in drain (water head value). This seems to indicate that some type of resonance phenomenon had occurred.

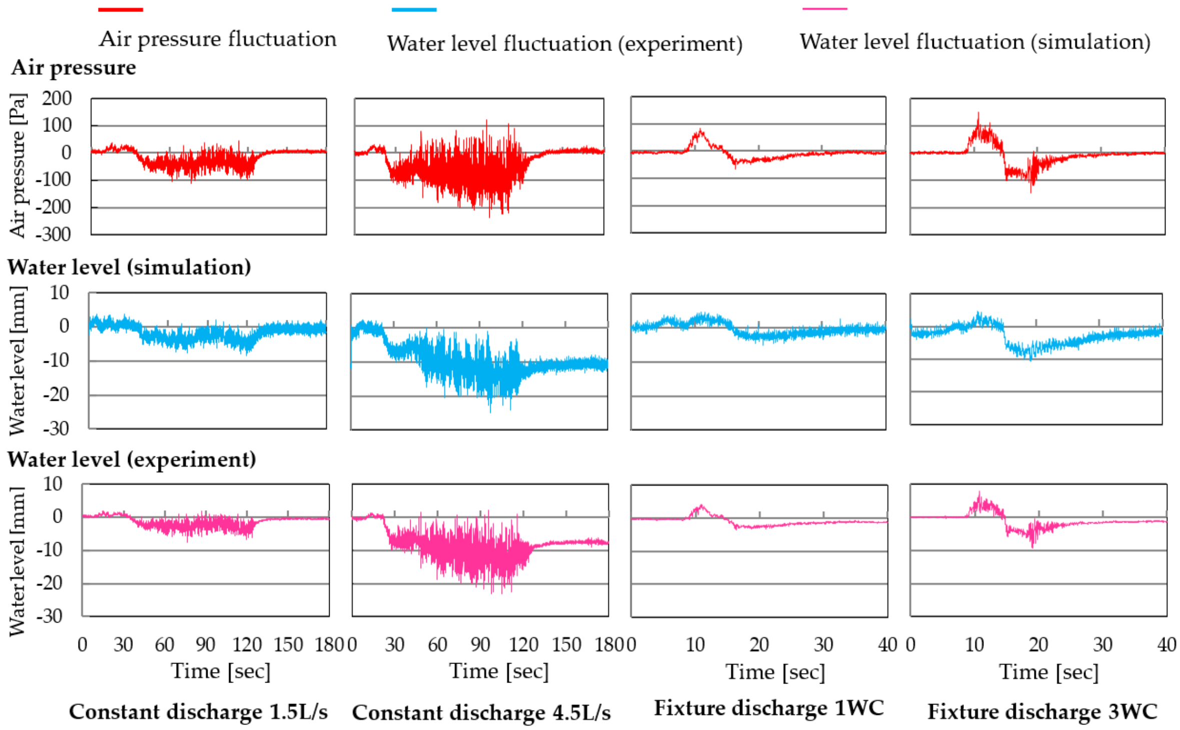

Figure 4 Experimental results of air pressure fluctuations in drain and experimental and simulated results of seal water fluctuation

Table 3 Maximum and minimum values of seal water level, and seal loss

Discharge load		**Air pressure [mmAq]**		**Water level [mm]**				**Seal loss [mm]**	
				Experiment		**Simulation**		**Experiment**	**Simulation**
		Max	**Min**	**Max**	**Min**	**Max**	**Min**		
Constant discharge	1.5L/s	4.5	-11.0	3.8	-8.5	1.9	-7.5	0.0.8	0.7
	4.5L/s	12.2	-23.8	2.5	-24.9	2.1	-23.2	11.6	6.2
Fixture discharge	1WC	8.4	-6.6	4.7	-5.1	4.0	-3.8	0.9	0.7
	3WC	14.9	14.8	4.6	-10.7	6.9	-9.2	1.9	1.6

5.2 Power spectrum of pressure in drain and seal water fluctuations

Experimental results of pressure fluctuations in drain, and experimental and simulated power spectrum distribution of seal water fluctuation with constant discharge of 1.5 L/s and 4.5L/s, and fixture discharge with 1 WC are shown in Figure 5. Dominant frequencies of pressure fluctuation in drain and seal water fluctuation are shown in Tables 4 and 5.

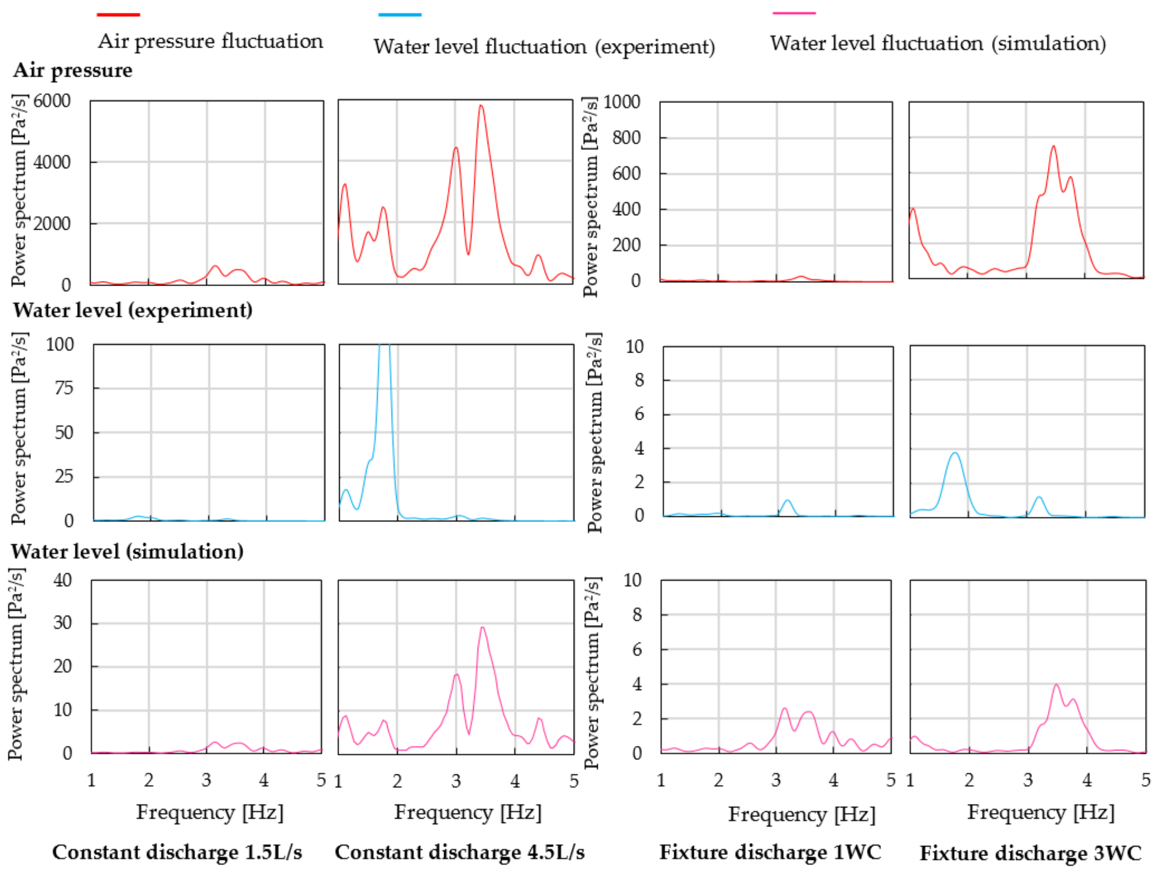

Figure 5 Power spectrum distribution of seal water fluctuation

Table 4. Dominant frequencies of air pressure

Dominant frequency [Hz]	**Constant discharge**		**Fixture discharge**	
	1.5L/s	**4.5L/s**	**1WC**	**3WC**
The first	3.17	3.42	1.22	3.47
The second	3.56	3.03	6.59	3.22
The third	3.96	1.12	3.47	3.76
The fourth	2.54	1.76	2.25	1.07
The fifth	4.3	1.51	2.0	1.51

Table 5. Dominant frequencies of air pressure

Dominant frequency [Hz]	Constant discharge				Fixture discharge			
	1.5L/s		4.5L/s		1WC		3WC	
	Expt.	Sim.	Expt.	Sim.	Expt.	Sim.	Expt.	Sim.
The first	1.81	3.17	1.76	3.42	3.17	3.47	1.75	3.47
The second	3.32	3.56	1.12	3.03	-	1.22	3.22	3.76
The third	1.22	4.0	3.08	1.12	-	2.25	1.22	1.07
The forth	-	4.3	2.29	4.39	-	4.05	-	1.95
The fifth	-	2.54	3.42	1.76	-	4.88	-	1.51

6 Conclusion

The authors derived a motion equation for simulated induced siphonage in P trap, and examined the validity of the equation by analyzing seal water fluctuation using EXCEL BVA based on the force of vibration in drain and by comparing with experimental data. The results of analysis can be summarized as follows:

(1) The trend of simulated seal water fluctuation roughly corresponded to experimental data.

(2) Simulated maximum and minimum seal water level, and seal depth were 10 to 20% smaller than experimental data.

(3) The first and second dominant frequencies of pressure in drain fluctuation fell in the range of 3.0～3.6Hz except for fixture discharge with 1 WC.

(4) The simulated power spectrum distribution of seal water fluctuation resembled to that of pressure in drain.

(5) Partial resonance phenomena seem to have occurred in constant discharge load of 4.5 L/s as the maximum water level exceeded the maximum negative pressure (water head) in experiment. This has been confirmed by the analysis of the power spectrum, but the simulation analysis failed to give any supportive evidence to this finding.

Based on these we can safely conclude that our simulation was validated in its application. As for (2) and (5), small damping coefficient may have contributed to the results. Along with seal loss rate, it prompts future studies.

Table 6. Dominant frequencies of air pressure

A: cross-sectional area of trap leg [m^2]	c: damping coefficient [N・s/m]
c_c: critical damping coefficient [N・s/m]	g: gravitational acceleration [m/s^2]
L: length of seal water [m]	m: mass [kg]
P: air pressure [Pa], [mmAq]	q_d: average flow rate of fixture discharge [L/s]
t: time [s]	t_s: time step [s]
y: water level [m], [mm]	y_{max}: maximum water level [m], [mm]
γ: seal loss rate [-]	ζ: damping ratio [-]
ρ: density [kg/m^3]	σ: logarithmic decrement [-]

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8 Presentation of Authors

Kyosuke Sakaue (Ph. D) is a professor at Department of Architecture, School of Science & Technology, and a head of New Plumbing System Institute, Meiji University. His fields of specialization include water environment, building services and plumbing system. He is currently engaged in the studies of next drainage system, trap performance, WC, stainless steel piping, water saving systems, maintenance.

Kazuya Fujimura (Ph. D) is a mechanical engineer at Mitsubishi Jisho Sekkei Inc. He is engaged in research / development of drainage plumbing system.

Takehiko Mitsunaga (Ph. D) is an mechanical engineer at Yamashita Sekkei Inc. He belongs to Mechanical Systems Design Development.

D5 - A Study on Evaporation Phenomenon of Trap Seal Water

T. Kojima (1), K. Sakaue (2)

1. ce63012@meiji.ac.jp
2. sakaue@isc.meiji.ac.jp
1. Graduate student at dept. of Architecture, School of Science and Technology, Meiji University, Japan
2. Dept. of Architecture, School of Science and Technology, Meiji University, Japan

Abstract

At present, there is no design measures have been taken for evaporation of trap seal water. In order to prevent seal break, it depends only on the water replenishment by using water supply system. Therefore, in order to know the drain cycle as a guide it is necessary to calculate the evaporation rate of the seal water in consideration of each weather condition, etc. However, although there are existing studies on the method of calculating the evaporation rate of water, it has been confirmed that there is a large difference between the conventional theoretical value and the measured value. In other words, there is no existing calculation formula that can be applied to a water seal trap.
In this study, we compared the theoretical value of water evaporation rate with the measured value in order to create new theoretical formula modified based on the existing theoretical formula. Also, we conducted experiment by reproducing the evaporation phenomenon on the inflow leg side of the trap using a cylinder.

Keywords

Trap, seal break, evaporation, theoretical formula

1 Introduction

Up to the present no design measures have been taken to deal with evaporation of trap seal water, and nothing can be done except to rely on water replenishment with the water supply system to prevent seal break. The cycle of replenishment must be established for effective water replenishment, which in turn requires calculation of the evaporation rate of seal water under various weather conditions. However, although some studies have been done on the calculation method of evaporation rate of water, it is a well-known fact that the theoretical values obtained from the conventional formulas greatly differ from actual measurements. This practically means that no reliable calculation method exists, that can be applied to water seal trap.

In view of this situation, we compared theoretical values of water evaporation rate with measured values to create a new theoretical formula, one modified based on the existing one. We also conducted an experiment using cylinders to simulate an evaporation phenomenon that occurs on the inflow leg side of a trap.

2 Measurement of evaporation rate using cylinders

2.1 Purpose

The effects of various experimental conditions on evaporation rate were analysed to collect data on evaporation volume inside cylinders.

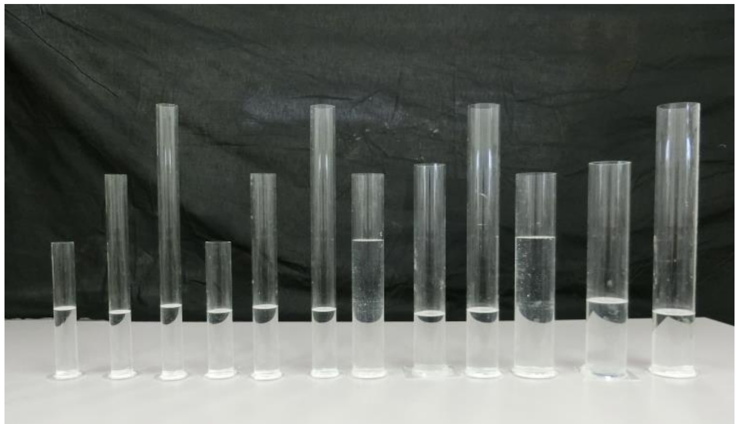
2.2 Outline of experiment

The list of measurement parameters and apparatuses are shown in Table 1. Cylinders filled with water under various conditions were weighed with an electronic scale, and evaporation volumes were calculated as the differences of weights at each measurement cycle.

The photograph 1 shows the placement of cylinders in the experiment. The diagram of cylinders is shown in Figure 1, and an electronic scale used in Photograph 2.

Table 1. List of measurement parameters and apparatuses

Measurement parameters	Measurement apparatuses
Temperature [℃]	Multi-functional anemometer
Humidity[%]	
Wind velocity [m/s]	
Water temperature [℃]	Radiation thermometer
Evaporation volumes [g]	Electronic scale



Photograph 1. An example of cylinder placement in evaporation experiment

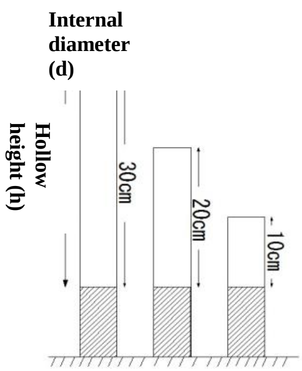


Figure 1. Diagram of Cylinders **Photograph 2. An electronic scale**

Table 2. Internal diameters and hollow heights of cylinders

Internal diameters (d) [cm]	hollow heights (h) [cm]
2.5	10 · 20 · 30
3.0	
4.0	
5.0	

The internal diameters of the cylinders and the heights from the water surface to the upper ends of the cylinders (referred to as hollow heights below) are shown in Table 2. Under each condition, measurements were made and evaporation volumes were recorded for cylinders with internal diameters of 2.5, 3.0, 4.0, and 5.0 cm, and hollow heights of 10, 20, and 30 cm. All the cylinders were made of acrylic.

Sampling was made with a multi-functional anemometer at the cycle of 720 seconds, and water temperatures and evaporation volumes were measured at the cycle of 8 hours. The average of measurement time was calculated for each parameter and incorporated into the theoretical formula. All measurements were made indoors (with no air conditioning, doors and windows closed) from September to November 2016.

2.3 Results and discussion

The data of the interior environment from October 31 to November 6 are shown in Figure 2. An example of the trend of evaporation volumes in a cylinder with 3 cm internal diameter during the period is shown in Figure 3, and that in a cylinder with hollow height of 20 cm in Figure 4. As measurements were made indoors, wind velocity stayed around 0.0 m/s, and no significant changes in temperature and humidity were recorded. Therefore it was confirmed that the theoretical formula for evaporation by natural convection could be applied.

The comparison of various size cylinders indicated that the larger the internal diameter and the smaller the hollow height, the larger the evaporation rate, and that evaporation varied depending on the time of measurement. This seems to suggest that evaporation areas increase in proportion to the internal diameter and the effect of turbulence becomes more prominent with smaller hollow heights. Evaporation volumes were extremely small with hollow heights of 20 and 30 cm, and no significant difference was seen. These results show the extremely strong influence of internal diameter and hollow height on evaporation volume.

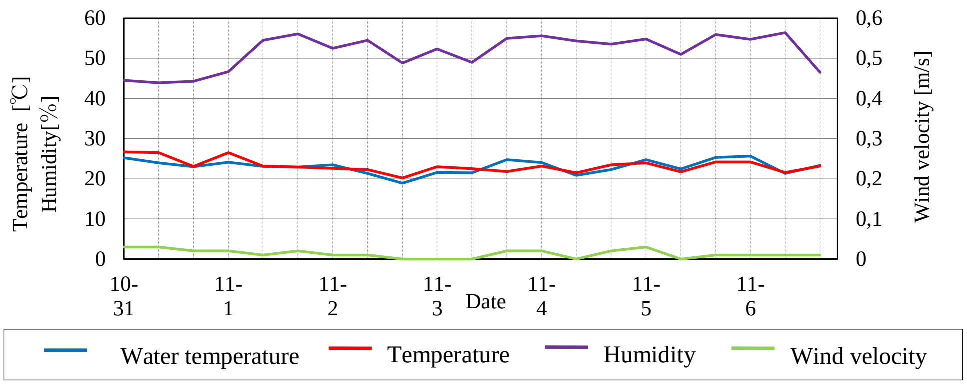


Figure 2. Indoor environmental data (10/31 ~ 11/6)

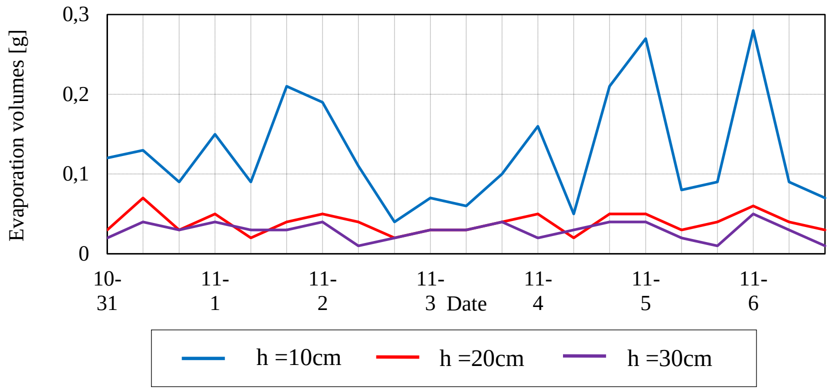


Figure 3. Changes in evaporation volume in cylinders with internal diameter of 3 cm (10/31 ~ 11/6)

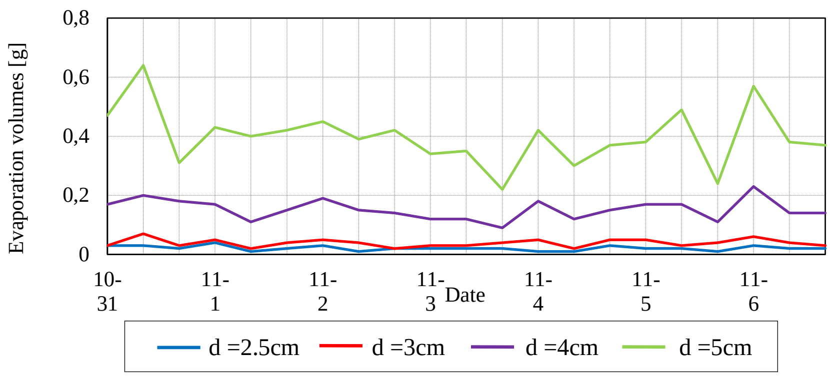


Figure 4 Changes in evaporation volume in cylinders with hollow height of 20 cm (10/31 ~ 11/6)

3 Derivation of modified theoretical formula

3.1 Theoretical formula

The previous studies indicated that the evaporation of water increases in proportion to the difference in water vapor pressure (e_s-e) and water surface area. The conditions of water surface also play an important role in effecting changes in evaporation volume. In particular, it was shown that hollow height affected the evaporation volume of water inside vertically held cylinders. In view of this we took a formula that uses hollow height (h) as a parameter from a previous literature, and used it as a basis for creating a modified formula. The evaporation rate theoretical formula is shown in Table 3.

Table 3. Evaporation rate theoretical formula

$$\omega_t = 0.59 \frac{1}{h^{1/4}} (e_s - e)$$

ω_t: Evaporation rate [mg/(cm^2・h・hPa)]
e_s: Water vapor pressure on the water surface [hPa]
e: Water vapor pressure of air [hPa]   h: Hollow height [cm]

3.2 Comparison of theoretical values with actual measurements

The theoretical values of evaporation rate per unit time and unit surface area are calculated from the theoretical formula and compared with actual measurements.
An example of the scatter diagram of the evaporation rate ω and the difference in water vapor pressure (e_s-e), and their primary regression equation according to internal diameter is shown in Figure 5, and the comparison in terms of hollow height in Figure 6. Figure 5 indicated that actual measurements were relatively small compared with theoretical values as hollow height became smaller while the internal diameters of the cylinders stayed the same. Figure 6 showed the actual measurements increased in comparison with the theoretical values as hollow height became smaller while the internal diameters of the cylinders stayed the same. From these results, it has been confirmed that the internal diameter and hollow height have a correlation with the fluctuations of the scale factor of theoretical values and actual measurements.

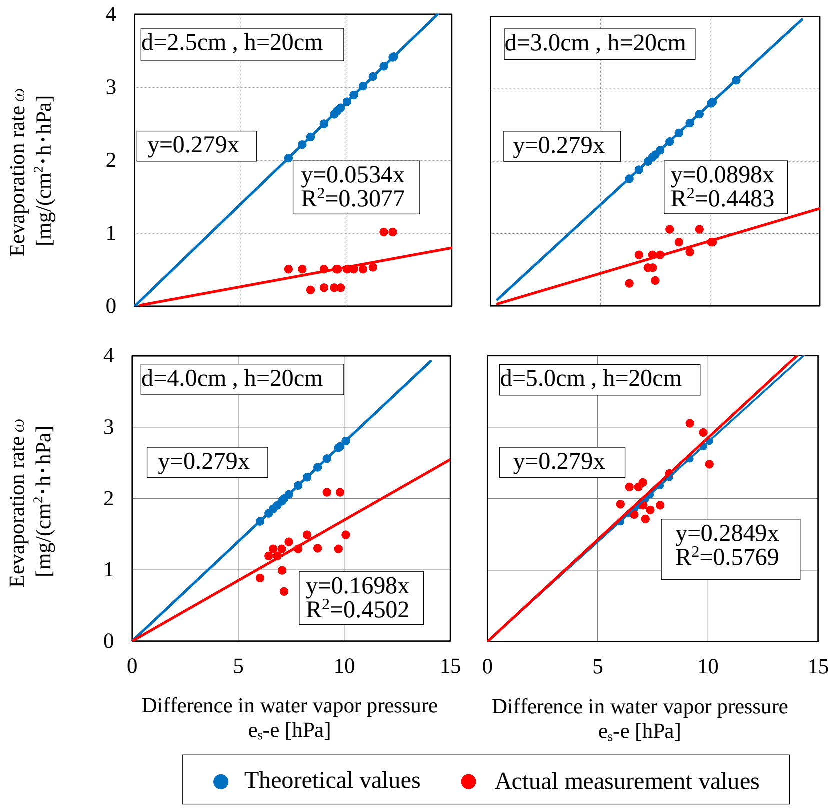


Figure 5. Examples of comparison with h = 20 cm (11/14 ~ 11/21)

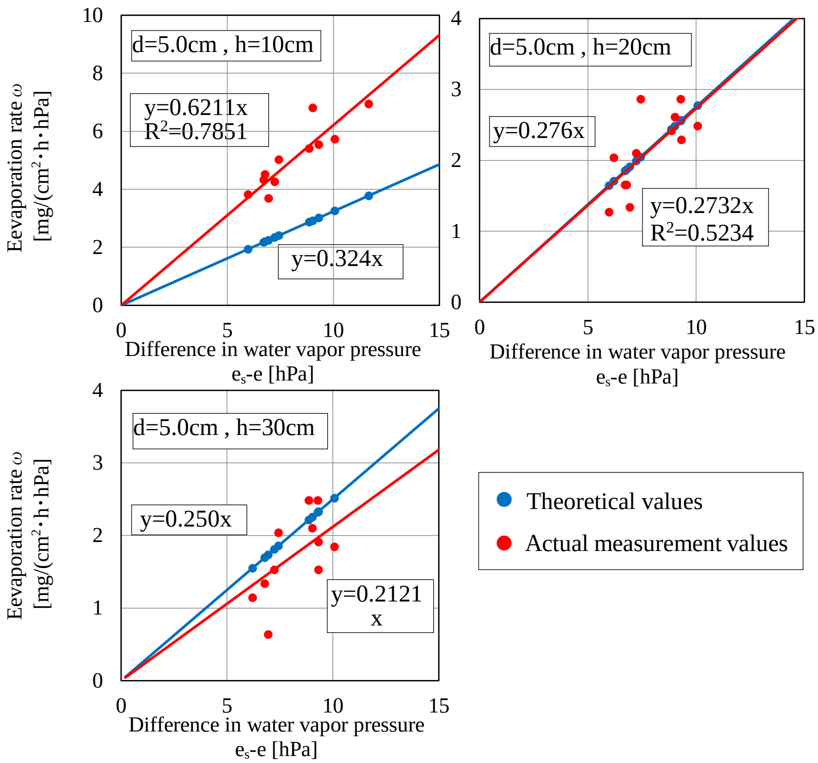


Figure 6. Examples of comparison with d = 5 cm (11/7 ~ 11/14)

3.3 Modification of theoretical formula

Actual measurements as a function of theoretical values under each condition were calculated to obtain a correction function that is necessary to yield values approximate actual measurements.

3.3.1 Ratio of theoretical value to actual measurement

The list of the ratios of theoretical values to actual measurements during November 14 ~ 21 is shown in Table 4. The ratios under all conditions decreased as the internal diameters increased and increased as the hollow height increased.

The scatter diagrams of the ratios during the entire measurement period are shown in Figure 7. The approximate curves relative to the internal diameter indicated ascending powers, and tended to position themselves in the upper regions as hollow heights increased. Therefore, it has been confirmed that the internal diameters and hollow heights have a correlation with approximate curves that shows the fluctuations of the ratios.

Table 4. List of ratios (theoretical values / actual measurements) (11/14~11/21)

Conditions		Internal diameter (d) [cm]			
		2.5	3.0	4.0	5.0
Hollow height (h) [cm]	10	2.337	0.867	0.650	0.537
	20	5.225	3.107	1.643	0.979
	30	5.932	3.780	2.009	1.083

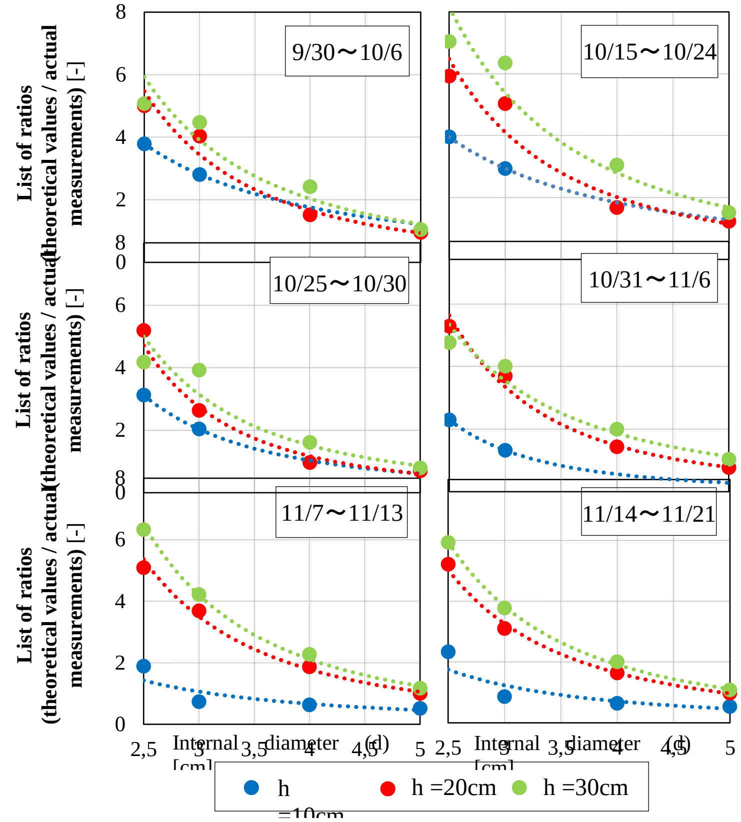


Figure 7. Variations of ratios

3.3.2 Derivation of correction coefficient

The list of regression equations for each approximate curve in Figure 7 is shown in Table 5.

The coefficient of each regression equation tended to increase in proportion to hollow height, and the indices were found to be more or less constant. The scatter diagram and primary regression equation indicating the changes of coefficient in relation to hollow height are shown in Figure 8. The indices are calculated based on the average for each period and the primary regression equation as a coefficient. The corrective coefficient obtained is shown in Table 6.

Table 5. List of regression equations of each approximate curve

Period	Hollow heights [cm]		
	10	20	30
9/30～10/6	$14.87x^{-1.54}$	$35.00x^{-2.22}$	$64.56x^{-2.50}$
10/15～10/24	$29.90x^{-2.21}$	$47.76x^{-2.32}$	$58.27x^{-2.28}$
10/21～10/30	$27.00x^{-2.36}$	$55.63x^{-2.81}$	$86.54x^{-2.90}$
10/30～11/6	$36.16x^{-3.01}$	$48.78x^{-2.553}$	$45.56x^{-2.30}$
11/7～11/14	$8.12x^{-1.78}$	$46.11x^{-2.35}$	$58.09x^{-2.39}$
11/14～11/21	$12.18x^{-2.03}$	$44.70x^{-2.38}$	$54.66x^{-2.42}$

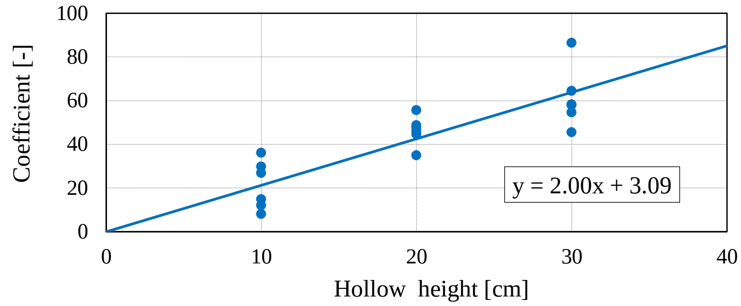


Figure 8. Average rate of change in coefficient

Table 6. Correction coefficient

$$\alpha = \frac{1}{(2h + 3.09)d^{-2.35}}$$

h: Hollow height [cm]   d: Internal diameter [cm]

3.3.3 Modified theoretical formula

A new formula for computing evaporation rate was created by incorporating the corrective coefficient shown in Table 6 into the theoretical formula. The modified formula is shown in Table 7.

Table 7. Modified theoretical formula

$$\omega_t' = \alpha\omega_t$$

ω_t': Evaporation rate (modified theoretical formula) [mg/(cm^2･h･hPa)]

α: Correction coefficient

ω_t: Evaporation rate (theoretical formula) [mg/(cm^2･h･hPa)]

4 Verification of the modified formula

4.1 Purpose

Evaporation rates were calculated based on the formula created in 3.4, and compared with actual measurements.

4.2 Outline

The experiment was set up in the same way as the evaporation rate experiment described above in Section 3, and the volume of evaporation was measured from March 5 to 15, 2017.

4.3 Results and discussion

The calculated theoretical values of evaporation volume were compared with actual measurements for each period and cylinder. An example of the scatter diagrams of the evaporation rate ω and the difference in water vapor pressure $(e_s\text{-}e)$, and their primary regression equation according to internal diameter is shown in Figure 9.

In each diagram, the differences were found to be smaller than the theoretical values obtained by the conventional formula. Although there were some discrepancies, the trend of the changes in evaporation volume was similar. Therefore, it can be concluded that the formula for evaporation rate created in 3.4 is, on the whole, applicable to the calculation of evaporation rate in cylinders. However, the data used for verification were collected during a short period of time, thus, may not represent all possible environmental conditions. Accordingly, a more accurate formula applicable to various conditions can be derived if we collect a variety of data based on a number of similar experiments.

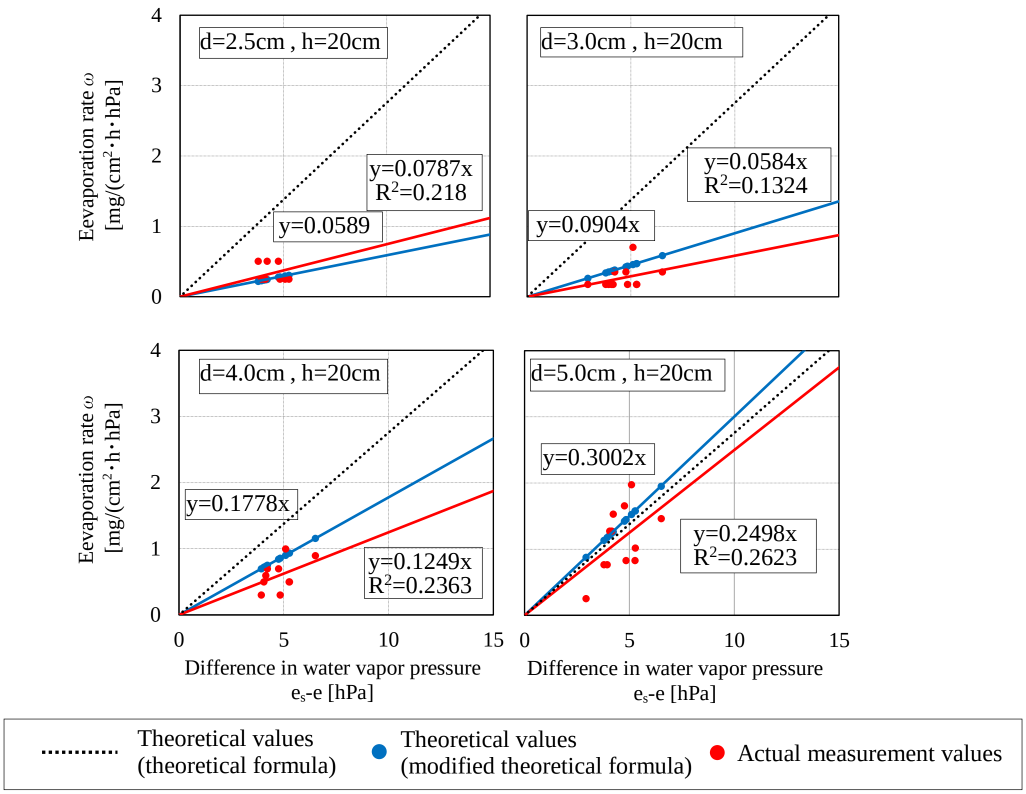


Figure 9. Examples of comparison with h = 20 cm (3/5 ~ 3/15)

5 Conclusion

In this study we conducted an experiment using cylinders to measure evaporation rate, and compared the values with those obtained by the conventional theoretical formula. The results can be summarized as follows:

1) Water in cylinders evaporated faster with larger internal diameters and smaller hollow heights.
2) The rate of evaporation can be expressed by the equation below:

$$\omega = \frac{1}{(2h + 0.309)d^{-2.35}} \cdot 0.59 \frac{1}{h^{1/4}} (e_s - e)$$

$[\mathrm{mg/(cm^2 \cdot h \cdot hPa)}]$

3) Although some differences were noted between the theoretical values obtained by the equation above and the actual measurements, evaporation volume changed in a similar way.

Some issues that need to be addressed in the future include: the collection of a wide range of data, the improvement of the accuracy of the formula, and the use of test trap to simulate actual drainage conditions.

6 Reference

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2. Ueda,M.(2000), Humidity and evaporation - Foundation and measurement technology (*shitudo to jyouhatu kiso kara keisokugijyutu made*), *Copyright CORONA PUBLISHING CO.,LTD,pp102.*

7 Presentation of Authors

Takahiro Kojima is a master of the student at the Sakaue laboratory, Department Of Architecture, School of Science and Technology at Meiji University in Japan.

Kyosuke Sakaue (Dr. Eng.)
Professor at Meiji Univ.
He is engaged in research/development of drainage plumbing systems

D6 - Connections to a discharge stack at the same floor

Ing. René Offringa
rene.offringa@wavin.com
Technical Advisor Building and Installation, Wavin Nederland B.V.

Abstract

According EN 12056-2 it is not allowed to connect a non-swept branch at a discharge stack opposite to another branch at the same level or somewhat below, this to prevent flow from one branch into another.
To examine the need of this rule and the effects under different circumstances, a lot of flushing tests were carried out. The conclusion is that the rules can be simplified.

Keywords

Discharge; stack; branch; connection; cross flow; back flow

1 Introduction

According EN 12056-2 it is not allowed to connect a non-swept branch at a discharge stack opposite to another branch at the same level or somewhat below, this to prevent flow from one branch into another, so called *back flow*. This demand doesn't make life easy because in practice sanitary devices at one floor are often designed at both side of a stack and then extra pipe lengths and bends are needed to connect one of the branches under 90° instead of 180°. This is an undesirable situation because a drainage pipe system should be as short and as straight as possible.
To examine the need of this demand and the effects if you do not follow this rule, a lot of flushing tests were carried out. Before starting the tests we made an inventory of possible problems which may occur when *back flow* happens:

1. Contamination of the branch with possible clogging
2. Pressure fluctuations which results in water losses at water traps
3. Slow discharge at small devices flushing at the same time
4. Contamination of water traps

To have a kind of reference also a test with a standard stack was carried out to see how much water was flushing into a branch when water was just running along the wall of the down pipe.

2 Description of the test equipment

Figure 1 gives an impression of the test set up for the reference test.
At the top of the system water was supplied at the end of an 1 m branch with the possibility to supply also dirt in the shape of 25 small plastic particles, PE cubes with a rib length of 10 mm (mass 950 kg/m³). At the bottom of the stack a branch was connected to the stack. At the end of the branch a water trap with a water height of 50 mm was installed, total length of the branch 1 m. A pressure measuring device was connected to the top of the branch at a distance of 0.25 m from the stack.

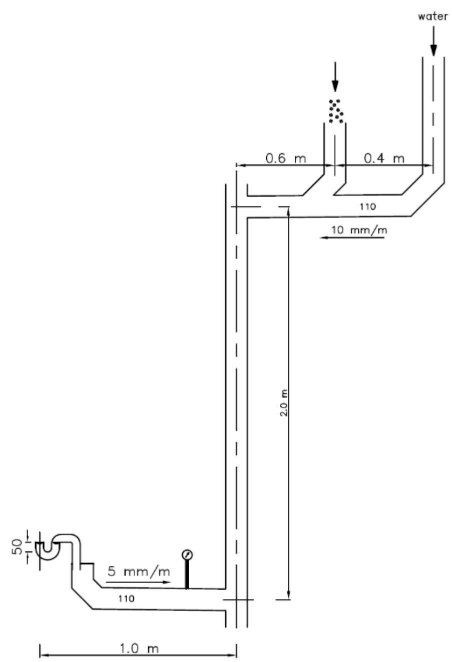

Figure 1 – Test set up reference test

Figure 2 gives an impression of the test set up for the *back flow* tests. The figure shows the situation with a double T-piece 180° (cross), the receiving branch could also be placed under an angle or with a distance H between the branches. For branches 75 mm and H=0, equal T-pieces 110 were used together with a reducer 110x75 with the top of pipe 110 and 75 at the same level.
The water flow of 2 l/s is based more or less on the flow of a toilet. At the moment the first flush reached the stack the particles were dropped in the supply branch. The flow duration was about 10 sec, so the total amount of water was about double the amount from 1 standard toilet.

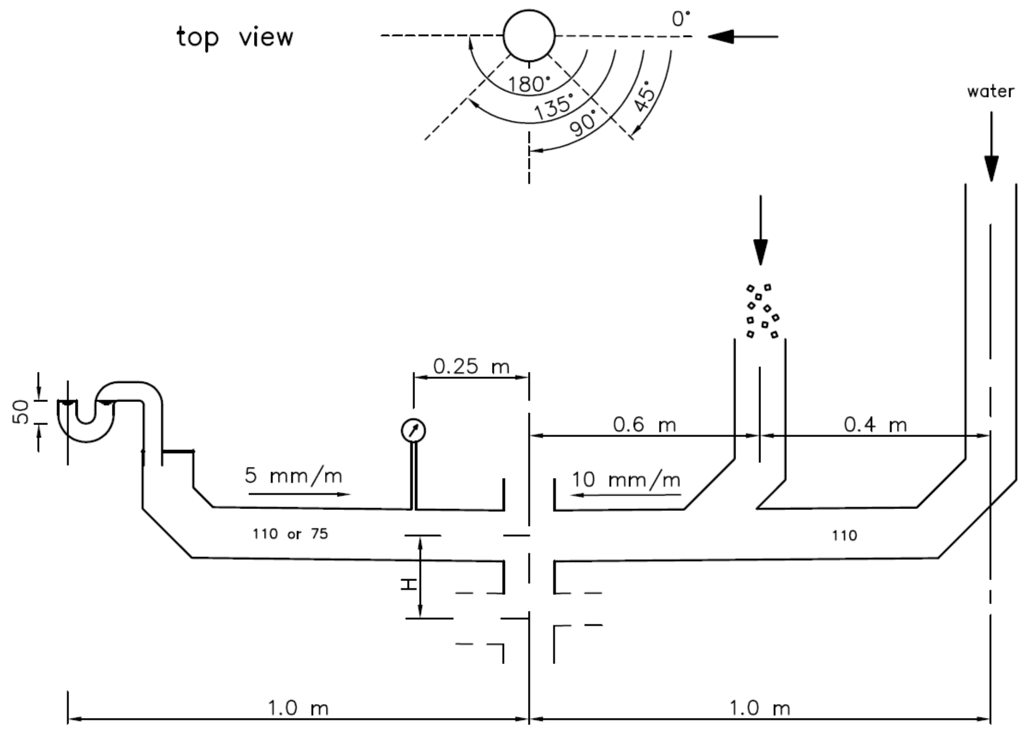

Figure 2 – Test set up back flow test

3 Test results

An overview of the test results is given in table 1.
We made a distinction in the different series of tests:

Test 1	Just the stack (figure 1)
Test 2 – 9	Tests with all branches at the same level (figure 2)
Test 10 – 25	Tests with a difference in height of 150 mm
Tests 26 – 35	Tests with a difference in height of 300 mm
Tests 36 – 46	Tests with a difference in height of 450 mm

Table 1 – Overview of test results

-	fitting	flow (l/s)	H (mm)	angle (°)	water loss siphon (mm)	pres-sure (Pa)	contami-nation (%)	water level 5 sec
1	single T 110	2.0	2000	180	0	<10	0	0,2.D
2	double T 180° 110	2.0	0	180	0	15	40	0,4.D
3	ball T 180° 110	2.0	0	180	0	<10	32	0,7.D
4	double swept T 180° 110	2.0	0	180	0	<10	32	0,5.D
5	double T 180° + 110/75	2.0	0	180	0	<10	0	0,3.D
6	ball T 180° + 110/75	2.0	0	180	0	25	20	0,3.D
7	swept T 180° + 110/75	2.0	0	180	0	<10	0	0,3.D
8	double T 90° 110	2.0	0	180	0	<10	20	0,4.D
9	double T 90° + 110/75	2.0	0	180	0	<10	16	0,4.D
10	single T 110	2.0	150	180	0	<10	8	0,2.D
11	single T 110	0.5	150	180	0	<10	40	0,2.D
12	single T 110	2.0	150	135	0	20	24	0,3.D
13	single T 110	0.5	150	135	0	<10	24	0,2.D
14	single T 110	2.0	150	90	0	20	40	0,3.D
15	single T 110	0.5	150	90	0	<10	0	0.1.D
16	T 110x75	2.0	150	180	0	25	4	0,3.D
17	T 110x75	0.3 [2])	150	180	0	<10	> 50	0,5.D
18	T 110x75	2.0	150	135	0	- [1])	8	0,3.D
19	T 110x75	0.3 [2])	150	135	0	<10	4	0,2.D
20	T 110x75	2.0	150	90	0	- [1])	16	0,4.D
21	T 110x75	0.6	150	90	0	<10	0	0,1.D
22	T 110x75	2.0	150	45	2	- [1])	0	0,3.D
23	T 110x75	0.6	150	45	0	<10	0	0,1.D
24	T 110x75	2.0	150	0	0	<10	8	0,3.D
25	T 110x75	0.5	150	0	0	<10	0	< 0,1.D
26	single T 110	2.0	300	180	1	-	0	0,2.D
27	single T 110	0.5	300	180	0	<10	0	0,2.D
28	single T 110	2.0	300	135	0	<10	0	0,2.D
29	single T 110	0.5	300	135	0	<10	0	0,1.D
30	single T 110	2.0	300	90	0	<10	0	0,2.D
31	single T 110	0.5	300	90	0	<10	0	0,1.D
32	single T 110	2.0	300	45	0	- [1])	16	0,2.D
33	single T 110	0.5	300	45	0	- [1])	24	0,1.D
34	single T 110	2.0	300	0	0	<10	32	0,3.D
35	single T 110	0.5	300	0	0	<10	24	< 0,1.D
36	single T 110	0.13	450	180	0	<10	4	0,1.D
37	single T 110	0,5	450	180	0	<10	0	0,1.D
38	single T 110	2.0	450	180	0	14	28	0,2.D
39	single T 110	2.0	450	135	0	14	8	0,2.D
40	single T 110	0.5	450	135	0	<10	0	0,1.D
41	single T 110	0.5	450	90	0	<10	4	0,1.D
42	single T 110	2.0	450	90	1	10	0	0,2.D
43	single T 110	2.0	450	45	2	12	0	0,2.D
44	single T 110	0.5	450	45	0	<10	0	0,1.D
45	single T 110	0.5	450	0	0	<10	24	< 0,1.D
46	single T 110	2.0	450	0	0	13	8	0,2.D

[1]) - : not measured or doubts about the measurement
[2]) most critical flow

All tests were captured in movies, a lot of the values in table 1 are based on the movies.

The column *pressure* in table 1 indicates the pressure measured by the pressure device at a distance of 0.25 m from the stack. In some cases water droplets entered the hose of the device which causes an unreliable measurement. Of course the pressure fluctuates a little bit during the test and we tried to put the highest reliable value in the table. Anyway, pressure differences are very low, obviously the air velocities above the water level are so low that they do not cause much pressure differences.
The column *contamination* in table 1 indicates the percentage of particles which entered the receiving branch during the test. A lot of these particles were flushed back to the stack after the water supply was stopped. The amount of contamination gives an impression of the chance on contamination, but because the percentage was not well reproducible, we have to be a little bit careful with conclusions. It also seems that the percentage of contamination was dependable on the moment of dropping the particles (before the flush or during the flush). To see if the plastic particles do not completely behave different from standard contamination in a discharge system, we also did some tests with mandarin parts. Although mandarin parts have the tendency to stick more at the wall of the pipe, the results did not differ much from those with the plastic particles.
The column *water level* in table 1 is the by movie estimated water level at a distance of 0.5 m from the stack, 5 seconds after the start of the flow in the branch. The 5 seconds period is based on the assumption that this is the maximum level which can be reached during one toilet flush. The water level is a very good reproducible value.

Some interesting pictures are shown below.

Figure 3 - Test 2, double T 180°. Contamination 40%, water level 0.4.D

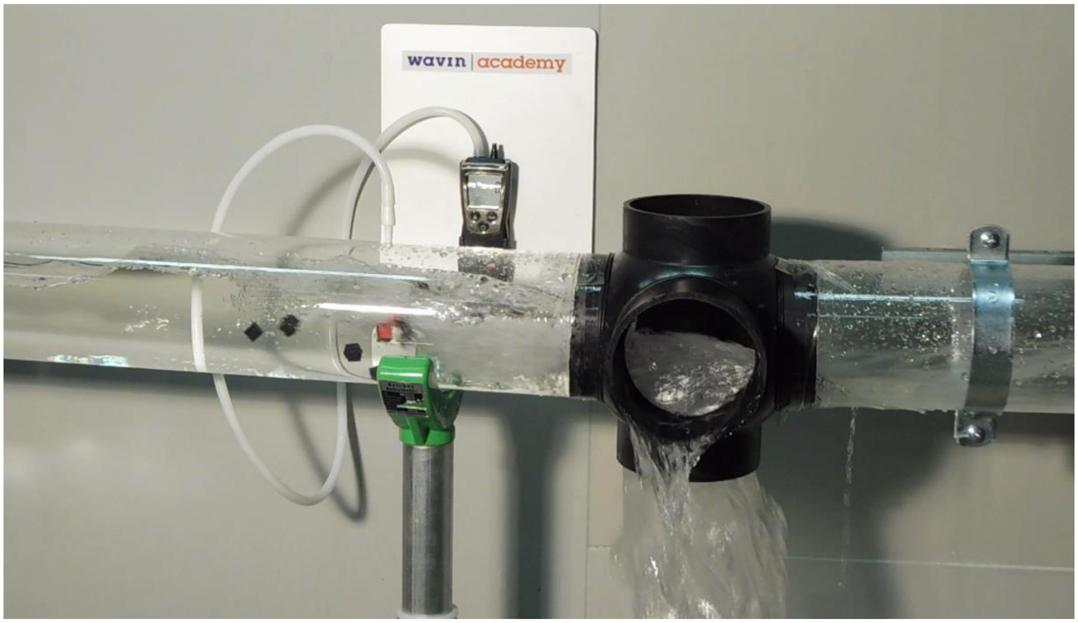

Figure 4 – Test 3, ball T 180°. Contamination 32%, water level 0.7.D

It may be a little bit surprising that it seems that the *back flow* with ball Tees and swept Tees seems to be worse as with just standard straight double Tees. But when we consider the flow paths in the fittings it is clear what happens.

Straight T

Swept T

Ball T

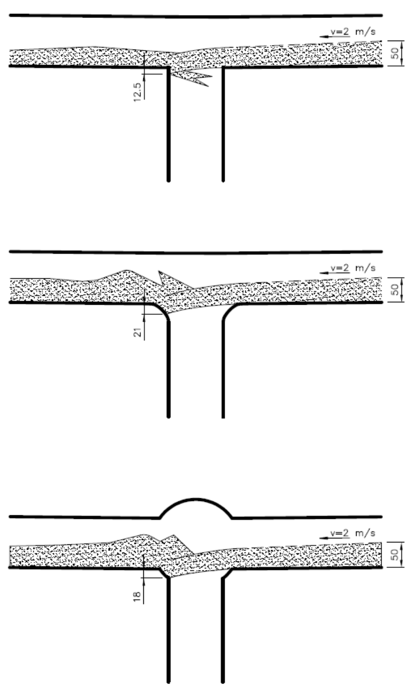

Figure 5 – Flow paths within different kinds of double Tees

The different flow paths are shown in figure 5. Of course the flow is curved downwards after leaving the supply branch. How much the flow will be curved can be calculated with the gravity rules when the horizontal velocity is known.
A part of the flow in the straight double T will flow directly into the opposite branch while another part will hit the wall directly under the opposite branch. This part will be thrown back and will disturb the flow.
Although de flow inside the swept T and the ball T will be bended a little bit more downwards, most of the flow will hit the curved part just under the opposite branch and will be thrown into the opposite branch.

Figure 6 – Test 8. Double T 90°. Contamination 20%, water level 0.4.D. Mind the spectacular entrance of the water flow.

Figure 7 – Test 10. T at 90°. H = 150. Contamination 16%, water level 0.4.D

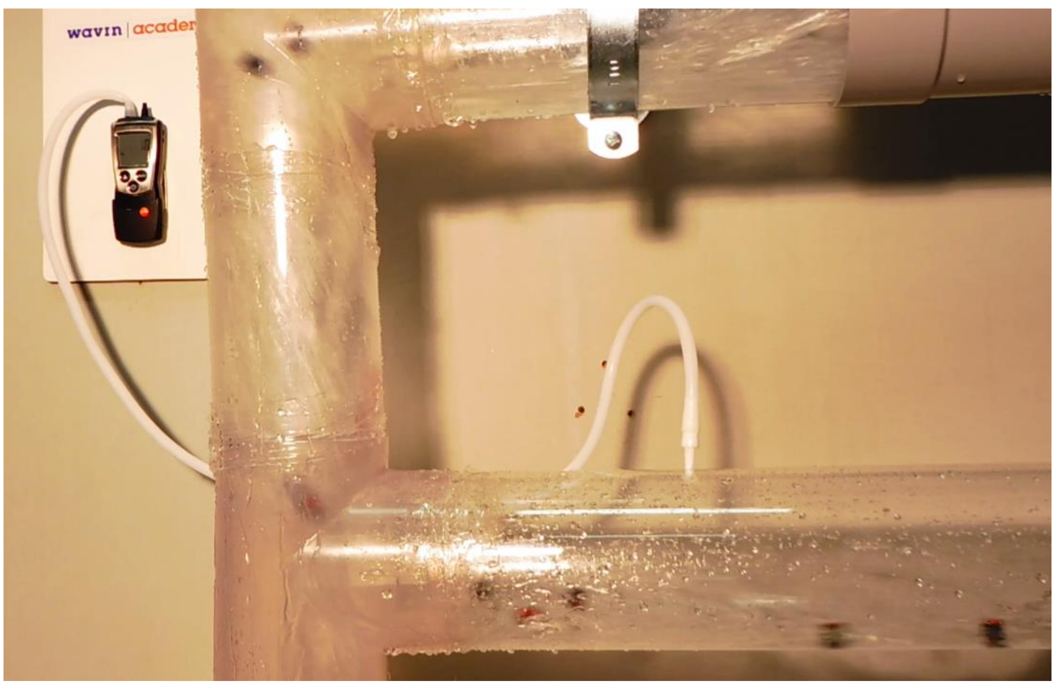

Figure 8 – Test 34. T at 0°, H = 300. Contamination 32%, water level 0.3.D

As shown in figures 6, 7 and 8, reflection of water against the opposite pipe wall may cause considerable contamination and high water levels. Nevertheless these situations are common practice and obviously do not give much trouble in practical discharge systems.

4 Conclusions

When we compare the results with the possible *back flow* problems mentioned in the introduction, we can conclude that

- pressure fluctuations are very low, even at high water levels
- there is no serious water loss at water traps
- if connected above the water level there will not occur any contamination of water traps
- in fact the only negative effect of *back flow* may be contamination
- some situations which are common practice delivered in laboratory much contamination and high waters levels like connections under 0° or 90°

In practice mostly toilets will deliver a lot of contamination, so only branches with toilets may cause possible contaminations in other branches.

One remark about water level: in the test we only used branches of 1 m length. It may be expected that a shorter branch causes a higher water level and a longer branches causes a lower water level. Some provisional tests show that this is indeed the case. These provisional tests also showed that long branches with lower water levels are more sensitive for contamination staying behind.

5 Discussion

The question about the risk on contamination caused by *back flow* still remains a difficult one. In the tests we saw several situations in which contamination occurred, but the reproducibility was low and in most cases a lot of the contamination was flushed away at the end of the test.
Water level was good reproducible and could therefore be a better criterion. But what should be the limit?
We know that with just flow from the stack (test 1) a water level of 0.2.D occurs.
We have also seen that some situations with water levels up to 0.4.D do not give problems in practice. And also we may expect that even when some contamination will stay behind, this does not mean that serious problems occur when the branch will be used regularly. We may expect that the contamination will flush away within reasonable time.
For all these reasons we think that a limit of 0.4.D will be a pretty save limit.

This limit leads us to the following advice:

Any branch opposite another branch on which a toilet or other device with a lot of contamination is connected should be avoided, meaning all connections 180° at the same level, straight T, swept T or ball T.
All other branch connections at the same floor are harmless provided that the length of the branch is at least 1 m and there is a regularly discharge and/or the water traps are

situated min. 100 mm above the branch to flush away possible contamination staying behind.

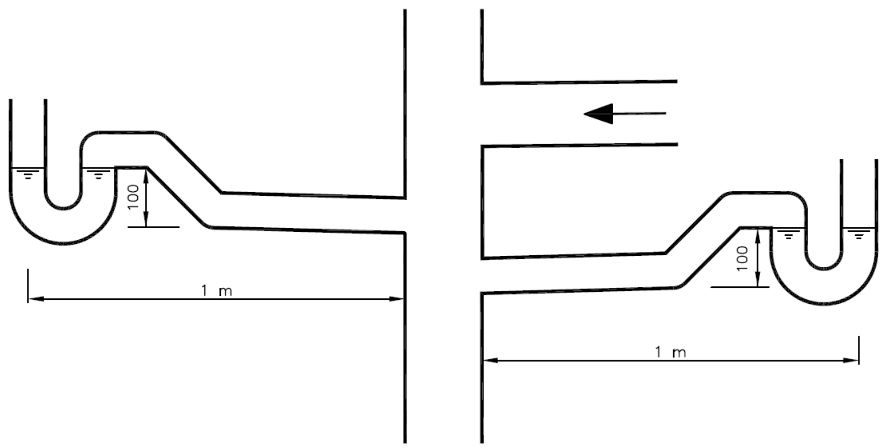

Figure 9 – Allowable connections at the same floor

Acknowledgments

All test were executed at the Wavin laboratory in Hardenberg (NL) in cooperation with Akatherm, Dyka and Geberit.

6 References

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D7 - Experiment on flow capacity for drainage system of stack vent system with vent cap

Norihiro Hongo (1), Masayuki Otsuka(2), Yuki Kuga (3)

1.hongou@yamagata-cit.ac.jp
2.dmotsuka@kanto-gakuin.ac.jp
3. m17J3006@kanto-gakuin.ac.jp
(1) Assoc. Prof. M. Eng, Architecture Environment System Engineering, Yamagata College of Institute of Technology, Japan
(2) Prof. Dr. Eng, Department of Architecture and Environmental Design, Kanto Gakuin Univ, Japan
(3) Graduate Student, Graduate School of Engineering, Kanto Gakuin Univ. Japan

Abstract

In Japan, it's necessary to open an end of stack vent pipe in a drainage system to the atmosphere, and installs vent cap in an edge of the vent pipe is general. It's said that the design which considered vent resistance value and equivalent pipe length is important to a design of stack vent pipe. Vent resistance value of a marketed vent cap is grasped and expansion with a design of vent pipe has been measured. But there is little data which show the relationship of vent resistance value and flow capacity about the drainage capacity of the drainage system. In this report, 2 basic experiments were performed to make the problem with a vent pipe design clearly. The 1st experiment about vent resistance value of vent cap was made and the 2nd experiment about the flow capacity of the drainage system in stack vent system with vent cap was made. As a result, by the 1st experiment, the vent resistance value of vent cap confirmed the difference about the ventilation performance of the type 2 different in the shape. The flow capacity of the drainage system in stack vent with vent cap was grasped quantitatively by the second experiment, based on the 1st experimental result. When the flow capacity of drainage system with a vent cap different in the shape and the vent resistance value was installed is compared, the difference in flow capacity was small result.

Keywords

Flow capacity; Drainage system; Vent resistance value; Vent cap

1 Introduction

In Japan, it's necessary to open an end of stack vent pipe in a drainage system to the atmosphere, and installs vent cap in an edge of the vent pipe is general. It's said that the design which considered vent resistance value and equivalent pipe length is important to a design of stack vent pipe. Vent resistance value of a marketed vent cap is grasped and expansion with a design of vent pipe has been measured. But there is little data which show the relationship of vent resistance value and flow capacity about the flow capacity for drainage system. This paper's purpose is that the drainage flow capacity of the drainage system of stack vent system of JIS-DT joint was grasped quantitatively. And drainage flow capacity influence by vent resistance in a ventilation edge was considered using a typical vent cap based on the result vent resistance measured. The experimental item is indicated below.

1. Experiment in vent resistance of vent cap grasped.
2. Experiment in the drainage flow capacity of the drainage stack system with a vent cap

2 Experiment in vent resistance of a vent cap grasped

2.1 Experimental purposes

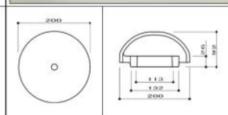
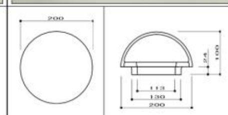
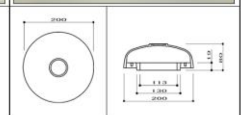
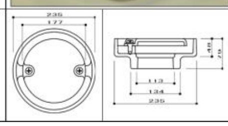
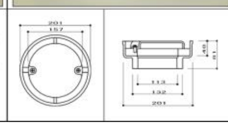
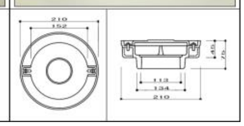
When estimating the drainage flow capacity of the drainage stack system with a vent cap, vent resistance of an employed vent cap will be an important parameter. Therefore, this experiment purpose is to grasp those vent resistance using the exposure type and the embedded type of the vent cap used for a drainage system of collective housing.

2.2 Experimental methods

2.2.1 The kind of vent caps

Table 1 shows the vent cap used by experiment. The vent cap used in an experiment used a vent cap of the biggest vent resistance value and the smallest vent resistance value more than the past reference. And a vent cap of the vent resistance value near the mean selected, too. The kinds of vent cap are 3 kinds of exposure types and 3 kinds of embedded types, and a total of 6 kinds of vent cap is used. And the vent resistance of the bell-mouth (BM) established in an edge of a vent pipe (BM) is grasped.

Table 1- The kind of vent caps

Company		Company D	Company K	Company I
Exposed type	type	A I	A II	A III
	appearance			
	Detail view			
Embedded type	type	B I	B II	B III
	appearance			
	Detail view			

2.2.2 Experimental equipment and measuring method

Figure 1 shows the vent resistance equipment using a blower. A blower is installed on an end of equipment and the wind velocity in pipe is controlled by the ball valve installed in the way for the pipeline. A vent cap is installed in an edge in the equipment upper part. The vent pipe diameter used for equipment was set to 100 [mm].

A vent cap of the exposure type, bell-mouth and a vent cap of the embedded type uses equipment of figure 1.

A measurement item measures the pressure in the vent pipe and the central wind velocity in the vent pipe. The pressure in the vent pipe installs a pressure sensor in P1 in the figure. A digital manometer is installed in P1', and it's confirmed that there are no pressure value of P1 and difference. The central wind velocity in the vent pipe measures 2 points of W1, W2 and confirms that there are no differences.

When calculating the ventilation resistance coefficient, the pressure in pipe of P1 and the wind velocity in pipe of W1 is calculated using the measured data.

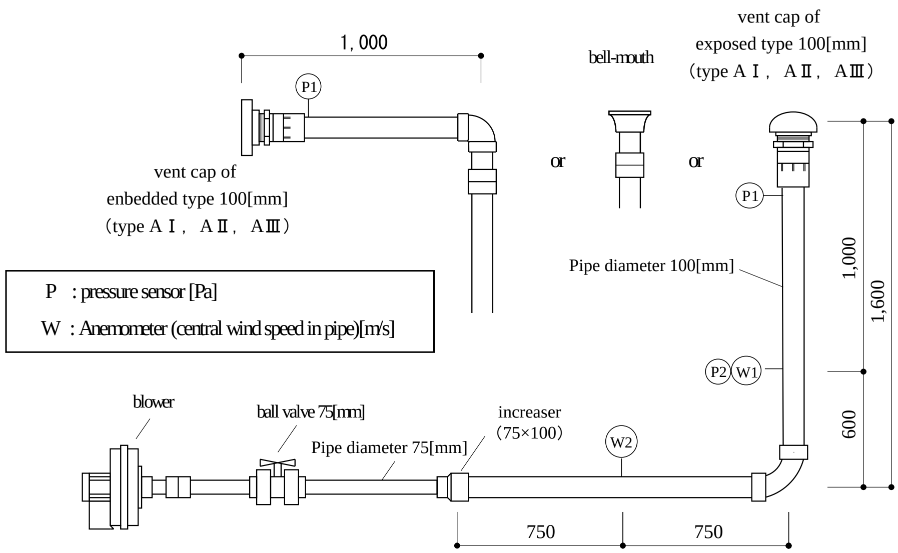


Figure 1- Vent resistance equipment

2.2.3 Experimental condition

The ventilation velum of a vent cap is controlled by a ball valve. And a pressure fluctuation in pipe when ventilation velum became stable and central wind speed fluctuation in pipe are measured. The pressure in pipe uses the value of the average of a measured pressure fluctuation in pipe. The wind velocity in pipe uses the value of the average of a measured wind velocity fluctuation in pipe. Ventilation velum areas set the central wind velocity in the vent pipe to 1 [m/s] -6 [m/s] in an interval of 1 [m/s] from the past reference.

2.2.4 Calculation of vent resistance

Calculation of vent resistance calculates a Reynolds number by equation (1), and confirms that its value is a perfect turbulent flow. When it's a perfect turbulent flow, the value of measured central wind velocity in pipe W1 multiply by 0.82 and it's wind velocity in pipe. The density of air was made 1.2 [kg/m^3] on the use. The vent resistance coefficient was calculated by equation (2). The value used for calculation is the pressure in pipe value, the average wind velocity in pipe and density of air.

$$\mathrm{Re} = \frac{Va}{\nu} \times D \quad \cdots \text{Equation (1)}$$

$$P_1 = \zeta \times \frac{\rho}{2} \times Va^2 \quad \cdots \text{Equation (2)}$$

R_e : Reynolds number
V_a : Average wind speed in pipe [m/s]
D : Diameter of pipe [m]
ν : Viscosity coefficient of air [m^2/s]

P_1 : Pressuer in pipe [Pa]
ζ : Vent resistance
ρ : Density of air [kg/m^3]
V_a : Average wind speed in pipe [m/s]

2.3

Experimental results of vent resistance and discussion

2.3.1 Vent resistance

Figure 2 shows the relation between the vent resistance and the ventilation flow rate of each vent cap-type. There were no great differences in the value of the vent resistance of each exposure type, but vent resistance of the embedded type was the result with the great difference in the value of BII more than BI and BIII.

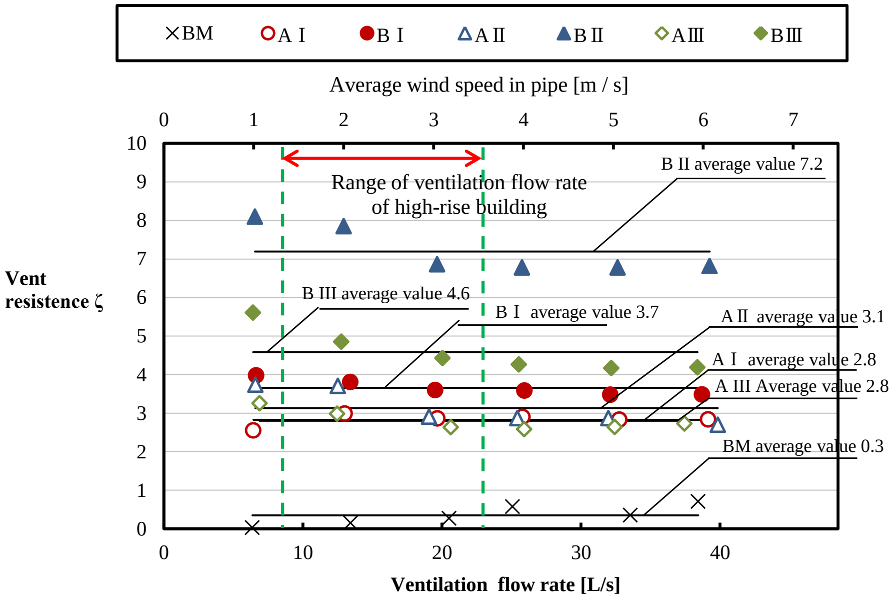


Figure 2- Vent resistance of each vent cap-type and ventilation flow rate

Figure 3 shows the average value of vent resistance of each vent cap-type. The vent resistance of each vent cap in the past reference was written in Figure 3 as a reference value. The measured values of the exposure type were 3.1 at the maximum and 2.8 at the minimum, and the average was 2.9. Comparing the average value of the reference values, the actual measured value was 0.7 above the reference value. In the actual measurement value of the embedded type, the maximum was 7.2, the minimum was 3.7, and the average was 5.1. Comparing the average value of the reference values, the actual measured value was 0.9 above the reference value. When comparing the average value of the exposed type of the measured value and the average value of the embedding type, the embedded type has a larger vent resistance of 2.2 than the exposed type.

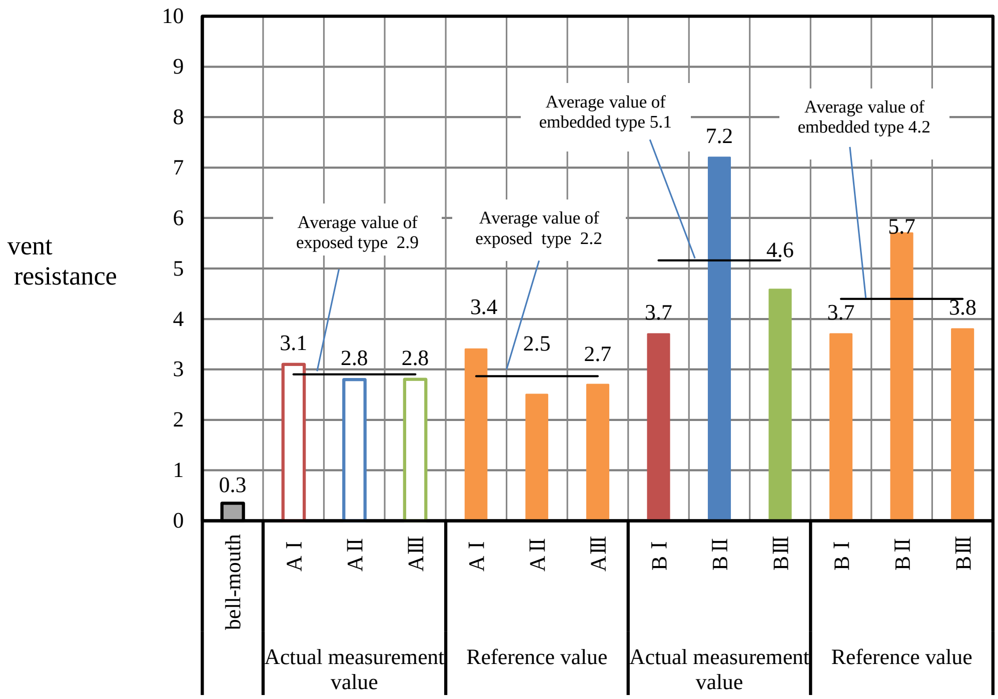


Figure 3- Average values of vent resistance in each vent cap type

2.3.2 Calculation of equivalent length

Figure 4 shows the average value of the equivalent pipe length in each vent cap. The equivalent pipe length was calculated from the equation (4) using the vent resistance obtained by experiment by calculating the friction coefficient inside the pipe from the equation (3). The calculation result is shown in Figure 4.

From this figure, the equivalent pipe length of the exposed type was 11.3[m] at the maximum and 10.2[m] at the minimum, and the average value was 10.6[m]. The equivalent pipe length of the embedded type was 26.1[m] at the maximum and 13.3[m] at the minimum, and the average value was 18.7[m]. For the equivalent pipe length, when comparing the average value of the exposure type and the average value of the embedded type, the average value of the embedded type is 8.1[m] longer.

$$\lambda = 0.0055 \times \left\{ 1 + \left(2000 \times \frac{\varepsilon}{D} + \frac{10^6}{Re} \right)^{\frac{1}{3}} \right\} \quad \cdots \text{Equation (3)}$$

$$L = \zeta \times \frac{D}{\lambda} \quad \cdots \text{Equation (4)}$$

λ : friction coefficient inside the pipe
ε : Absolute roughness [mm]
D : Inner diameter of pipe [mm]
Re : Reynolds number [m/s]

L : Equivalent length [m]
ζ : Vent resistance
λ : friction coefficient inside the pipe
D : Inner diameter of pipe [m]

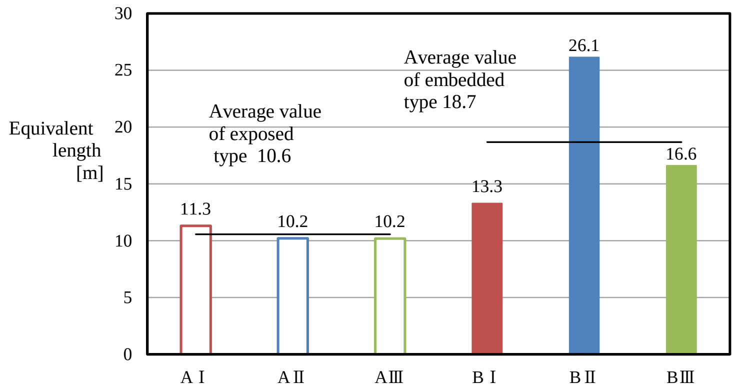


Figure 4- Average value of equivalent pipe length in each vent cap

3 Experiment in flow capacity for stack vent system with a vent cap

3.1 Experimental purposes

The purpose of this study is to investigate the influence of the ventilation resistance at the end of the vent pipe on the flow capacity for drainage system. At the end of the vent pipe of drainage stack system in the JIS-DT fittings, three types of exposure type vent cap, three types of embedded type vent caps and bell-mouths were installed, and grasp to the influence of the vent resistance of each vent cap on the flow capacity of the drainage stack system .

3.2 Experimental methods

3.2.1 Test discharge drainage stack system

Figure 5 shows is test discharge drainage stack system. This system is 9 stories above ground (height 25m) and connects the JIS-DT fitting to the drainage stack pipe and the horizontal drain pipe, each floor side branch pipe. The drainage stack pipe and stack vent pipe have a pipe diameter of 100 [mm], the drainage horizontal branch pipe have a pipe diameter of 75 [mm], the gradient 1/100, the drain horizontal pipe have a diameter of 125 [mm], gradient 1/150.

3.2.2 Vent cap used in the experiment

For the vent cap used in the experiment, three types of exposed type of vent cap used in 2.2.1 and three types of embedded type were used. As a comparison target, a bell- mouth was installed at the end of the vent pipe. The exposed type, the embedded type, the bell-mouth was installed at the end of the vent pipe as shown in Figure 6.

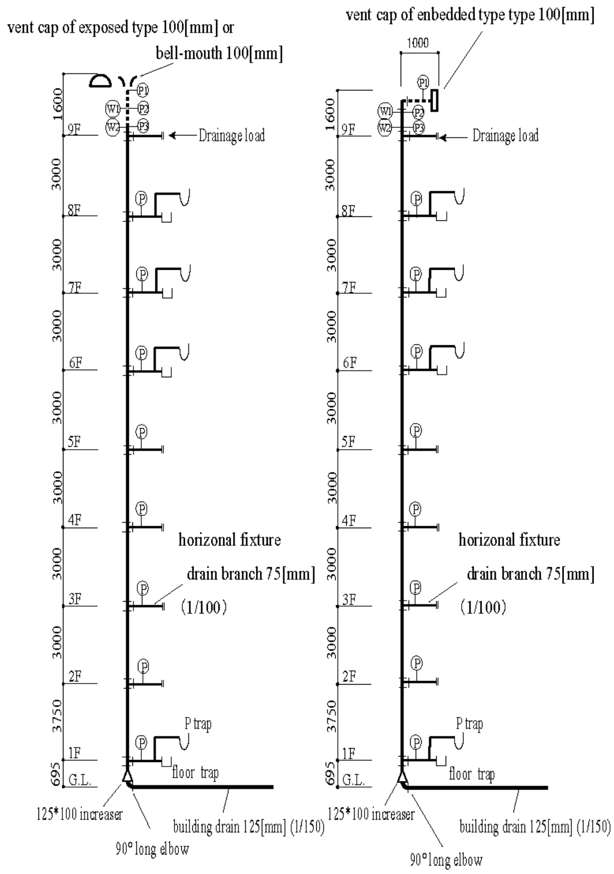


Figure 5-Drainage stack system

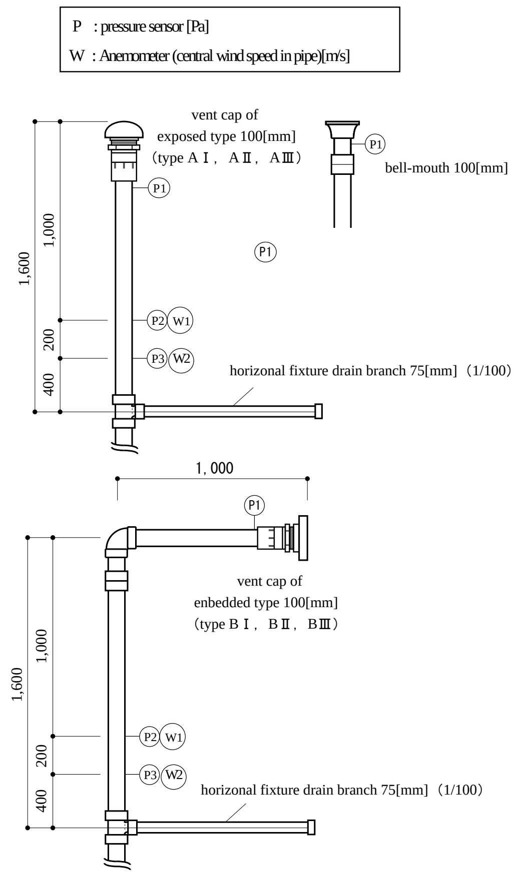


Figure 6- Detailed of end of vent pipe end to install

3.2.3 Measurement items and measurement methods

The measurement items are two items, pipe pressure and center wind speed of pipe.The measurement method of vent resistance is the same as "1.2.2 Experimental equipment and measuring method".

3.2.4 Drainage load and judgment condition of experiment

The drainage load is based on SHASE-S218 and gives drainage load from 0.5 to 2.5 [L/s] in increments of 0.5 [L/s] from the 9th floor drainage branch pipe. Drainage load is started in 10 [sec] from the start of measurement, and finishes in 60 [sec]. In addition, the range of analysis of experimental data is from 30 [sec] to 60 [sec] where the drainage load is in a steady state.

The judgment criteria is the judgment criteria for the pressure in pipe of the maximum and minimum values of the pressure fluctuation in pipe which serves as an evaluation index in determining the flow capacity of the drainage stack system. The pressure in the pipe shall be within ± 400 [Pa] of pipe pressure in accordance with SHASE-S218.

3.3 Experimental results of vent resistance and discussion

3.3.1 Comparison of ventilation flow rate

Figure 7 show is a comparison of the vent cap 6 types and the bell-mouth of ventilation flow rate. When the flow rate of drainage load is 0.5 [L/s], variation in the ventilation flow rate is observed for each type, but as the flow rate of drainage load increases, the change in the value becomes small. When the flow rate of drainage load was 2.0 [L/s] and 2.5 [L/s], the difference in the ventilation flow rate was 1.2 [L/s], and the difference in the air flow rate was slight.

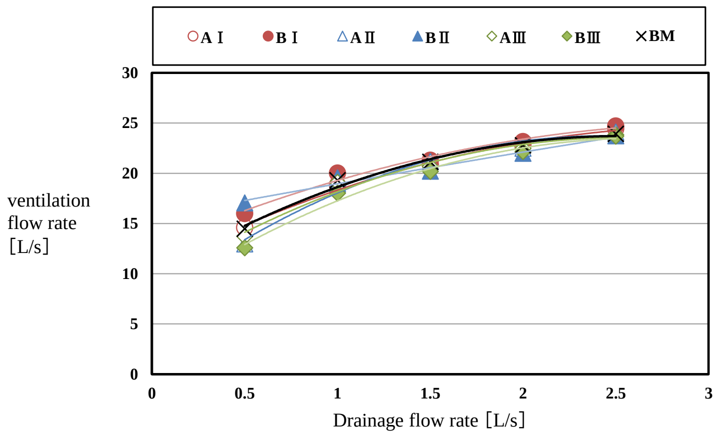
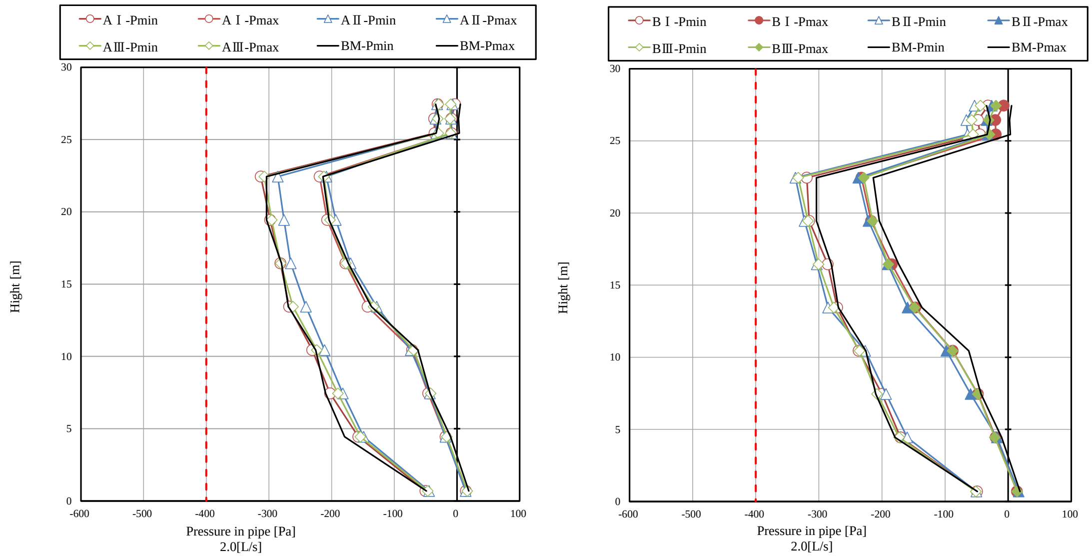


Figure 7- Comparison of the vent cap and the bell-mouth of ventilation flow rate

3.3.2 Comparison of pressure in pipe

Figure 8(1) and (2) shows three types of exposed type of vent cap, three types of embedded type of vent cap, and pressure distribution in the pipe of bell-mouth (BM) as an example. The figure shows the minimum pressure (Pmin) and the maximum pressure (Pmax) in pipe on each floor at a drainage load of 2.0 [L/ s].

Even as the drainage load of 0.5 to 2.5 [L / s], as in Figure. 8, there was no significant difference in the pressure in pipes at each floor depending on the type of vent cap, and the difference was about 50 [Pa] at the maximum. The influence of the external wind speed during the experiment is that the average wind speed during each experiment is 1 [m / s] to 3 [m / s] and the maximum wind speed is about 5 [m / s] to 8 [m / s].



(1)exposed of vent cap (2.0[L/s]) (2) embedded type of vent cap (2.0[L/s])

Figure 8- Pressure distribution in the pipe

3.3.3 Flow capacity for drainage system

Figure 9 shows the relationship between the drainage load in 6 types of vent caps and bell-mouth (BM) and the maximum value (Psmin) and minimum value (Psmax) of pipe internal pressure on each floor. Regarding the negative pressure in pipe, when comparing Psmin of each vent cap, a difference of 51.2[Pa] at the maximum at 2.0[L/s] and a maximum of 32.4[Pa] at 2.5[L/s] was observed. The flow capacity for drainage system of each was 2.0 [L/s] which was the same as in the case of bell-mouth.

Figure 10 shows is the comparison of the values read by complementing the flow rate of the maximum drainage load not exceeding -400[Pa] of pressure in pipe by SHASE - S218 from the approximate curve. The difference in the value of the flow rate of drainage load of various vent caps was 0.12 [L/s] at the maximum, with almost no difference.

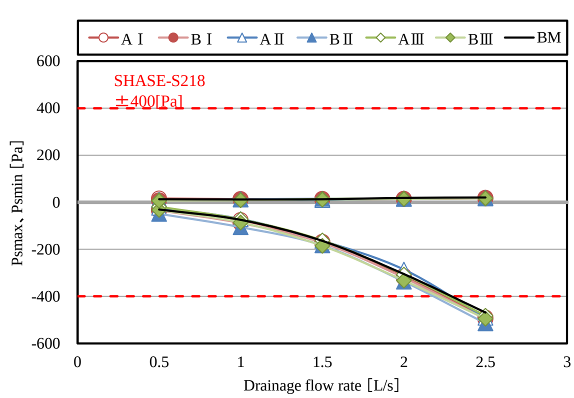


Figure 9- Comparison of flow capacity for drainage system

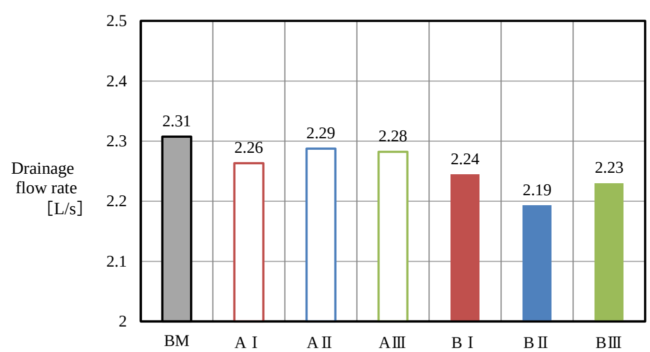


Figure 10- Comparison of the drainage flow rate at -400 [Pa]

3.3.4 Calculation of vent resistance in experiment of flow capacity

Figure 11 compares the vent resistance of the outdoors conducted flow capacity experiment (outdoor vent resistance) and the vent resistance of the indoor vent resistance experiment (indoor vent resistance). When comparing the vent resistance in the indoor and the vent resistance in the outdoors, when installing the vent cap outdoors, since it is affected by the outside air, the difference in vent resistance tends to become large.

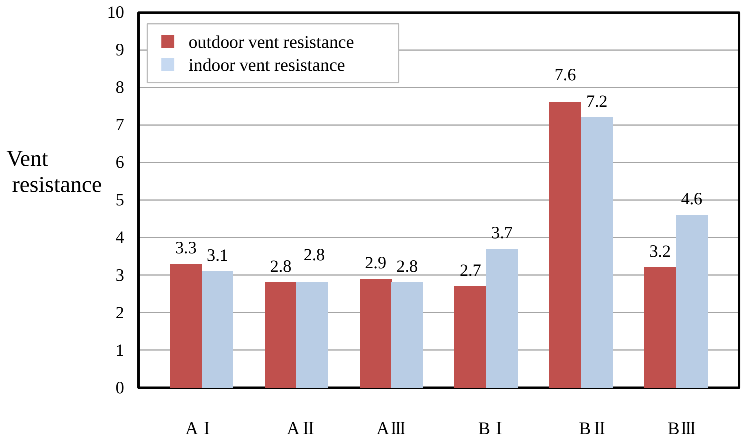


Figure 11- Comparison of the vent resistance

4 Conclusions

The findings obtained from the two experiments are shown below.

1) In an experiment that grasped the vent resistance of each vent cap indoors, the exposed type vent resistances is smaller than the embedded type vent resistance, and have high ventilation performance.
2) In the experiment confirming the influence on the flow capacity of the drainage stack system, the distribution of pressure in pipe when drainage load was given and the flow capacity for drainage system at that time were grasped. In the distribution of pressure in pipe, a maximum difference of about 50[Pa] was observed with each vent cap, but the flow capacity for drainage system in various vent caps became 2.0[L/s] similar to bell-mouth. In this experiment, it was found that there is no influence on the flow capacity for drainage system by the difference of the vent cap.
3) Comparing the outdoor vent resistance and the indoor vent resistance, there was a difference in the vent resistance between outdoor and indoor. In particular, there are large differences in the 3 types of embedded type, and it is inferred that there is a difference in vent resistance due to the influence of the airflow (outside wind) etc. around the vent cap and the likes.

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6 Presentation of Authors

Norihiro Hongo is Associate professor at Department of Architectural Environment System Engineering, Yamagata College of Industry and Technology. He is a Master of Engineering. He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan).

Masayuki Otsuka is the Professor at Department of Architecture and Environmental Design, Kanto Gakuin University. He is a member of AIJ (Architecture Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His latest interest is the development of a hybrid drainage system that uses both force feed type and gravity type drainage methods compatible with commercial building conversion.

Yuki KUGA is a master of the Otsuka Laboratory, Kanto Gakuin University. He is a member of AIJ (Architecture Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan).

D8 - Performance evaluation for same-floor drain technology in residential buildings

C.L. Cheng. (1), C.J. Chen. (2), W.J. Liao.(3)
1. CCL@mail.ntust.edu.tw
2. M10513017@mail.ntust.edu.tw
3. jenny0250@hotmail.com
(1) (2) National Taiwan University of Science and Technology, Department of Architecture, Taiwan, R.O.C.
(3) China University of Technology, Department of Interior Design.

Abstract

The life cycle of drainage plumbing system in building is far shorter than building construction, thus maintenance and system reform are often necessary during the whole building life cycle. Domestic construction usually put the drainage plumbing system under the floor and caused the problems for the maintenance and retrofitting work during the building life cycle. This research would focus on the same-floor drain technology and the fundamental performance issues, and surveys on the solutions for building drainage system design. The current practical drainage issues in domestic residential buildings would be investigated. Questionnaire and statistical analysis are used to figure out the feasibility and design strategy for same-floor drain technology. There are still many field procedure and construction method should be integrated and regulated for the same floor drain technology. The results reveal the feasibility of optimal adaptation and application for same floor drain technology in residential buildings.

Keywords

building drainage system; residential building; same-floor drain; performance evaluation; plumbing engineering

1 Introduction

Drainage system is one of the most essential facilities in building service engineering, the relevant technology used today was developed decades ago. However, little progress has been reported for building drainage systems. Meanwhile, the life cycle of drainage plumbing system in building is far shorter than building construction, thus maintenance and system reform are often necessary during the whole building life cycle. Inappropriate design of the drainage system within existing buildings can result in sanitary problems including infection and maintenance issues. The fundamental requirement of a building drainage system is to carry away sanitary appliance drainage and preventing foul odors into the habitable space from drainage network, which is important for the healthiness and comfort of living environment. Domestic construction usually put the drainage plumbing system under the floor and caused big problems for the maintenance and retrofitting work during the building life cycle. According to the clarified authority area for residential building, the same-floor drain principle was adopted to building construction in recent years. This research would focus on the same-floor drain technology and the fundamental performance issues, and surveys the solutions for building drainage system design. Firstly, the current practical drainage issues in domestic residential buildings would be investigated. Questionnaire and statistical analysis would be used to figure out the feasibility and design strategy for same-floor drain technology. Building information model would be used to study the boundary condition and performance requirement for Same-Floor Drain (SFD) technology. Furthermore, the evaluation for drainage system would be explored which would improve the building drainage system design regulation and decision making for residential building.

2 Investigation and review

The regulation of water supply and drainage in building code of Taiwan has more provisions on the system performance and materials design. The allocation of plumbing area and construction patterns are not the clear provided items for regulation. On the other hand, the apartment management and control guideline provided the property authority and privilege. This guideline was issued by government in 1995. According to the apartment management and control guideline, the housing private area and relevant privilege should be clearly defined and control. However, the insufficiency of provision regarding the drainage system caused the conventional construction allowance for the drainage system to allocate under the slab of construction involve to other private authority area of neighborhood. The resident has no choice but accept the conventional construction with drainage system bring down to the next floor and same situation within the celling from upper floor for decades. Fig.1 shows the situations of plumbing system from upper floor and hanging on the ceiling height. This conventional construction method caused a great difficulty for the life-cycle maintenance. The problems are not only the technology issues but also the negotiations and conflicts between resident neighbors.

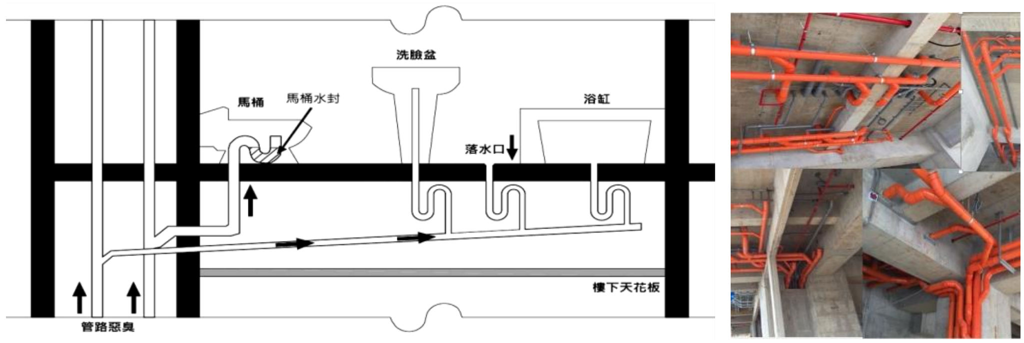


Fig.1 diagram of conventional construction in residential buildings

According to the housing statics document of Ministry of the Interior in Taiwan, the dispute of plumbing leakage maintain the top ranking within thousands housing resident problems and conflict events. In order to clarify the consciousness and aspiration of the people in Taiwan, interviews and 333 questionnaire for public opinions was executed and concluded. The surveyed people of age range from 20 to 60 years old and 70% with experience of living in residential apartment. The usage age of object housing apartment including new buildings of under 5 years and old ones of over 30 years. Most of the surveyed people have experience of water supply and drainage problems, especially suffered for the leakage plumbing issues. There are even 15% of the surveyed people have experiences of plumbing problems with over 4 times and very trouble to their daily life.

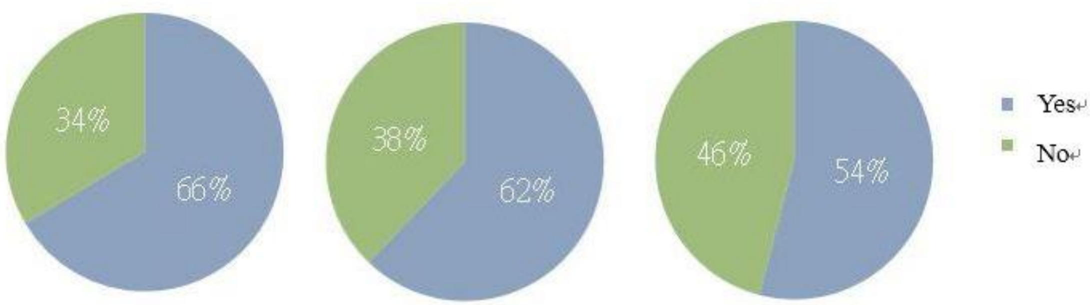


Fig. 2 Questionnaires response about the professional consciousness for the public (life-cycle maintenance, plumbing allocation planning and plumbing regulation)

A series questions about the professional consciousness including life-cycle maintenance, plumbing allocation planning and plumbing regulation, there are around 50-60% with positive answers. It means that not many people understand the problems of plumbing maintenance could be resolved by technical treatment and regulation. An assumption questionnaire as if provision of building code with adoption of same floor drain principle can solve the problems of life-cycle maintenance, there are 92% of surveyed people positively support this regulation providing to building code.

3 Regulation and solutions

Same-Floor Drain (SFD) is a conceptual principle for building drainage design and construction work. This principle can avoid the authority conflict of property in residential building. There was a clear definition and law for housing zoning property regulation in Japan from 1970's. It strictly defined and ruled the water supply and drainage system and equipment should be planned and allocated in the area of private authority in a housing unit. The critical point is the plumbing system must be allocated above the construction slab in the same floor of one housing zoning property. There are some definitions regarding the residential property zoning in the housing authority including public, communal and private piping line zoning as shown as Fig.2.

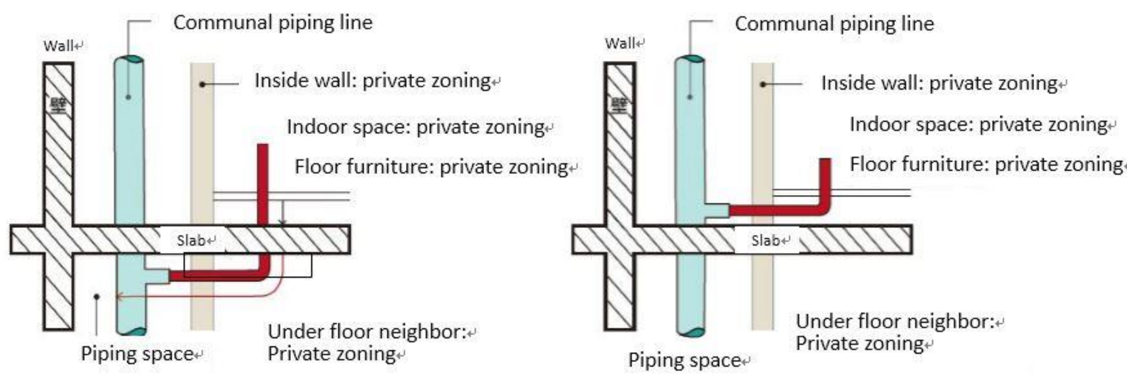


Fig 2. Definition diagram of residential property zoning

According to the clear definition and regulation, the building plumbing system allocated in private authority zoning would not cause the conflict situation for the plumbing system life-cycle maintenance and retrofitting work. Therefore, some technology and innovation are developed and followed the principle of same-floor drain for decades, such as skeleton infill construction (SI). Meanwhile, the provisions of building drainage regarding the performance and sanitation issues are concluded in Hass-206 and relevant regulation. The common construction for residential is to bring down the slab in the area of water supply and drainage. Thus, the maintenance and cleaning work for plumbing system would be a matter for one housing unit without causing the negotiation or conflict between neighborhood of upper and lower floors.

Building water supply and drainage regulation of China had major reviews and amended from 2003. The provision of GB50015-2003 recommended and guideline the adoption of same-floor drainage principal in regulation. Due to the increasing problems and conflicts of plumbing maintenance between neighborhoods of upper or lower floors, the regulation positively promoted the adoption of same-floor drain technology in residential building. The guideline recommended the concept of solutions for same-floor drain construction including bring down slab, inside wall and lift up floor as shown as Fig.3. China Industrial Standard (CJJ232-2016, J2203-2016) issued technical specification for same-floor drainage engineering in buildings and provided the adoption necessary of same-floor drain for residential buildings in China recently.

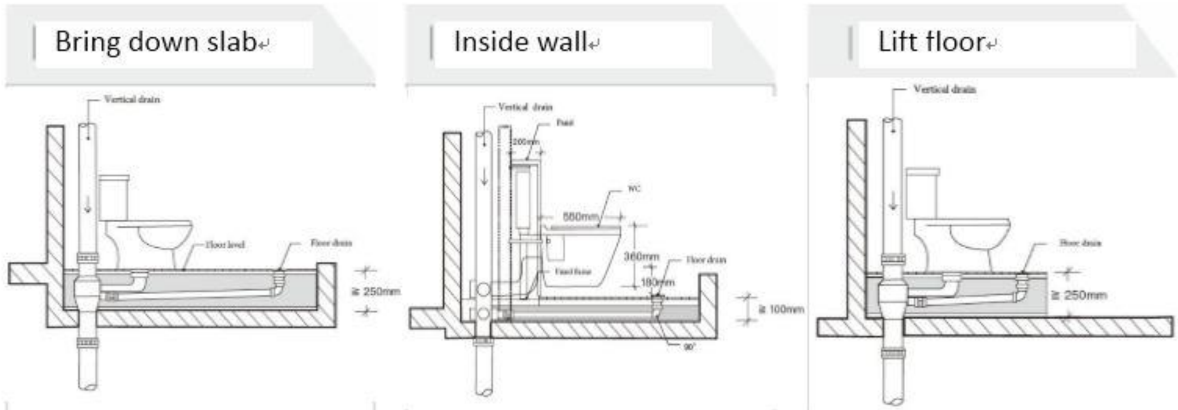


Fig.3 Conceptual solutions for same-floor drain construction

Regarding the feasibility of adoption same floor drain principle, the water area and planning in residential housing have to be considered for the drainage performance issues. There are many type of bathroom layout for residential building in Taiwan. The size of water area depends on the scale of the housing unit and its design. Three pieces with basin, toilet and bathtub in one room is the most typical design for residential building and Fig.4 shows the common set of bathroom design and sizes in Taiwan. The planning of how many sets of involved bathroom depend on the design and needs of the housing units. The confirmation of the drainage performance in housing unit is a crucial issue for the feasibility of adoption same floor drain principle in regulation. The sizing of bring down slab either the wall inside space for piping must be clarified for fitting the drain slope and construction process. Otherwise, the same floor drain principle cannot work for the water supply and drainage system with normal practicality.

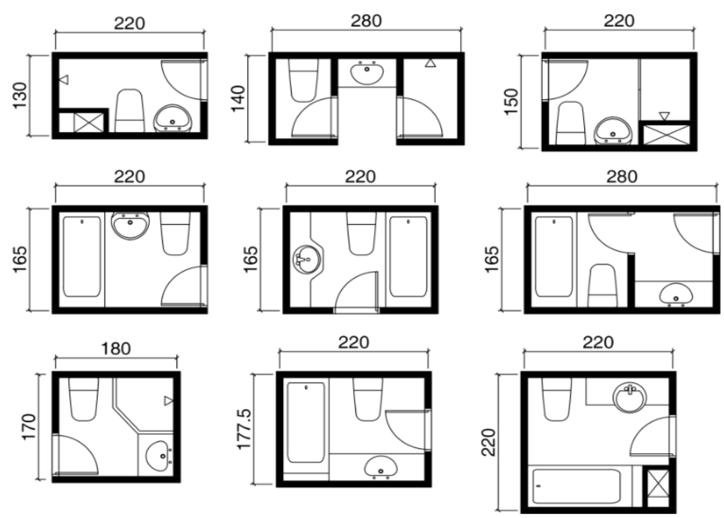


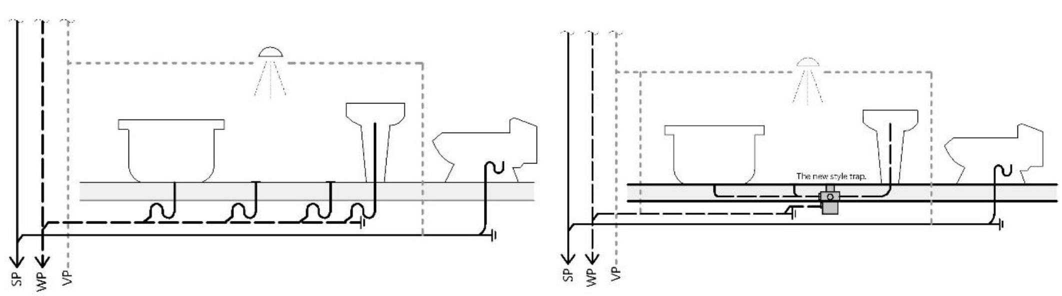
Fig.4 Domestic typical bathroom unit in common (unit：cm)

4 Observation and discussions

In order to enhance the performance of building drainage system, an innovation of new technique of building water drainage equipment was developed. A confluent device of Integrated Unit Trap (IUT) is verified as a feasible concept and substitute for individual trap of floor and washbowl and bathtub in bathroom. This compact device IUT is conducted by manufactures and applied to residential buildings for recent years in Taiwan.

Currently, several types of the IUT device have been developed and used in buildings. This device adopts centralizes water supply mechanism by collect the sewage from all sanitary equipment. For solve blocked drains pipes problem and cleaning needs, this device also has screens designed to filter impurities. The water outflow when the surface of the water reaches the line effluence out of the system. All sanitary equipment only needs install one trap device which can avoid problem of complicated drainage system, reduce waste materials and assures the water-tightness. It can improve the seal depletion problem and suitable for bathroom space use in house.

Fig.5 (a) shows the plumbing drainage design for toilet which was usually adopts "one sanitary with one trap" following technical regulation. There are some issues including the seal depletion and the complexity of fitting construction, it would causes the sewage odor into the interior environment through the building drainage system. Fig.5 (b) shows the improved fitting for IUT applying in bathroom, which allows all sanitary equipment used one trap in a bathroom. IUT device adopted centralizes water drainage mechanism by collect the sewage from all sanitary equipment for improve the seal depletion problem. This device has steady seal water and simple drainage system design.



(a) (b)

Fig.5 The setting configuration in bedroom

According to the conditions of building construction, there are four installed type IUT which can be applications for engineering options. Designer can take into account overall drainage system design for the IUT in planning. First, the construction of the embedded type which is must increase the thickness of floor and the new style trap shall be installed among the floor. Second, construction adopts the double-floor and the trap can be installed above the second floor. The second floor can be as partition for the householder in one story below. So, in order to assure the performance of drainage system, the floor drain cover can be opened to make routine maintenance which would not affect the residents in one story below. It's more suitable for householder with high indoor environmental quality space and more frequent interior design updates. Third, the construction adopts the suspended piping and the IUT can be installed under the floor. Forth, the half-buried type which is similar with the suspended type can be with half part of trap installed among the floor. It's more suitable for residence house use. The IUT is an influent device integrated multiple equipment and its trap to be one facility. The major function of the building drainage system is to ensure proper operation and to keep a clean and health interior space for human's life. Therefore, there usually exists an interior health problem from trap seal depletion in general building in Taiwan. The IUT device has been developed and preliminary confirmed the performance in bathroom unit of buildings.

Although the IUT technology can release the problems of life-cycle maintenance, the retrofitting works have face the negotiations and conflicts between resident neighbors. The optimal solution is still the same floor drain principle. Currently, the same floor drain technology about construction includes bring down slab, inside wall and lift up floor as mentioned above. However, the confirmation about the performance for drainage system is necessary for the practical work. The parameters and index for evaluation and confirmation for drainage system would be concluded by statistic methodology. This study will continuously use the Fuzzy Delphi Method (FDM), Analytic Hierarchy Process (AHP) and Failure mode and effects analysis (FMEA) to conclude the parameters for evaluation and confirmation in building drainage system.

According to previous documents, the building drainage performance index could include equipment materials, construction, heat resistance, allowable flow rate, self-cleaning, seal stability and etc.. There are some testing methods for the conformation of these index, such as the allowable flow rate should be under 1.25 l/s which adopts the bathtub 0.6 l/s, washing basin 0.25 l/s, shower 0.15 l/s and allowance factor. Through the expert's interview and questionnaire by the methodology of FDM, AHP and FMEA, the evaluation system for the drainage performance could be concluded. The results would improve the feasibility of same floor drain technology to apply in the building water supply and drainage system.

The major construction of water area in building has a conventional process and method in field as shown as the Fig.6. It is an increasing trend for some real estate to emphasis the quality of residential housing with higher construction cost. Some advanced solutions and the same floor drain technology would be adopted in such projects to release the problem risk for building water supply and drainage. The prefabrication is an advanced operation for construction and some countries used for many years such as Japan as well, however, there are still reasons for the adaptation and application in many countries.

Fig.6 Diagram conventional process and method in construction field

5 Conclusion

Domestic construction usually put the drainage plumbing system under the floor and caused great problems for the maintenance and retrofitting work during the building life cycle. This research focuses on the same-floor drain technology and the fundamental performance issues, and surveys on the solutions for building drainage system design. There are still many field procedure and construction method should be integrated and regulated for the same floor drain technology. Due to the difference of domestic situation for construction and water supply and drainage system, the optimal adaptation and application for same floor drain technology including the drainage performance and bounding conditions need to be conducted in the future.

Acknowledgments

The authors would like to thank the Ministry of Science and Technology (MOST106- 2221-E-011-048) for financially supporting this research.

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7 Presentation of Authors

Cheng-Li Cheng is the Professor at National Taiwan University of Science and Technology. He is a researcher and published widely on a range of water supply and drainage in building. He has published extensively on a range of sustainable issues, including the water and energy conservation for green building.

Chiung-Jui, Chen is the Master student at National Taiwan University of Science and Technology, Department of Architecture. His research is focus on water resources and Green Building.

Wan-Ju Liao is Ph. D. of National Taiwan University of Science and Technology, Department of Architecture, and Associate Professor at Department of Interior Design, China University of Technology. Her research is focus on Green building and Building water supply and drainage system.

D9 - Field evaluation of water consumption and drainage system performance when 6.8Lpf toilets were replaced by 4.8Lpf toilets

VALENCIO, Isabella P. (1), GONCALVES, Orestes M. (2)

1. isabella_valencio@usp.br
2. orestes.goncalves@usp.br

(1) Department of Civil Engineering, University of São Paulo, Brazil
(2) Professor at the Polytechnic School of University of São Paulo, Department of Civil Engineering, Brazil

Abstract

This paper aims to present the current results of the field phase of a Brazilian study of the performance evaluation of building water and drainage systems with 4.8Lpf toilets. The first results were presented at the CIBW062 Symposium 2016. The complete research aims to evaluate the performance of 4.8Lpf toilets and the performance of drainage systems when these toilets were installed. In this study, 2 phases were performed: a laboratory phase and a field phase. In the laboratory phase, 20 toilets were tested, and it was possible to verify that the reduction of flush volume could be a viable solution to reduce the consumption of potable water of the houses. In the field phase, the monitoring of the water consumption of the 10 houses and filming of the drainage system were conducted during 8 months, after 6.8Lpf toilets were replaced by 4.8Lpf toilets. Although problems were not reported in the performance of the toilets by the users, data monitoring revealed successive flushes in some houses, specifically in those in which there was not a reduction in water consumption. The results showed that not all models of toilets monitored have resulted in a reduction in water consumption. The average water consumption of all houses monitored remained constant after the replacement of the toilets. The reduction of the flush volume may have caused negative effects in the performance of the building drainage system, checked through 5 real-time videos, performed between August/2015 and April/2016. The real-time videos showed blockages in the horizontal pipes of the public sewage system. The deposit of solids may have occurred due to the reduction of the water consumption. Thus, it is not possible to conclude that the replacement of 6.8Lpf toilets by 4.8Lpf toilets has a major impact on water consumption nor positive effects on the performance of drainage systems in Brazil.

Keywords

Low flush toilet (4,8Lpf); water consumption; drainage system performance.

1 Introduction

The growing scarcity of natural resources required by the population, among them water, has reflected in an environmental crisis and encouraged the world population to reduce water consumption in buildings. Among the actions that can be taken to reduce water consumption in buildings, there are those that depend solely on the change of the habits of users and those that do not.

Actions to reduce water consumption that do not depend on the behavior or habits of users, but, rather, on the characteristics of the water supply system and that depend directly on the decisions that are taken by the professionals involved in the process of production of buildings, such as technological actions, are more effective in reducing water consumption in building. It is in the stages of design and execution of buildings that technology-based actions can be established that will determine the possibility of an efficient use of water throughout their lifespan (CBIC, 2016).

Using water efficiently means using only the amount of water required and sufficient for the expected performance of a given activity or equipment, without waste, without compromising the quality of the activity, and ensuring the health of users. At its limit, all the water supplied (measure) is used, in the smallest amount possible, to perform the aimed-at activities (CBIC, 2016).

The study introduced in this paper, which complements the paper presented at the CIBW062 Symposium 2016 (VALENCIO, I. P, GONÇALVES, O. M., 2016), was carried out to experimentally evaluate if the reduction of toilet water consumption (from 6.8 Lpf to 4.8 Lpf) will result in an effective reduction of water consumption for the users, without causing blockages and deposits of solids in the building drainage and sewage systems.

2 Reduction of toilet discharge water consumption

Even with the evolution of toilets, they are still accountable for most of the water consumption in residential buildings. However, the reduction of toilet water consumption requires an understanding of the characteristics of the discharge, to verify the effect on the performance of the building drainage system. Most countries such as Brazil use 6 Lpf toilets, but the discharge volume has followed a downward trend to 4.8 Lpf.

According Akiyama, Otsuka and Shigefuji (2013), several countries have regulations that limit the volume used in discharge. Some states in North America have introduced standards that limit the discharge volume to 4.8 Lpf, and the concept of this new limit has become a worldwide trend. Toilets in Japan use a discharge volume of 4.8Lpf and 6.0Lpf, and 4 Lpf toilets have been used since 2011 (KOBAYASHI, N. and OTSUKA, M., 2012).

3 The drainline transport of solid waste in building

It is essential to avoid deposit of solids in the building drainage system, to prevent a reduction of the useful section over time, or so that larger solids are not agglomerated, causing abrasion on the inner walls of the pipes, thus damaging the flow and the pipes themselves. Since the flow varies over time, the analysis of the deposit of solids in building drainage systems is complex. Since the drainage flow is variable over time, water depth and speed also vary. At low contribution times, if the speed is low, the solid materials may deposit on the pipeline. Thus, the pipeline must be designed so that this does not occur, with sufficient flow speed to ensure a self-cleaning action. These conditions are usually critical at the beginning of the system, when the contribution flows are smaller.

Over the years, the volume of water used by sanitary appliances has reduced significantly. This caused projects of the drainage system to be analyzed differently, aiming to adapt the size of pipes to the new values of flow and volume of water (OLIVEIRA Jr., 2002). The reduction of sanitary appliance water consumption directly interferes in the performance of the drainage system, mainly in the capacity of transporting solids along the pipe.

The evaluation of the transport of solids in the building drainage systems depends on the interaction of water and solid factors (CHENG, C.L. et al., 2011). The adequate performance of the building drainage systems is essential in projects and, with a greater use of water saving equipment, the volume of water has been reduced to its limit, affecting the transport of solids and causing pipe blockages.

Motivated by these issues, the Plumbing Efficiency Research Coalition (PERC) created a research network on the reduction of water consumption in sanitary appliances and its implications on the performance of drainage systems.

In 2012, PERC published the first phase of the study “The Drainline Transport of Solid Waste in Buildings” (PERC, 2012). In this study, PERC verified the effects of the adoption of different variables, among them, a 1% and 2% slope angle of the piping system and discharge volumes of 3 Lpf, 4.8 Lpf and 6 Lpf. Problems of blockage with 3 Lpf discharges were reported, and it was verified that the performance of the 6 Lpf toilets may be better than those of 4.8 Lpf for the total cleaning of the drainage system.

This same study, also showed that a 3 Lpf toilet requires at least four times more discharges than a 6 Lpf toilet, to remove all the media from the building drainage system (simulated in a laboratory with a 41-meter pipe). This indicates that a new toilet with reduced volume may not be economical, since it needs more discharges to have the same performance of the current one.

Phase 2 of this study (PERC, 2015) analyzes the effects of two variables: 3.8 Lpf discharges and cross sections of the pipeline with a diameter of 75 mm. The results showed that the reduction of the discharge volume from 4.8 Lpf to 3.8 Lpf makes the system performance decrease considerably for the 1 % slope angle of the pipe. Regarding the cross section of the pipe, a decrease in diameter from 100 mm to 75 mm did not indicate improvement in system performance.

As a reduction of the total water consumption is only obtained when the operation of the toilet meets minimum performance requirements, established by the knowledge of the actual needs and local operating conditions, if reduced volume toilets cause obstruction, users will have to flush twice or more times and a reduction of water consumption will not take place.
To verify the impact that a reduction of the discharge volume causes in the performance of a toilet is also fundamental to verify the impact on the performance of the building system. It should be evaluated if this reduction can be sustained by the building drainage and sewage systems and if it will not provide blockages and obstructions, causing damages for the users.

4. Evaluation of the impact on the water supply and drainage systems due to the replacement of 6.8Lpf toilets for 4.8Lpf toilets

The replacement of a 6.8 Lpf toilet for a 4.8 Lpf toilet theoretically reduces water consumption by 2 L at each discharge. However, the reduction of the discharge volume should be associated to the performance of the toilet so that a reduction of the total water consumption may occur. If the toilet does not offer satisfactory performance for a user, he will flush once or twice - and the reduction will not occur.

The study introduced in this paper focused on the laboratory and field evaluation of the impact of replacement of 6.8 Lpf toilets for 4.8 Lpf toilets, in order to verify if an effective reduction of water consumption occurs for users, without causing blockage and deposits of solids in the pipeline of the building drainage and sewage systems.

4.1. Laboratory study

The laboratory study was divided into two phases called "Phase 1" and "Phase 2". The purpose of Phase 1 was to verify which toilets had potential conditions to offer adequate performance in the field, without causing inconvenience for the users. Phase 2 consisted in a prospective evaluation, which aimed to classify the toilets in relation to their capacity to transport solids along the pipeline of the building drainage system (Figure 1).

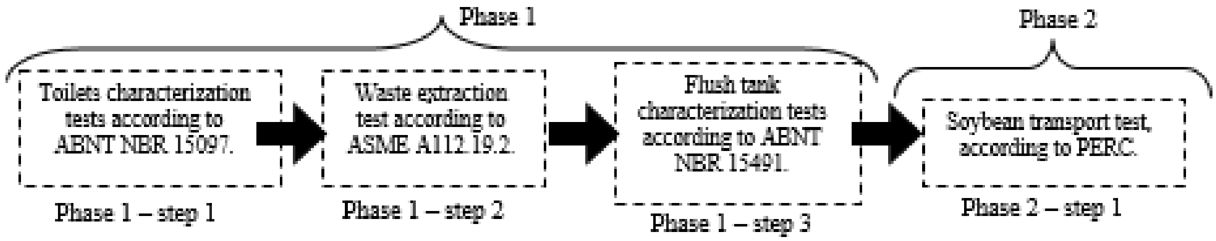

Figure 16 – Laboratory study – step by step

In all, twenty different models of 4.8 Lpf toilets were tested from different manufacturers. Among the toilets tested and currently sold in Brazilian market, some toilets were designed to operate with 4.8 Lpf and some were designed to operate with 6.8 Lpf but regulated to 4.8 Lpf. In the latter, a regulation of the flush tank was made so that it provided the volume of 4.8Lpf.

The results showed that most toilets are able to remove waste from the toilet itself, but they do not promote the cleaning of the building drainage system:

- With regard to the tests that verify the removal of the waste from the toilet itself (granule and ball test, mixed media test and spheres removal), nineteen toilets (95%) passed all the tests. Only one toilet failed in the mixed media removal test.
- One toilet (5%) did not restore the trap seal, and had a water trap seal height value after flushing up to 24% less than the minimum required to avoid the return of odors into the dwelling. Thus, it was deemed to have failed in the trap seal restoration test.
- One toilet (5%) did not affect proper cleaning of its interior and failed in the surface wash test.
- Four toilets (20%) failed in the solids transport test because they did not carry the polypropylene spheres along 10 meters of the pipeline, i.e., they did not provide sufficient discharge flow for the tested media to be transported along the pipe, which simulates the horizontal conductor, along the minimum distance of 10 meters. This indicates that a major problem found in reducing the discharge volume may be the removal of solids from the drainage system. The results of this requirement were up to 36% below the normative minimum limit.

Of the twenty toilets evaluated, thirteen (65%) passed all the requirements of NBR 15.097.

In the second step of Phase 1, the waste extraction test was performed to evaluate the removal of the media (seven specimens of soybean paste of 50g each and four balls of toilet paper, each ball consisting of six pieces of paper) from the toilet itself. Only five of the thirteen toilets (38%) evaluated passed in this requirement.

In the third step of Phase 1, the flush tank characterization tests were carried out in order to verify their performance. Only one (12.5%) failed due to leaking. Failure to comply with this requirement may result in users using unnecessary water. In these cases, the water from the flush tank may flow into the toilet, which is often imperceptible to users.

Non-compliance with the current Brazilian standard in 35% of the toilets evaluated reflects the need for product evolution. All toilets designed to operate with 6.8 Lpf, but regulated to 4.8 Lpf failed the laboratory tests. This proves that simply reducing the water level in the flush tank is not a viable solution to reduce toilet water consumption.

Thus, at the end of the Phase 1, five toilets were deemed to have passed in all tests of Brazilian standards ABNT NBR 15097 and ABNT NBR 15491 and in the waste extraction test, which represents 25% of the toilets evaluated. Note the difficulty of the products in meeting the current regulatory requirements.

After Phase 1, the soybean paste transport test was carried out to characterize the toilets and to find a relationship with their performance in the field.

In the soybean paste transport test, the amount of discharges required to remove all media from the 18-meter-long pipeline was measured. The toilets evaluated required two to six discharges to remove the soybean media along the 18-meter pipe.

4.2. Field study

The filed study was conducted to verify:

- How the toilets approved in the laboratory study behave in the field, that is, if they promote a reduction of water consumption, linked to the proper functioning of the product;
- The correlation of the results obtained in the field with the results of the laboratory tests;
- If there was an effective reduction of water consumption and, if this reduction implies impacts on public sewage and building drainage systems.

For such purposes, two steps were carried out: a monitoring of the toilet water consumption and real-time videos in the sewage system.

Firstly, the houses to be monitored were selected. The chosen houses consist of twelve houses (six houses on the ground floor and six on the first floor), according to Figure 17, with a frontal scheme of the units. Although the housing development has twelve houses, the residents of houses 9 and 23 did not allow monitoring. Therefore, the field study was conducted with ten houses.

The five toilets considered to have been approved in the laboratory study, were installed in the field. As the residents of ten houses accepted to participate in the study, each toilet was installed in two houses. As far as possible, the same model was installed on the floor unit and on the first floor, as shown in Figure 17.

Figure 17 – Scheme of the houses monitored

These houses were selected because of the critical characteristics that they have: beginning of sewage system and final low-slope pipe section, and without any extra contribution. These characteristics can be visualized in the scheme of Figure 18.

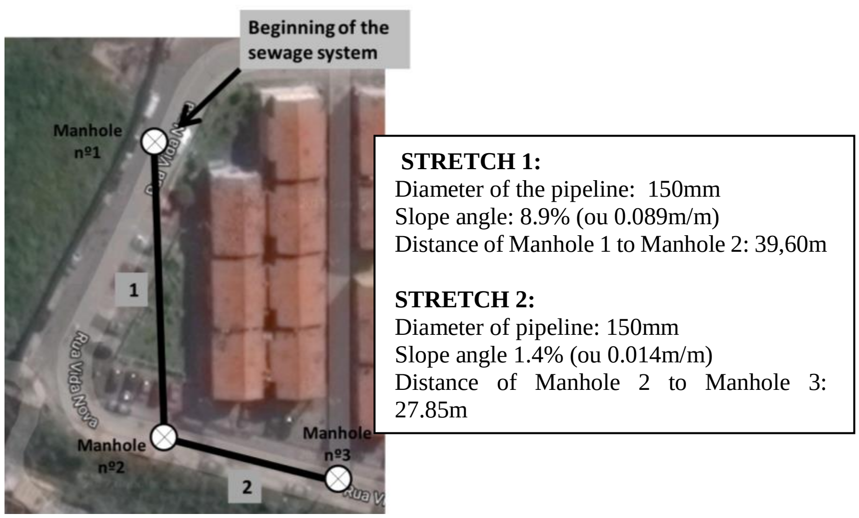

Figure 18 – Scheme of the sewage system monitored (top-view scheme)

A questionnaire was applied to characterize users and housing units. The questionnaire for user characterization has the function of identifying the number of inhabitants, age and habits. This questionnaire is important for future analysis of consumption data. The questionnaire characterizing the houses was carried out to assist in the planning of toilet replacement, in order to define the most appropriate model for each house.

The monitoring of 6.8 Lpf toilet water consumption was accomplished for a month. Then, the 6.8 Lpf toilet was replaced for a 4.8 Lpf toilet approved in the laboratory study. After the replacement, the monitoring of the toilet water consumption continued. During the monitoring, questionnaires to verify the satisfaction of the users with the product were applied, in order to verify the need for a second discharge, the frequent occurrence of blockages or other usage problems.

The total water consumption was considered from the monthly water bills for each dwelling. Thus, it was possible to calculate the percentage of the consumption related to each toilet, and if the total water consumption in each house decreased with the change of the toilet.

4.2.1. Water consumption monitoring

With the monitoring equipment installed, on August 14, 2015, the monitoring of the initial water consumption with the toilets existing in the dwellings (all of them of 6.8 Lpf) began. This monitoring occurred for about 30 days. It was possible to observe that the total volume per discharge was close to 6.8L and no successive flushes were verified.

In this initial phase (before the replacement of toilets), with the number of inhabitants per dwelling obtained in the questionnaires and the daily toilet water consumption, it was shown that the general average toilet water consumption of all the monitored houses was 16.6 liters per inhabitant per day, as shown below.

Table 12 - Toilet water consumption per house, when the 6.8 Lpf toilets were considered

House	6,8Lpf toilet water consumption per day(L)	Total water consumption per house per day - last year's average (L)	Toilet water consumption/total water consumption	6,8Lpf toilet water consumption per day per inhabitant (L/person/day)	Number of inhabitants
3	35.0	92.3	37.90%	**17.5**	2
5	23.9	141.0	17.00%	**12.0**	2
7	37.9	220.5	17.20%	**126**	3
11	56.8	992.3 (*)	5.70%(*)	**15.2**	3.5
13	25.0	138.5	18.10%	**12.5**	2
15	103.9	430.8	24.10%	**20.8**	5
17	44.0	553.8	7.90%	**147**	3
19	45.9	441.0	10.40%	**115**	4
21	42.8	192.3	22.30%	**21.4**	2
25	81.1	425.6 (*)	19.10%(*)	**27.0**	3
Average	**49.5 L**	**276.3 L**	**19.4%**	**16.6**	**-**

(*) Leaking was verified in the hydraulic system (but not in the toilet). The leaking had not been completely solved by the end of the study. Thus, there values were not accounted for in the calculation of the average water consumption.

The replacement of the toilets for the 4.8 Lpf models occurred between days 15 and 17 of September of 2015.

The monitoring of the 4.8 Lpf toilets had two objectives: to evaluate the performance of the product - verified through questionnaires and the presence or absence of successive discharges - and to evaluate if a reduction in water consumption occurred.

Monitoring of the 4.8 Lpf toilet water consumption took place between September/15 and April/16. During the monitoring, it was verified that the total volume per discharge was close to 4.8 L, indicating that no change was found, in the field, in the discharge volume obtained in the laboratory.

After the toilets were replaced, the general average of the toilet water consumption of all monitored houses was 17.6 liters per inhabitant per day, according to the table below.

Throughout the field study, questionnaires were carried out to verify users' satisfaction with the performance of the toilets. The users did not report problems related with the 4.8 Lpf toilets.

Considering all the houses monitored, it was verified that a reduction in the average toilet water consumption did not occur, which indicates that the users needed to give successive discharges when the 4.8 Lpf toilets were installed. There was a reduction in the toilet water consumption in only five of the ten houses monitored.
Although no problems were reported with the 4.8 Lpf toilets in the questionnaires carried out during the study, the analysis of the monitoring data indicates the presence of successive flushes in houses 11, 13, 15, 17, and 19.

Table 13 – Toilet water consumption per house, when the 4.8 Lpf toilets were installed

House	4,8Lpf toilet water consumption per day(L)	Total water consumption per house per day after the replacement (L)	Toilet water consumption/total water consumption	4,8Lpf toilet water consumption per day per inhabitant (L/person/day)	Number of inhabitants
3	22.7	60.0	37.8%	**11.4**	2
5	21.1	140.0	14.8%	**10.6**	2
7	25.4	263.3	9.6%	**8.5**	3
11	127.9	643.3(*)	19.9%(*)	**25.6**	5 (**)
13	36.9	130.0	28.4%	**18.5**	2
15	114.1	360.0	31.7%	**22.8**	5
17	58.5	596.7	9.8%	**19.5**	3
19	63.5	330.0	19.2%	**15.9**	4
21	33.2	130.0	25.5%	**16.6**	2 (***)
25	78.3	440.0(*)	17.8%(*)	**26.1**	3
Average	**58.2**	**251.6**	**22.1%**	**17.6**	**-**

(*) Leaking was verified in the hydraulic system (but not of the toilet). The leaking had not been not solved by the end of the study. Thus, these values were not considered in the calculation of the average water consumption. (**) an increase in the number of dwellers occurred during the monitoring. (***) This house often receives a visitor who remains there for long periods of time.

Fout! Verwijzingsbron niet gevonden. shows a comparison of the daily toilet water c onsumption per capita of each house. The positive values represent a reduction of water consumption and negative values, an increase in water consumption:

- Houses 3, 5, 7, and 21 showed a significant reduction in toilet water consumption.
- House 25 reduced 3% of consumption, which can be considered constant. However, in House 7, where the same 4.8 Lpf toilet model was installed, a 33% reduction in toilet water consumption was observed.
- Houses 11, 13, 15, 17, and 19 showed an increase in toilet water consumption.

- **Table 14 - Toilet water consumption per person**

Houses	toilet water consumption per day per inhabitant (L/person/day)		Difference in water consumption	
	6.8 Lpf toilets	4.8 Lpf toilets	(L/person/day)	(%)
House nº3 (toilet nº11)	17,5	11,4	**6,1**	**35%**
House nº5 (toilet nº11)	12,0	10,6	**1,4**	**12%**
House nº7 (toilet nº2)	12,6	8,5	**4,1**	**33%**
House nº11 (toilet nº13)	15,9	25,6	**-9,7**	**-61%**
House nº13 (toilet nº13)	12,5	18,5	**-6**	**-48%**
House nº15 (toilet nº15)	20,8	22,8	**-2**	**-10%**
House nº17 (toilet nº15)	14,7	19,5	**-4,8**	**-33%**
House nº19 (toilet nº20)	11,5	15,9	**-4,4**	**-38%**
House nº21 (toilet nº20)	21,4	16,6	**4,8**	**22%**
House nº25 (toilet nº2)	27,0	26,1	**0,9**	**3%**
Average	**16,6**	**17,6**	**-1,0**	**-8%**

Obs.: the house numbers have been paired according to the model of 4.8Lpf installed (see figure 2).

It is clear that in the houses where successive flushes were registered (Houses 11, 13, 15, 17, and 19), an increase in per capita of water consumption was observed in the toilets. This is because the reduction of water consumption is only obtained if users need a single flush; if the toilet has an obstruction or lack of adequate interior cleaning, users flush once or more times, and the water consumption will increase.

In the monitoring period, no direct relationship was found between the volume consumed by the toilet and the total water consumption of the dwelling. This fact can be explained by several leaks verified in the hydraulic system during the study. Although the average toilet water consumption was not reduced, the total average water consumption of the dwellings decreased by 24.7 liters per day.

4.2.2. Sewage system monitoring

During the field study, the sewage system was filmed in order to verify problems. The filming system was used to check for possible initial damage to the sewage system and to verify if any damage or clogging in the pipeline occurred after the installation of 4.8 Lpf toilets.

Five real-time videos of the sewage system were performed on 08/28/15, 11/19/15, 01/28/16, 03/03/16 and 04/11/16. Thus, the first real-time video was carried out before the replacement of the toilets and the following videos were carried out after the installation of the 4.8Lpf toilets.

On August 28, 2015, the pipeline was cleaned, avoiding that the dirt accumulated in the sewage system until that moment interfered in the results of the study.
The timeline of the real-time videos is detailed in Figure 19.

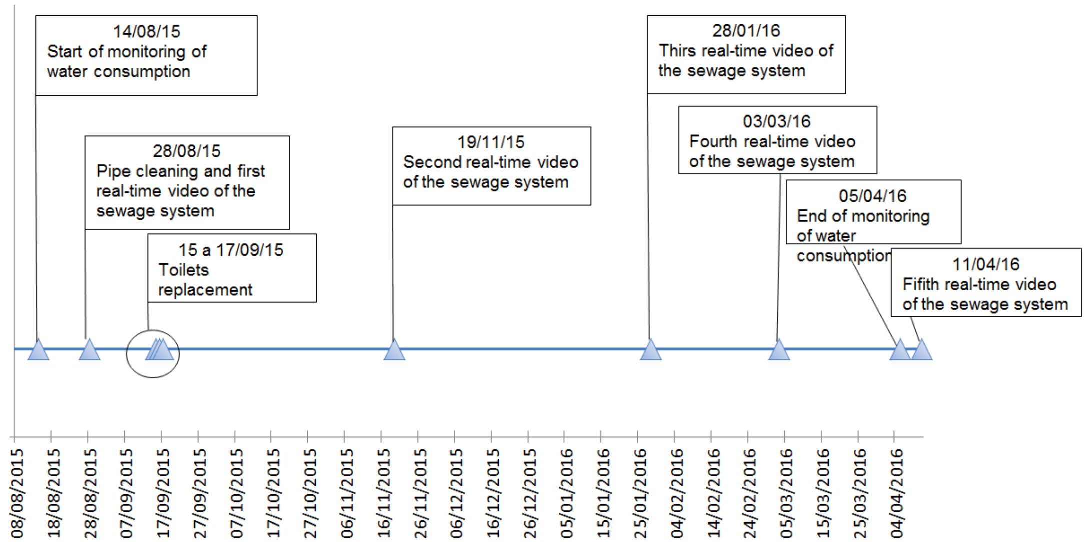

Figure 19 – Timeline of the real-time videos

During the eight months of field study, a progressive accumulation of solids in the pipeline of the sewage system was verified. Figure 20 summarizes the findings of these real-time videos.

Since the first filming after the installation of the 4.8 Lpf toilets (the 11/19/15 video), it has been possible to identify two points in the sewage system with obstructions. In the following videos, these points were kept with obstructions and new points with problems were observed as from March/16.

Another observation during the filming was a dark pipeline after certain points in the sewage system, indicating that the pipe was full a short time before the video. This can already be seen in the filming of 11/19/15, just at the beginning of the Pipe n.1, which is the beginning of the sewage system - and has a high slope angle (8.9%).

Figures 5, 6 and 7 show examples of damage verified during the real-time videos.

Figure 5 – Detail of the branch verified in the real-time video of 08/28/15

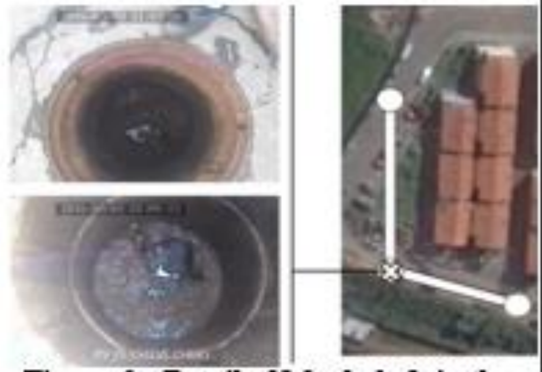

Figure 6 – Detail of Manhole 2, in the real-time video of 03/03/16

Figure 7 – Detail of obstruction noted in real-time video of 11/19/15

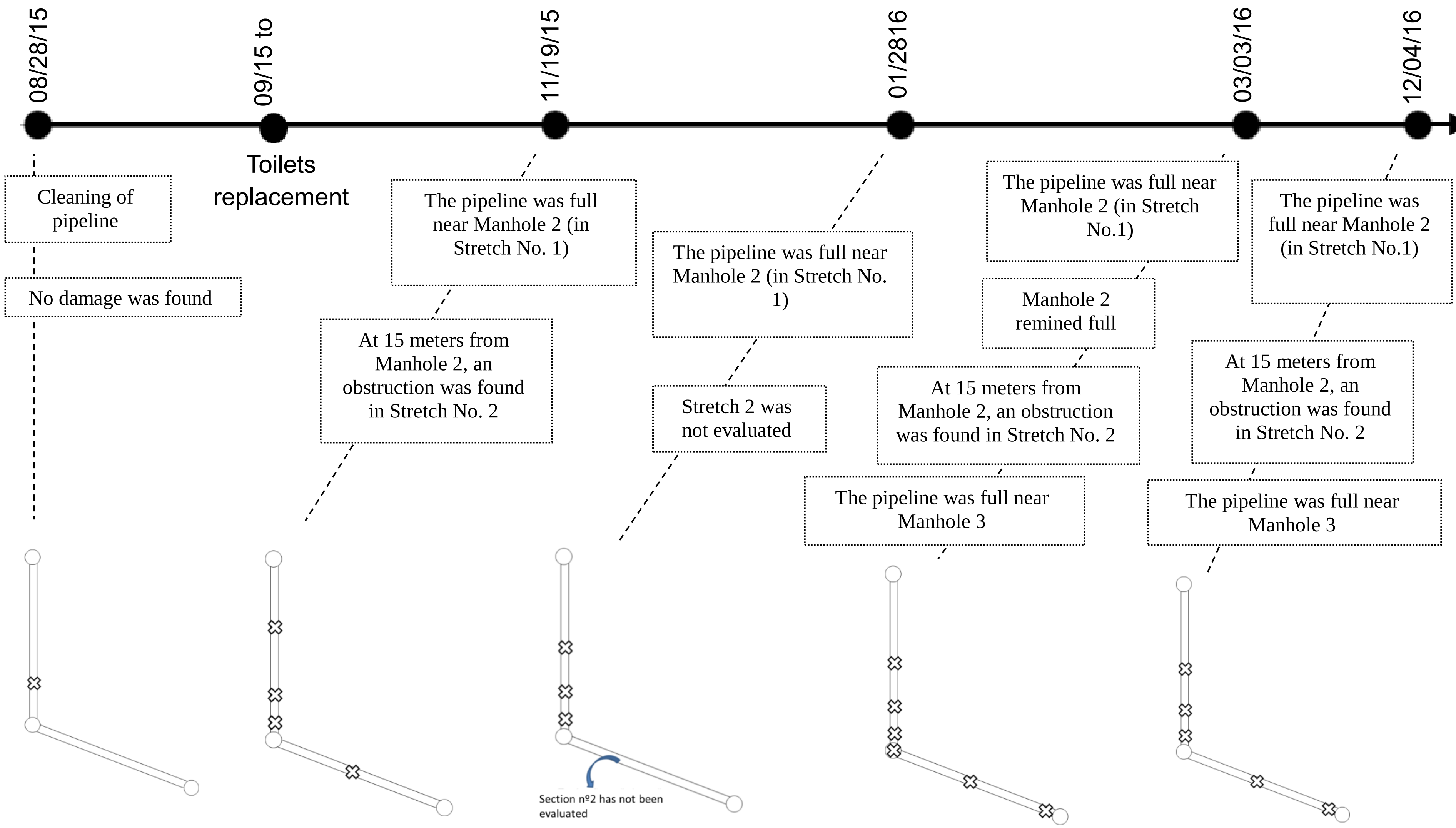

Figure 20 – Timeline with the results obtained in the real-time videos

The real-time videos showed deposit of solids in the pipes. From the second real-time video onwards, it was already possible to detect the accumulation of solids in the pipeline, which may have occurred due to the reduction of the total volume of water discharged in the system. The deposit of solids continued to be verified until the end of the study and each real-time video showed maintenance and/or increase of accumulation points. Therefore, it is possible to affirm that the replacement of the 6.8 Lpf toilets for 4.8 Lpf toilets can have an impact on the performance of the sewage system. Therefore, such a measure cannot be performed unrestrictedly. Figure 20 shows a timeline, with the results obtained in the real-time videos.

It was verified that, over time, the accumulation points increased, both in terms of quantity and in relation to magnitude, even with a high slope angle of 8.9% of the horizontal collector.

The comparison of the results of the field study with those of Phase 1 of the laboratory study, showed that the results of the tests offered in the current standards were similar among the toilets installed in the field, indicating that these tests are not sufficient to determine the performance of toilets in the field.

In the comparison of the field study results with Phase 2 of the laboratory study, it was found that those toilets that required three or less discharges to remove all media from the 18-meter pipeline in the soybean paste transport test, had good performance in the field, i.e., they did not offer problems for the users and led to a reduction of toilet water consumption.

Fout! Verwijzingsbron niet gevonden. shows a graphical comparison between the p erformance of the toilets in the field and the soybean paste transport test. The graphs show the results per house monitored.

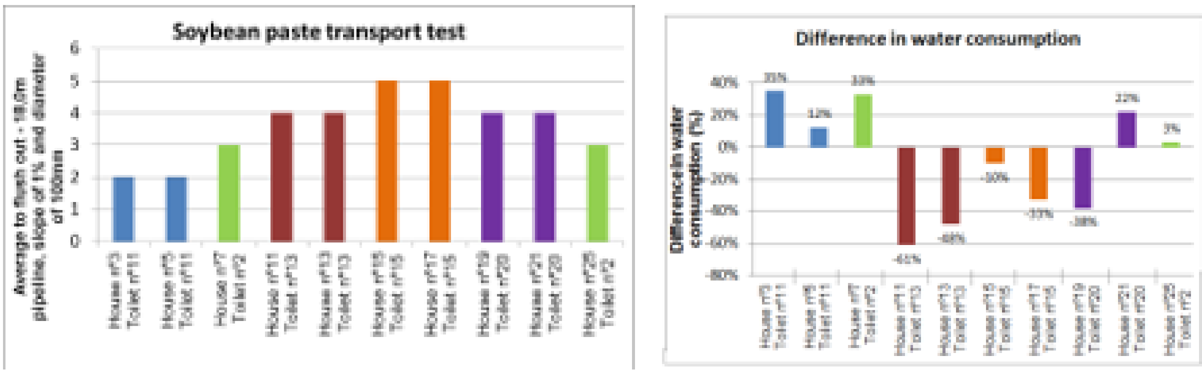

Figure 9 – Graphical comparison between the performance of the toilets in the field and the soybean paste transport test

In the case of the 4.8 Lpf toilet installed in House 3, there was a reduction in the toilet water consumption of 35%, when compared to the toilet that was installed before the replacement. This 4.8 Lpf toilet, installed in House 3, when tested in the laboratory (soybean paste transport test), required two flushes to remove all media from the pipeline. Therefore, one verifies that the toilet that required three discharges or less to remove the media from the pipe in the soybean paste transport test caused a reduction in water consumption (with the exception of House 21, which, although the test result equaled four flushes, showed a reduction of water consumption).

This study needs to be expanded to confirm this correlation, since the sampling of toilets tested was small and one of the toilets, even with a result of four flushes in this laboratory test, showed a reduction of water consumption (House 21). And House 25, even with a good laboratory result, offered only a 3% reduction in toilet water consumption.

5 Conclusions

Current studies show that 4.8 Lpf toilets have the potential to meet the requirements of users and the system. That is why this study focused on the evaluation (laboratory and field evaluation) of the impact of replacement of 6.8 Lpf toilets for 4.8 Lpf toilets, in order to verify if an effective reduction of water consumption was offered to users, without causing blockage and deposits of solid in the pipeline of the building drainage and sewage systems.

Through the laboratory tests, one could verify that some toilets met the performance of the removal of waste from the toilet itself. This shows that some products have enough technology to work with reduced volume. However, 75% of the evaluated products did not meet the minimum requirements of the current standards. This reflects the need for toilet evolution.

Both toilets designed to work with 4.8 Lpf and toilets designed to work with 6.8 Lpf, but regulated to 4.8 Lpf were tested. All the latter failed in the laboratory tests. This proves that simply reducing the water level in the flush tank is not a viable solution to reduce toilet water consumption.

A major problem is related to the performance of the building drainage system – expressed through the solid transport test. Reducing the discharge water consumption without an in-depth study of the effect generated in the system can lead to deposits of solids in the pipeline, causing blockage. Only 80% of the toilets met this requirement.

In the field study, it was verified that different models of 4.8 Lpf toilets, all approved in laboratory study, offered different performance when installed in the field, ranging from reduction to increase of water consumption, in relation to 6.8 Lpf toilets. The toilets with better performance in the field, that is, those that led to a reduction of water consumption and did not offer problems to the users were the ones with better performance in the test of transport of soybean paste (those that required three discharges, or less, to remove the media from the pipe). This study must be broadened to confirm this correlation, because the sampling of toilets tested was small, but it is an indication that the soybean paste transport test is adequate to evaluate 4.8Lpf toilets.

During the field study, it was verified that, although the users did not report problems in the performance of the toilet, data monitoring revealed the presence of successive periodic flushes in some dwellings, specifically in those where there was an increase in water consumption after the replacement of the toilets. This observation points out the fact that the reduction of water consumption is not obtained simply by reducing toilet water consumption, and that it is essential that the toilet meet the minimum operating requirements.

The average water consumption of the toilets (considering the average of all houses monitored) was not found to be reduced, which once more indicates that users had flush successively when the 4.8Lpf toilets were installed. A reduction in the toilet water consumption occurred in only five out of the ten houses monitored.

With the real-time video, deposits of solids were verified in the sewage system throughout the monitoring, after the toilets were replaced, even with the horizontal collector slope angle of 8.9% - which indicates that this measure cannot be adopted unrestrictedly.

The results indicated that a reduction of water consumption is only effective should facilities are planned together, i.e., if the water supply and drainage systems are planned taking into consideration the sanitary appliances that will be installed in dwellings, as well as the volume of water discharged by them.

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7 Presentation of Authors

Isabella Pastore Valêncio is civil engineer graduated from UNESP (São Paulo State University) in 2012 and is currently pursuing a master's degree at the Civil Construction Engineering Department at the Escola Politecnica of the University of Sao Paulo – USP, Brazil. Her research interest involves performance of building drainage system, reducing water consumption in buildings and the use of saving devices.

Orestes Marraccini Gonçalves is Professor of the Civil Construction Engineering Department at the Escola Politecnica of the University of São Paulo – USP, Brazil. His areas of interest and expertise are: Water Systems Building Services, Rational Use of Water, Performance Evaluation of the Components of Building Systems, among others.

D10 - Toilets: past, present and future

A. Silva-Afonso (1), C. Pimentel-Rodrigues (2), Myriam Kanoun-Boulé (3), João A. S. Almeida (4)

1,2. anqip@anqip.pt
3. myriam.boule@itecons.uc.pt
4. joao.almeida@itecons.uc.pt

(1) Chairman of the Board, Portuguese Association for Quality in Building Installations, Portugal.
(2) Researcher and Technical Director, Portuguese Association for Quality in Building Installations, Portugal.
(3) Grant holder, ITeCons - Institute for Research and Technological Development in Construction, Energy, Environment and Sustainability, Rua Pedro Hispano, 3030-289 Coimbra, Portugal.
(4) Researcher, ITeCons - Institute for Research and Technological Development in Construction, Energy, Environment and Sustainability, Rua Pedro Hispano, 3030-289 Coimbra, Portugal; Chemistry Centre, Department of Chemistry, University of Coimbra, 3004-535 Coimbra, Portugal.

Abstract

Introduction and aims: The objective of this work is to present a historical review of the evolution of the toilet, motivated for reasons of comfort, performance, public health and environmental sustainability, and present an ongoing research project that aims to combine several recent developments in order to design a new toilet model for the future. **Method**: The development of the toilet is based on several experimental studies, such as the study of systems of separation, recovery and use of urine as fertilizer in the building itself, in green roofing or urban agriculture. **Results and conclusion**: In addition to other outcomes related to aspects of comfort and performance, the results regarding the separation and maturation of urine are presented, demonstrating the feasibility of these systems in buildings and the conditions under which they can be designed. **Contributions**: The contribution to be achieved with the ongoing research project is to enable new solutions for toilets combining aspects of comfort, performance and environmental sustainability.

Keywords

Toilet, environmental sustainability, urine recovery

1 Introduction

The toilet has an old history… More than two thousand years ago there were already open seats, situated on above a continuous stream of water, to drag the dejections. But it was throughout the twentieth century that its development and dissemination were more significant, benefiting from the appearance of the siphon in the late nineteenth century. Until the end of the World War II there was no evolution in the design of the toilets, whose design and functions remained very conservative. From that date, the population growth and the increased consumerism led to the emergence of more elaborate toilets, incorporating bidet valences and seeking essentially to increase comfort and hygiene in use. Japan has clearly been leading this development, although in Europe the emergence of similar products is also observed.

Concerns about sustainability and resource efficiency have also led to some innovations. Regarding water efficiency, the evolution was towards the reduction of discharge volumes and the appearance of dual flush mechanisms (invented by a Portuguese company) and interruptible (or discontinuous) discharge. The reduction of the volumes of discharge had great acceptance in the countries of central and northern Europe.

Beyond water, the challenges of the 21st century require attention for efficiency in the use of nonrenewable resources such as phosphorus. Toilets are mainly responsible for their loss in the value chain, through the flow of urine, but the innovations at this level that are available in the market are relatively simple (diverting toilets) and mainly directed to a rural environment. A revolution is needed at this level, developing toilets that contribute to environmental sustainability including the recent innovations of comfort and hygiene.

In Portugal, an innovative toilet is being developed that seeks to promote comfort, hygiene and sustainability together. However, this solution implies the dilution of urine with a small water volume and an increased risk of faecal cross-contamination. Consequently, studies on the maturation process of the urine effluent collected under these conditions are required to assess the efficiency of this new urine diverting system and the feasibility of the later use of the matured urine effluent as a fertilizer. This paper presents some results already obtained at this stage that suggest the viability of the solution.

2 Past

The toilet that we know today has evolved over time [1]. In the “western world”, the Greek and Roman civilizations, especially the latter, were the great precursors and promoters of sanitary engineering. At the boom of Greek civilization, Athens had 20 aqueducts, built of clay and lead, and already had legislation on the use of water. Ancient Greece has also developed home water distribution systems more than 2000 years ago. From natural streams, the water was diverted, running under the sidewalks of the streets, with shunts that passed through the interior of the dwellings. The Romans, being not great inventors, appropriated and perfected technologies of other people. Interested in promoting basic sanitation as a public health policy, they have made remarkable

progress, not only in the field of water supply and distribution, but also in sewage systems. "Per capita" water consumption in the city of Rome was already similar to that of some current cities (although with high losses, because it is a continuous supply with free surface), with water distributed by 590 sources and 700 reservoirs.
Just to supply the capital of their empire, the Romans made 11 large aqueducts, totaling 613 km, being know that at least 40 other Roman cities were supplied in a similar way. The first Roman aqueduct dates back to 312 BC (*Aqua Appia*), with the most extensive - *Aqua Marcia* - with a total length of 90 km. The supply of water to Rome in the II century is estimated at values close to 13 m^3/s for a population of more than one million inhabitants. The Greeks and Romans also built drainage networks in several cities. In Rome, 600 years before Christ, the so-called Cloaca Maxima was built, a brick collector (initially a canal but later covered) with a diameter of about 3.5 m, remaining in operation.

The invasion of Europe by the “barbarians” from the north, in the Middle Age, had natural reflexes in this field. During the millennium after the demise of the Roman Empire and until the end of the Renaissance, no significant progress was made in Europe in terms of sanitary engineering, despite some advances in hydraulics. Two of the most remarkable European constructions, Buckingham Palace in England (1761), and the Palace and Versailles in France (1676), had no sanitary facilities, despite the abundant water used for the ornamentation of the gardens. The first, only in 1904 was equipped with bathrooms.

In the Middle Age there was even a violent setback in the conditions of health, which gave rise to successive epidemics that devastated Europe and decimated more than a quarter of its population. It can be affirmed that only in the nineteenth century the level reached by the Romans in supply and drainage networks in the IV century was again reached in western countries. London and Paris, for example, only in the middle of the XIX century have had an adequate public water supply system. The first public drainage networks after the Roman Empire in the western world were held in 1843 in Hamburg and in 1850 in Chicago.

The development of building facilities has generally led to the development of public networks. It is known, for example, that there were already private baths and toilets in Rome and Crete. However, the Roman toilets did not have siphons, since these were only invented in the late nineteenth century. So the bathrooms were located outside or in the worst possible place of the house, connected to a cesspit or a sewer. The public latrines were nothing more than open seats, situated on above a continuous stream of water, to drag the dejections. In addition to the total lack of privacy, the latrines were smelly and potentially dangerous. Sometimes harmful gases accumulated under the seats, originating explosions and rats were also a risk to reckless visitors. The invention of the flushing cistern is attributed to Sir John Harington, in 1585, although it does not appear to have had immediate applications.

3 Present

As already stated, after World War II, the population growth and the increased consumerism led to the emergence of more elaborate toilets, incorporating bidet valences and seeking essentially to increase comfort and hygiene in use. As a glance of the main innovations introduced during the last years in the toilets operating with gravitational discharge, thus excluding vacuum systems, a summary of features is presented in Table 1.

Table 1 – Recent innovations on toilets

FEATURES	*Function*		
	Comfort	Hygiene	Sustainability
Dual flush	-	-	✓
Discontinuous flush	-	-	✓
Touchless flush button	-	✓	-
Tornado flush	-	✓	-
Rimless pan design	-	✓	-
Motion-activated, auto open/close seat	✓	✓	-
Soft close seat	✓	-	-
Heated seat	✓	-	-
Adjustable seat temperature	✓	-	-
Air purifier-deodorisation	✓	✓	-
Self-cleaning nozzle	-	✓	-
UV sanitising nozzle	-	✓	-
Removable nozzle	-	✓	-
Rear cleaning nozzle	-	✓	-
Adjustable jet position	✓	✓	-
Oscillating jet	✓	✓	-
Adjustable water pressure	✓	✓	-
Adjustable water temperature	✓	-	-
Air dryer	✓	✓	-
Adjustable dryer temperature	✓	-	-
Hands-free stylish remote control	✓	✓	-
Touch-screen remote control	✓	-	-
Ambient lighting	✓	-	-
More than one profile saved preferences	✓	-	-
Built-in speakers play (radio, music, etc.)	✓	-	-
Emergency flushing system during power outages	-	✓	-
Built-in sensors that alert you to possible tank leaks	✓	-	-
Chair-height seating	✓	-	-

As can be seen, most of these innovations concern hygiene and comfort, with sustainability concerns being reduced only to dual-discharge solutions and interrupted discharge. However, the exponential growth of the world's population and, above all, the current model of economic growth based on increasing consumption of resources, has made environmental sustainability one of the main issues of the future [2, 3]. With regard to toilets, increasing importance has also started to be given to their contribution to the efficient recovery of nutrients, such as phosphorus, shifting the focus from the innovations in comfort and hygiene to environmental sustainability.

In relation to phosphorus, it is a unique non-renewable resource and an essential chemical element for food production. About 90% of the world's P reserves are in China, USA, Russia and Morocco, where it has been estimated that today's recoverable reserves will be depleted within the next 30-40 years to 300-400 years [4 - 5]. Its uniqueness therefore makes it urgent to develop new technological solutions to enable the recovery of and enable its reuse in the value chain. Population increase and the intensification of global agriculture will place increasing pressure on the finite supply of this resource.

On the other hand, the rejection of domestic and industrial effluents rich in P and other nutrients into water bodies is the major cause of eutrophication, which is probably the most significant current unsolved problem in terms of freshwater resources protection. More than 50% of lakes are eutrophic and this is the main pressure responsible for the failure of the aim of “good status” by 2015 prescribed by the EU Water Framework Directive (EEA, 2010) [6].

Although the recovery of phosphorus constitutes an emergency in view of the security of food supply in Europe and pollution problems, its elimination through urine is one of the principal causes for the loss of the value chain and dissemination in the environment. An average adult excretes about 1 g of phosphorus per day through urine and there are no systems in current operation for its recovery from water bodies or in urban wastewater treatment plants. The recovery of phosphorus in wastewater treatment plants is possible, but recovery at source, i.e., in buildings, would have numerous advantages by reducing the load on the treatment plant, avoiding dilution and minimizing the costs and energy consumption in the process [7].

The use of urine directly for agricultural purposes has already been the subject of pilot projects in South Africa, China, Germany and Sweden, using urine separation toilets [8 - 11]. There is also potential for using urine or nutrients in the buildings themselves, on green roofs or urban agriculture, thereby boosting these two trends, which are now recognized as being of great importance in terms of sustainability policies.

Contrary to the toilets development trends for more hygiene and comfort valences, the separating toilets have been associated with simple low-tech solutions, with a design that allows the collection of urine [12]. Examples include: EcoFlush ™ from Wost Man Ecology AB, Dubletten ™ from BB Innovation & Co AB, Nordic 393U from Gustavsberg and NoMix from Roediger. However, some separating toilets using NoMix technology have revealed operating problems and high maintenance costs, which have led some companies to stop manufacturing.

In Portugal, an innovative urine-diverting sanitation solution is currently under development in the scope of the WashOne project. More attractive, from a commercial perspective, this system also allows to solve some issues inherent to the traditional systems such as mineral salts crystallization in the urine bowl. However, new challenges emerge from this system such as a higher risk of faecal cross-contamination and a higher urine dilution rate. In view of assessing the efficiency of this new sanitary solution, an investigation is currently in progress regarding the maturation process of a urine effluent collected under real conditions.

Results obtained during the first 120 days of urine effluent storage at 23ºC regarding pH and ammonia content clearly show that urine maturation process initiated shortly after collection and continued throughout the storage time (Figures 1 and 2). As expected, the total microorganisms' content exhibited a significant decrease within the first 30 days after collection (Figure 3).

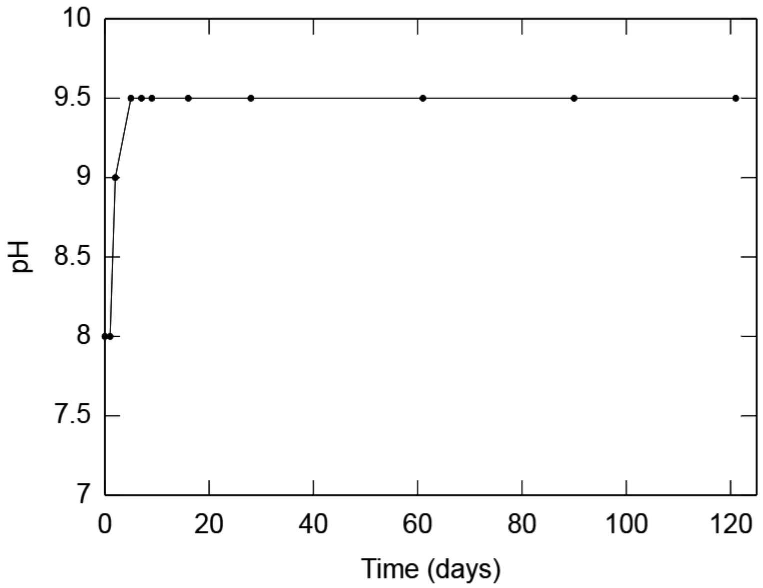

Figure 1. Evolution over time of the pH of urine effluent stored at 23ºC.

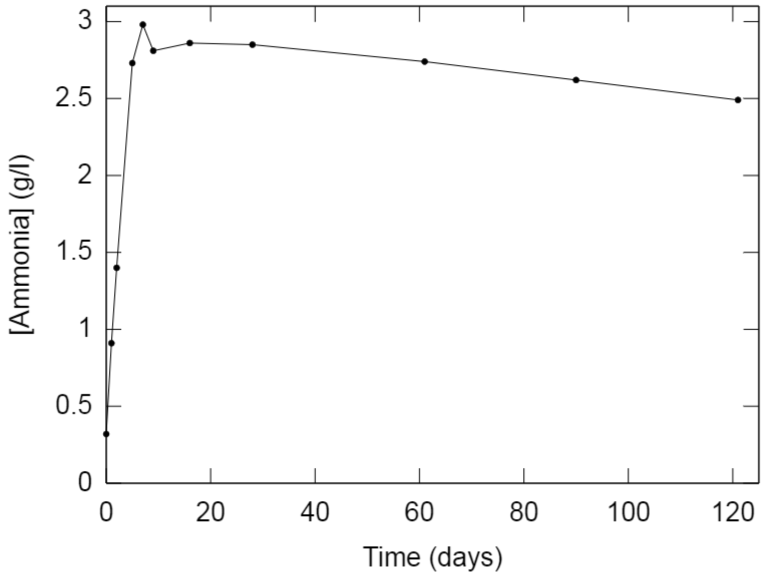

Figure 2. Evolution over time of the ammonia content of urine effluent stored at 23ºC.

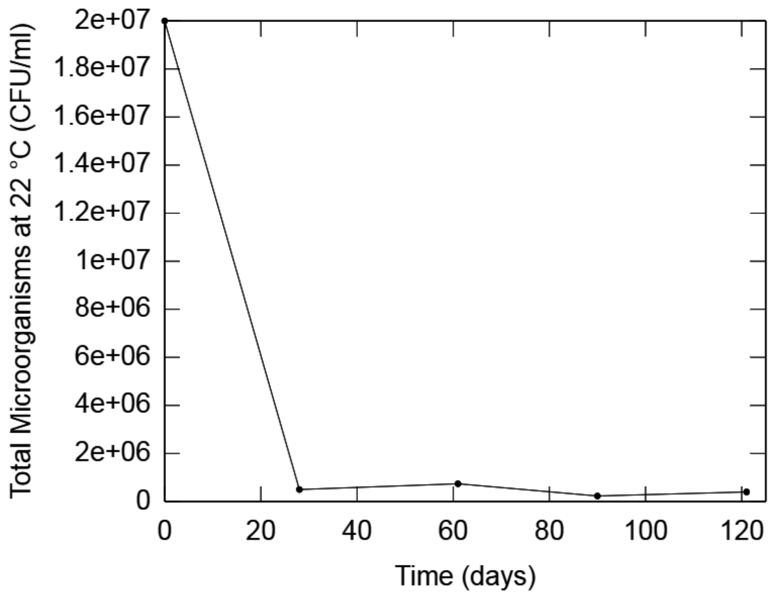

Figure 3. Evolution over time of microorganisms' content of urine effluent stored at 23ºC.

4 Future trends and final remarks

In addition to the demographic growth and the economic development, climate change has rendered drinking water scarce in large part of the planet. Policies for efficient water use in buildings are increasingly important and can include the adoption of efficient products. In this field, it has been observed in the last decades a significant reduction of the volumes of the cisterns put on the market and the adoption of technical solutions to reduce the discharges, as the dual flush and the interrupted discharge, being verified the tendency for some excess, which can compromise the good performance of drainage networks [13]. This shows that the reduction of the volume of the discharges must be accompanied by an adaptation in the design of the building drainage. Concurrently, the alternative use of rainwater, groundwater and even salt water in flushing cisterns can contribute to a significant reduction in freshwater consumption. In the same way the efficient use of water turned a requirement of the Community strategy, nutrients recovery from wastewater has been gaining interest from the scientific and political community [3].

In buildings, the bathroom can make a very important contribution by allowing a more efficient use of water, the recovery of some critical resources, such as phosphorus, with a subsequent reduction of freshwater pollution and a significant energy savings through the water-energy nexus. The innovation at the level of the toilets should seek to incorporate these valences, combining the current trends of developing very sophisticated and "urban" toilets, in terms of comfort and hygiene, with the very simple and "rural" toilets, oriented to the recovery of urine/phosphorus. This conjugation means a significant innovation effort from the technical and scientific community over the next few years. The results obtained with a model in development in Portugal, presented partially in this paper suggest the viability of these solutions.

5 Acknowledgments

The authors are grateful for the Project WashOne (POCI-01-0247-FEDER-017461) funded by the Operational Program for Competitiveness and Internationalization (POCI) of Portugal 2020, with the support of the European Regional Development Fund (FEDER).

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7 Presentation of the Authors

Armando Silva-Afonso is a retired Full Professor at the University of Aveiro (Portugal), Department of Civil Engineering, where he still collaborates as Visiting Professor. His specializations are urban and building hydraulics and water efficiency in buildings, and he is the President of the Board of ANQIP - Portuguese Association for Quality in Building Installations.

Carla Pimentel Rodrigues holds a PhD from the University of Aveiro (Portugal) in Civil Engineering (water efficiency). She is technical director of ANQIP – Portuguese Association for Quality in Building Installations.

João A. S. Almeida holds a PhD in Chemistry from the University of Coimbra (Portugal). He is responsible for the “Energy and Environment” section of the “Measurement and testing” unit at ITeCons - Institute for Research and Technological Development in Construction, Energy, Environment and Sustainability. He is also a researcher of the Coimbra Chemistry Center.

Myriam Kanoun-Boulé holds a PhD in Biology from the Université de Pau et des Pays de l’Adour (France). She is a researcher at ITeCons (Institute for Research and Technological Development in Construction, Energy, Environment and Sustainability) in the field of plant ecophysiology related to Green Roofs and Walls projects.

D11 - Water Out Shit In: a new paradigm for resource recovery

Wei-Shan Chen (1), Jan H.G. Vreeburg (2)

1. wei-shan.chen@wur.nl
2. jan.vreeburg@wur.nl

(1) Postdoctoral researcher, Sub department of Environmental Technology, Wageningen, the Netherlands

(2) Principal researcher KWR Watercycle Research Institute, Nieuwegein, The Netherlands

Abstract

Phosphate is the most essential nutrient that must be recovered from waste streams in the future, because the easily minable phosphorus rock reserves will be depleted within 50 to 100 years. For an efficient recovery and reuse, a waste water flow with a high concentration and a low volume is needed. However, the present system of production, collection, transport and treatment of sanitary waste water is aimed at safe disposal of waste water and focussed on health and minimisation of environmental effect. This resulted in a diluted, large volume of sanitary waste water from which the resource recovery is less efficient. To accommodate the new requirement of recovery of nutrients, a novel approach combining the health and environment requirements with the recovery necessity is needed.

A new approach "Water Out Shit In" (WOSI) is proposed in this perspective paper. Application results in a single concentrated flow of waste water with a high concentration of organic load. Main feature of the WOSI approach is its system wide approach addressing all elements of the urban waste water chain from production to transportation to treatment and recovery. WOSI starts at the individual houses, ends at the resource recovery and reuse. In each stage, the main question is: how to remove water or prevent it from entering and how to increase the organic load.

The chain starts in the houses. Reducing water consumption of the biggest sanitary waste water producers, i.e. the toilet, the shower and the washing machine, is a potentially effective step in this approach. Household and kerbside organic waste should be added into the sanitary sewer as much as possible. A small diameter gravitational in-house sewer is proposed to be used for collecting and transporting such highly-loaded flow. Within the transportation from household to the treatment, the storm water collection system could be disconnected from sanitary sewer system for preventing further dilution. The chain ends at the waste water treatment, which will be transformed into a resource recovery center via integrating several novel biotechnologies. Overall, a new paradigm for urban infrastructure and inner installation serving resource recovery is emerging.

Keywords

Low flush toilet, cascading shower effluent, small diameter sewer pipe, resource recovery, innovative biotechnology

1 Introduction

The necessity for resource recovery, in particular phosphorus recovery, is emerging (Cordell et al., 2009). For one reason, there is no replacement for phosphorus in the growing of crops. For the other reason, the easily minable phosphorus rocks will become scarce in the coming decades. Several immediate measures are needed to promote the phosphorus recovery from waste streams such as manure, agricultural residues, municipal organic waste and sanitary wastewater (Neset and Cordell, 2012). In addition, the need for recovering organic matter from waste streams for the decreasing soil fertility is also emerging.

Metropolitan area, being the place where all materials flow through and transform intensively and frequently, represents a place of interest for resource recovery. However, challenges exist as the current urban infrastructure setup was designed based on the public health, safety and comfort rather than on the need for resource recovery. The origin of current sanitary system can trace back to 150 years ago in the city of London. It utilises water as the main hydraulic transport media and pursues the public health and comfort. The public safety, e.g. flood prevention, was also incorporated into the design and resulted in the classic combined sewer system that handles both storm water and sanitary waste water in a single-pipe solution. Such solution features removing hydraulic flows with risks as far away and quickly as possible; the adoption of flush toilets together with the sewer system is the outcome as well as the paradigm that has been used until nowadays. Consequently, resource saving, e.g. reduction on water consumption of the household utilities, and resource recovery was not within the scope of this current sanitation paradigm. Furthermore, possibly due to the fear of potential blockage, in the current sanitation paradigm, organic solid waste is separately collected via vehicular transportation instead of the hydraulic system within the sewer.

The importance of treating waste water before discharging was acknowledged later, making the end-of-pipe treatment a logical choice. The end-of-pipe treatment was originally designed to serve only one purpose: producing an effluent that is safe and dischargeable to the environment. Organic matter and nitrogen are converted into carbon dioxide and nitrogen gas and released into atmosphere. The design serving the environmental protection has proven to be effective in the last couple of decades, until the rapid population growth and urbanisation making the resource recovery necessary. The need for resource recovery adds a new variable to the design and operation of the sewer system. The sanitation paradigm starts shifting from treatment towards recovering substances from the waste water in such a way that it can be re-used. The awareness towards resource scarcity as a consequence of population growth and urbanisation has existed before the sanitation paradigm shift; actions based on this awareness in the urban area have been taken, with the adoption of dual-flush toilet for water saving as a vivid example.

While resource recovery gradually emerges as a new variable, the existing requirements of public health, safety, comfort, environmental discharge are still valid and will becoming even more stringent given the changing climate, rapid population growth and urbanisation. The design criteria for the collection and transport system may encounter conflicts when considering both the emerging and existing requirements. During the transition from local to regional development (e.g. urbanisation), an element of transport and central treatment was introduced, which made it relatively easy to continue the service. In contrast, resource recovery requires intensive treatment and operates efficiently with a small, but concentrated flow. The transformation of current urban infrastructures poses a new challenge in continuing the service while transiting. The transition will take five to seven decades, which is in the same order of magnitude as the estimated approaching phosphorus scarcity. As the human excreta are anticipated as one of the main future sources for recoverable phosphorus, in addition to animal manure and agricultural residue, the transition needs to begin now and start with the sanitation paradigm shift. Removing water from and adding organics into the sanitary sewer system for creating a small but concentrated flow is the current fashion within the sanitation paradigm, which can be summarised as "water out, shit in". This paper reflects the current realisation of such concept, e.g. the source-separated sanitation and explores possibilities for a new system choice.

2 Transition towards the resource-recovery-oriented sanitation

2.1 Separate collection of storm water and sanitary waste water

Although not designed for serving resource recovery, the emergence of separate collection of storm water and sanitary waste water have contributed to the reduction of waste water volume and the prevention of further dilution of sanitary waste water due to the addition of storm water. The waste water treatment capacity could not catch up with the fast pace of metropolitan area growth, and the separated collection of storm water and sanitary waste water became a logical system choice and the new standard, especially for the areas with relatively abundant rainfall like the Netherlands. Rehabilitation and reconstruction of old combined systems mostly lead to separating the flows. These two systems may co-exist for a long time: the old system is gradually replaced by the new system. During the whole transition period, that will take decades, both systems must and can co-exist.

2.2 Source-separated sanitation system

More advanced solutions for recovering resources within the sanitation system have been proposed, examined and even upscaled (Zeeman and Kujawa-Roeleveld, 2011). A well-known example is the source-separated sanitation system, also known as "new sanitation", that develops into a new paradigm in the last two decades. A separated collection of flows according to their distinct hydraulic properties and compositions are applied. Grey water composed of effluents from shower, washing machine and sink features its high volume and low organic/nutrient concentration. Black water composed of mainly the toilet flush water and human excreta features its high organic matter and nutrient concentrations. Urine may be further separated from the black water, as it contains most of the nutrients (nitrogen and phosphorus) in the black water and can be directly used in biological nutrient recovery process (Tuantet et al., 2014). Different treatment options are applied to recover distinct resources from each flow, which was extensively studied and realised in practice(Zeeman et al., 2008).

The main advantages of source-separated sanitation system are the creation of effluents with a high organic or nutrient concentration and the use of vacuum toilet to facilitate the transportation of the concentrated flow. An effluent with high organic and/or nutrient concentration is beneficial for resource recovery via biological and/or anaerobic processes. The use of vacuum significantly reduces the water consumption for toilet flush (1 litre with vacuum versus minimal 4 litres without vacuum) and consequently increases the organic concentration of the black water with or without urine separately collected. In some cases, household organic waste is added into black water via the application of food waste disposal unit to further increase the organics in the black water.

Transition towards the source-separated sanitation system, however, is challenging. The plumbing within the households and the collecting and transportation to the treatment system is at least tripled (black water, grey water and storm water), implying a considerably higher cost and risk of misconnection in practice. The black water collection system is almost by default a vacuum system, which makes a gradual transition impossible. For newly built areas it can be applied, but for renovation project it cannot. Several operational challenges and cost of a vacuum system increases the vulnerability of the source-separated sanitation and decrease the potential of popularization. These include the flushing function dependence on electricity, the expensive maintenance and repair of the vacuum system and even the public acceptance towards it nuisance and noise (Hegger and van Vliet, 2010).

2.3 Water out, shit in: rethink the entire urban waste water chain

The separation of storm water collection and the source-separated sanitation system both aim at reducing the amount of water entering the sanitary waste water and preventing the possible dilution of sanitary waste water. Such aim can be expressed shortly but concisely as “water out, shit in”. We reflected the entire urban waste water chain, from its generation through the use of drinking water via the collection and transport to the treatment and recovery, using the Netherlands as an example. Based on the reflection, we proposed a systematic transition towards a resource-recovery-oriented sanitation and identify potentials and gaps within this proposal.

In this chain, three domain/stakeholders can be recognised(Vreeburg, 2017):
- Domain 1: The individual household, using drinking water and consequently producing waste water
- Domain 2: The collection and local transport of the waste water to points of local storage
- Domain 3: Transport to treatment location and treatment itself.

For each domain, the possibilities for decreasing the flow and increasing the concentration are considered.

Domain 1: domestic water use and waste water production

In the Netherlands, the domestic water use is relatively low: 116 litre per person per day (van Thiel, 2014). Still there are possibilities to reduce that water use. Table 15 gives an overview of present day use versus possibilities to reduce the water use of various end uses of water. The options given in the table are result of an internet search with criteria that the technology should be available at least on an experimental scale and applied in pilots.

Table 15 Water use options: present use against 'possible' use (Vreeburg, 2017).

Source	Water consumption (L/capita/day) (VEWIN, 2015)	Implied option	Water consumption (L/capita/day)	Water savings (%)
Toilet	33.3	Vacuum or grinder toilet	5.9	82.3
Kitchen sink	9.3	Flow delimiter	5.78	39.8
Shower	51.4	Recirculation shower	6.41	87.5
Wash basin	5.2	Water saving taps, sensor	3.77	27.5
Dishwasher	2	Water and energy saving dishwasher	0.79	60.5
Washing machine	14.3	Water and energy saving washing machine	11.14	21.3
Adding food waste		kitchen grinder	4.62	-
Total	115.8		38,41	66.8

Theoretically this reduces the domestic waste water flow with almost 70%. A crucial point, however is the application of a vacuum toilet, which is not fit for a gradual transition. A grinder toilet can be applied individually and may counter the same potential problems with vacuum toilets. An ozone washing machine can be used to save the water consumption for laundry.

Another potential solution would be cascading the household water use; for example, the use of shower effluent for assisting the toilet flush. Looking at the location and hydraulics of a toilet in the house installation, the crucial part is the actual connection of the toilet to a main sewer in which also water from other equipment is discharged. Research shows that solid transport over this distance in a relatively small pipe is very well possible. For further transport, water from the other equipment may serve. Theoretically, the shower effluent is sufficient for facilitating the toilet flush and transport of human excreta within the sanitary sewer (Table 1).

Domain 2: Collection and local transport

Though the collection and local transport part covers 80% of the total length of the sewer system, there is not much research available for the dimension and even less research or reliable data on the functionality of the system. There is a worldwide propensity to dimension these sewers based on assumptions for a minimal diameter of 200 to 300 mm. and relatively crude rules of thumb. An exception is Brazil where sewer systems are dimensioned to values of 110 to 160 mm pipes (Mara and Broome, 2008). Data on functionality, again very scarce, do not indicate that they function less: 2,24 for the small sewer vs. 2,77 incidents per km for conventional sewer (Melo, 2005).

In the Netherlands, the main stakeholder responsible for the collection of waste water is in many cases the municipality; dimensioning of the system is mostly done by technicians rather based on tradition than on hydraulic analysis. Design of collection sewers are made based on a minimal sheer stress, which can be translated in a velocity or self-cleaning velocity. However, the diameter has only limited effect on that value as can be seen in Figure 21. The volume flow range for which this basic hydraulic phenomenon is presented, represents the actual flows that can be expected for the collection of waste water based on the use of drinking water. The drinking water use is modelled with SIMDEUM (Blokker et al., 2010) with the condition that drinking water is almost instantaneously converted into waste water. The delay for e.q. the washing machine is of limited interest.

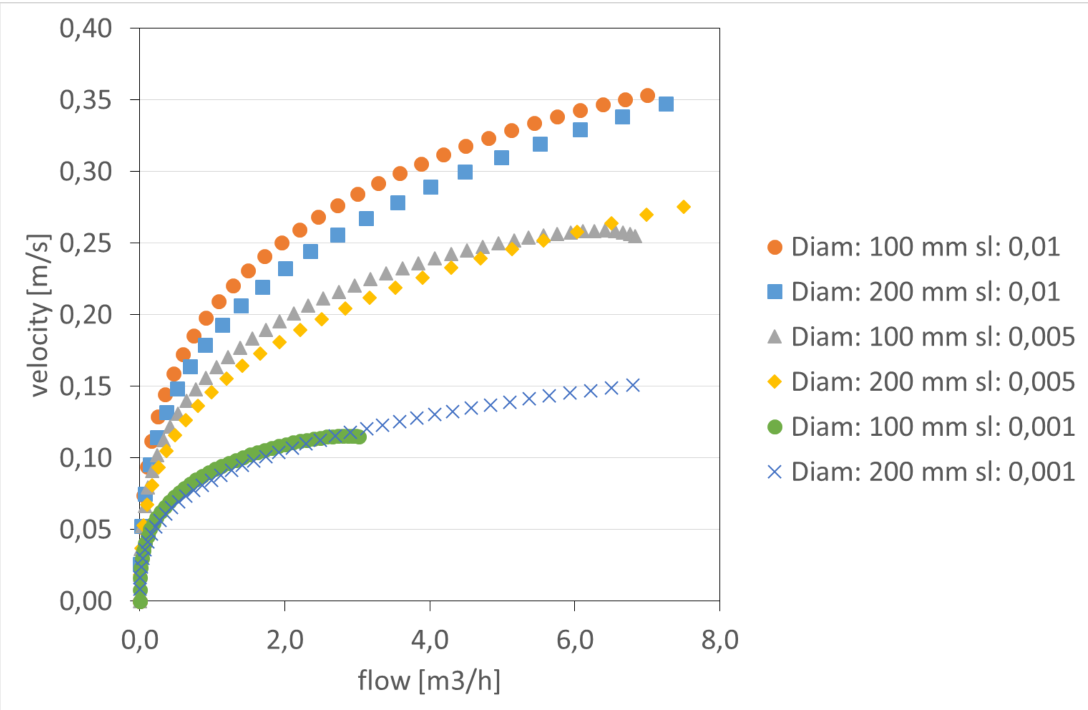


Figure 21 Relation between velocity, flow, diameter and slope for partially filled pipes. The flow is relevant for maximum domestic water use (and waste water production) for 20-40 houses (Vreeburg, 2017).

Domain 3: Transport to treatment and treatment

After collection in gravity systems, waste water is transported to treatment locations. Typically, this element has been added in the transition from local systems to regional systems. Most treatment is based on aerobic treatment because of the relatively low concentrations of organics. The resulting sludge may be treated anaerobically to further recover resources. The feasibility of anaerobic treatment is affected by the wastewater characteristics and temperature. The temperature of the water inside the reactor preferably should be between 25 and 35 ˚C, which determines the energy requirements (Metcalf et al., 2003). However, even at low temperatures, many laboratory studies have shown reliable performance, even at 5 °C (McCarty et al., 2011). In general, COD concentrations higher than 1500 to 2000 mg/L are needed to produce enough methane to heat the wastewater without an external fuel source.

3 Requirements and challenges for transition

Tervahauta (2013) showed that the total average COD-production per capita per day can be 120 gr (50 gr through feces, 11 gram through urine and 59 gram through kitchen waste) (Tervahauta et al., 2013). If only this parameter is considered for the efficient application of anaerobic treatment, the threshold concentration of 2000 mg/l may be reached if water consumption can be limited to 60 liter per person per day. The inventory presented in Table 15 shows that daily water use, including a kitchen grinder, may be limited to 40 liter per capita per day. Theoretically this may be feasible, but there are still challenges to overcome, especially in domain 1 and 2, the individual user and the collection.

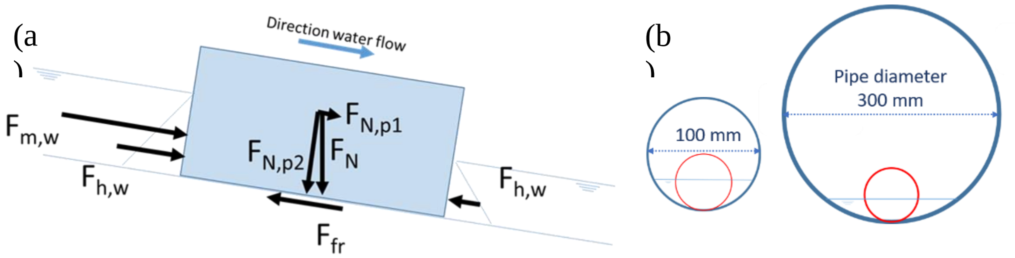
For domain 1, the biggest challenge will be to limit the use of water for showering and the toilet flushing. Toilet flushing will be possible when a different concept for toilets is developed in which the basic use of water is limited to rinsing the bowl. The other functions of water in a conventional toilet are filling the siphon and transport of solids. The first may be changed through construction of a valve, similar to the present vacuum toiles and the second may be taken over by other water in the system, discharged upstream of the toilet. How this can be done in real-life conditions and how end-users cope with the new setup need more practical experiment and research.

The second challenge in domain 1 is the shower water use, now limited through a recirculation system. However, if focusing on the amount of water entering the sewer system, this could also be addressed by using the technique of a dynamic multiple outflow: when the water is suitable for recycling, determined by sensors, it could also be redirected for infiltration in the ground. The hypothesis that the water after a few minutes of showering is almost not loaded with contaminants anymore may mean that it can be infiltrated, e.g under a house or in a gravel layer. If 50% of the shower water is redirected this would result for a 4 person family in 100 liter per day. With a 100 m^2 area this equals a 1 mm rain event. Alternatively, the water after a few minutes of showering can be used for toilet flushing as previously suggested.

For domain 2 there are multiple challenges. The biggest one is to create a collection system that only collects the sanitary waste water and is not infiltrated (diluted) with rain-

or groundwater. Before considering dimensioning and operating of such a dedicated system a short analysis of the interest of a correctly dimensioned collection system is made.
The introduction of the separated sewer systems took off in the early 1970's and coincided in the Netherlands with a huge activity in building houses and cities. Meanwhile, other European countries experienced this 'baby-boom' driven increase in building activities. The municipality, as main stakeholder responsible for the water household in the city and, was an important client for contractors that realised the subsurface infrastructure. Within the group of municipalities and the contractors there was a need for uniformity. Following that a national code for design and operation of sewers was made. Remarkably, in that code there is hardly a difference in dimensioning a sanitary sewer and a storm water sewer: they both end up with a minimum diameter of 250 mm for the gravity collection system. In the course of the years the difference between the two pipes faded away, also in the light of standardisation during construction. Nowadays, the experience is that both systems work satisfactorily, confirming that the design criteria are correct.

There are two reasons why the present design criteria for sanitary sewers may hamper a transition towards a resource recovery based sanitation: the first one is the extra costs for construction of a large dual pipe system and the second one is the hydraulic performance of small sewer pipe compared to larger ones for the transport of solids. Figure 2a shows a graphical representation of the forces working on an object in a sewer pipe. The main effect of the diameter in the relevant flow regime is an increase in the water depth (Figure 1). The effect of that is more buoyance of the solid to be transported leading to a smaller downward force (Normal force) resulting in a lower friction force. In fact, that is the only counter acting force in the direction of movement. Though possibly counter intuitive, smaller diameter sewer pipes will theoretically be more efficient: compared to larger diameters, the velocity will stay more or less the same, but through a higher water depth buoyance will be larger (Figure 2b). This is similar to the 'sliding dam' as described by Littlewood (2003)(Littlewood and Butler, 2003).



$\mathbf{F_{m,w}}$	Momentum (hydrodynamic) force of the water flow	[N]
$\mathbf{F_{h,w}}$	Hydrostatic force of the water	[N]
$\mathbf{F_N}$	Normal force due to net weight of object and buoyancy force	[N]
$\mathbf{F_{fr}}$	Friction force	[N]

Figure 22 (a) Forces on an object in a sloped pipe (Vreeburg, 2017); (b) With the same amount of flow, the water depth behind the object in a smaller diameter sloped pipe is higher and offers more buoyance for transporting the object.

4 Concluding remarks

Transition towards a system that can effectively recover resources from sanitary waste water should focus on promoting the installation of household water-saving utilities, though preferably without involving vacuum system, and the redesign of the sanitary sewer system.

The installation of household water-saving utilities not only reduces the drinking water consumption but also helps create a smaller, more concentrated sanitary waste water that are beneficial for resource recovery via biological processes at the end-of-pipe treatment. Use of vacuum system to assist water-saving, however, is debateable considering its cost, nuisance, transition challenges and dependence on electricity to fully functioning.

Considering the transitioning challenges, a dual pipe system for storm water and sanitary waste water is preferred over the source-separated sanitation system. Introducing more pipes in the street for the collecting black and grey water separately will be too complicated and costly. The focus of the sanitary sewer system should be on minimising flow and maximising organic load. As shown in Table 15 this is theoretically possible to a level that allows for an efficient anaerobic digestion. Nevertheless, a 1L flush toilet without vacuum system and the cascading of shower effluent are key components to be developed or sought for facilitating this transition.

The total flow will be much smaller than presently discharged; even for a modest drinking water use as in the Netherlands it results in a 60 to 70% reduction. This enforces also a reconsideration of the sanitary sewer collection system. Detailed knowledge of the drinking water end use allows for an evenly detailed insight in the sanitary waste water production and pattern. Applying that to a dedicated system results in pipes with diameters that are intuitively impossible. It should be born in mind though that the arguments for the larger diameters (inspection, buffer capacity and sediment storage capacity) are based on malfunctioning of the system. A smaller diameter system will probably need more skill and craftsmanship in installation, which may increase costs. Maintenance should not be more than nowadays, because the hydraulic performance in transporting organic solids is better due to the higher water depth and consequently more buoyance.

80% of system length of a completely centralised system is within the first mile: the gravity collection system (in analogy with the last mile in distribution systems). With that it is the most expensive part of the total system, though the costs are very spread both in space as in time. A considerable saving in projected costs for rehabilitation is an argument to further examine the possibility of a smaller diameter sewer system. However, this favourable effect investment should not cloud the possibility that the smaller system may perform better than the conventional system, especially with the prospect of less water used in the near future. The effect on concentration of the sanitary waste water and the possibility to recover the resources more effectively adds to the necessity to further explore these options.

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D12 - Air for the drainage system – limiting roof penetrations in tall buildings

S. White (1), M Gormley (2) Peter White

1. steve.white@studor.net
2. m.gormley@hw.ac.uk
3. peterwhite@phdc.co.uk

(1) Studor Ltd, Hove, East Sussex, United Kingdom

(2) School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, Scotland, UK.

(3) Public Health Design Consultants Limited, United Kingdom.

Abstract

A building cannot function without a drainage system; it is a fundamental requirement, removing drainage waste and protecting the occupants from gases and pathogens. The drainage system requires air to balance the pressures, preventing water trap seals from being depleted. The method of bringing air into the system directly impacts the architecture of a building, providing a challenge for Mechanical, Electrical and Plumbing (MEP) design engineers to find ways of providing air for the drainage system without compromising the design aesthetically.

Bringing air into the drainage system has traditionally been achieved by the use of vent pipes running from the base of the stack to top, protruding through the roof of the building. This is of particular concern in the design of tall buildings where, for health and aesthetic reasons, the large number of these unsightly pipes cannot be located near roof top pools, podiums, air handling units, etc.

To meet the architectural design of a building, MEPs often seek a solution to limit the roof penetrations by using linked vents and side venting. This paper addresses the limitations and risks of these methods and provides a solution using active drainage ventilation, which allows a building to fully function with limited drainage vents to atmosphere and removes any limitation on architectural design

Keywords

Vents, drainage systems, linked vents, side venting, modelling, AIRNET

1 Introduction

All buildings are different, and developers and architects often wish their buildings to stand out aesthetically. While this is important for the overall look of the building it also means that the developer can charge more for the space. Space is a premium commodity. Building services engineers (BSE) and Mechanical, Electrical and Plumbing Engineers (PME) are required to make their designs fit the ever decreasing allocation of space. Each engineering discipline provides solutions; this paper addresses the drainage ventilation, and the solution that public health and MEP engineers are using to limit the unsightly drainage vents that limit the aesthetics of the building. It is worth noting at this point that architect's drawings and models never show vent pipes as this is not part of their vision for the building (see Figure 1.)

Figure 1. Typical architect model without drainage vent pipes

The main methodology that the public health engineers and MEPs currently use to hide the vent pipes involve linking the stacks at the top of the building so that three or more stacks have only one roof penetrations to atmosphere, as shown in Figure 2. Alternatively designs can allow for the penetration of vents penetrating through the side of the building and covered by a louver screen Figure 3. The question is: do these solution work to protect the water traps seals in the building?

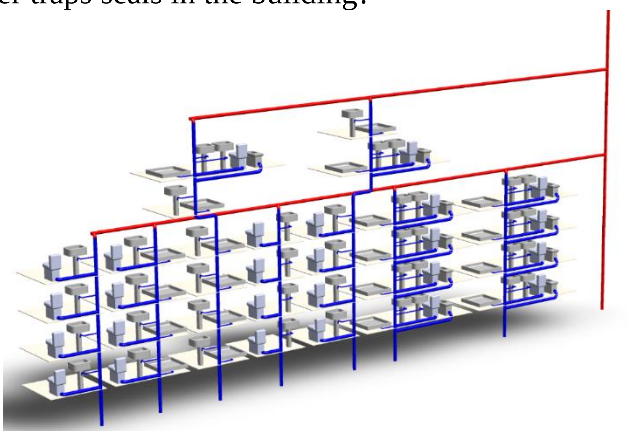

Figure 2. Linked Vents

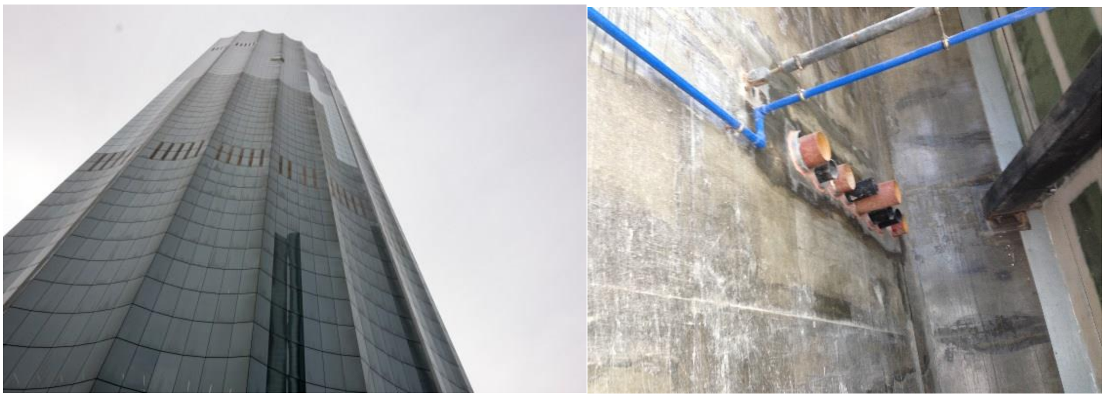

Figure 3 Louver screens and side vents behind them

2 Linked Vents

In practise every stack should be connected to atmosphere if passive drainage venting is used. The principle being that if there are discharges within the stack, the vent at the top of the stack will provide air through the drainage vent pipe network to relieve the negative transients generated in the system. The same vent pipe network is also perceived to provide relief paths for the positive transients generated within the drainage network to the vent at the top of the stack, however this is a less effective means of pressure surge alleviation.

The sizing and the efficiency of passive drainage venting has been discussed many time at CIB W062. The use of computer techniques to predict the generation, propagation and alleviation of air pressure transients in buildings has been well discussed previously and the computer program AIRNET has been instrumental in the analysis and performance of passive venting and the correct sizing that is required for it to work efficiently for tall buildings. A full anaylisis of the problem is given by Swaffield (2010), and this area of concern can be fiund in Chapter 5.7.

It should be remembered that all the research on passive drainage venting in the past, and which has gone on the inform codes and standards worldwide have been based on the assumption that each stack is vented individually to atmosphere. Within plumbing drainage codes themselves, it is also assumed that each stack is individually vented, although there has been room in some codes to interpret that as long as the stacks are connected to atmosphere it will me the requirement of the codes.

Engineers are using the interruption that as long as the stacks are connected to atmosphere, they can provide a cross link to connect a number of stacks to one open vent to meet the architectural requirements of the building.

To achieve this many engineers specify that the link vent used at the top of the stack is larger than the stacks in diameter. It is very typical for three to ten 100DN sized stacks, to have a 150DN linked vent running at the top of the building. In theory this will provide more air, however this arrangement interlinks all these stacks at the top and so facilitates the unwanted transmission of pressure transients from one stack to another.

This design principle is becoming more popular over the last five years. But there is no evidence that it will work using passive venting principles.

2.1 Design example

A 24 floor building was assessed by numerical modelling to see how it performed when linked vents were used. The system is designed to EN12056 and simulations were carried out using AIRNET (Swaffield, 2010)

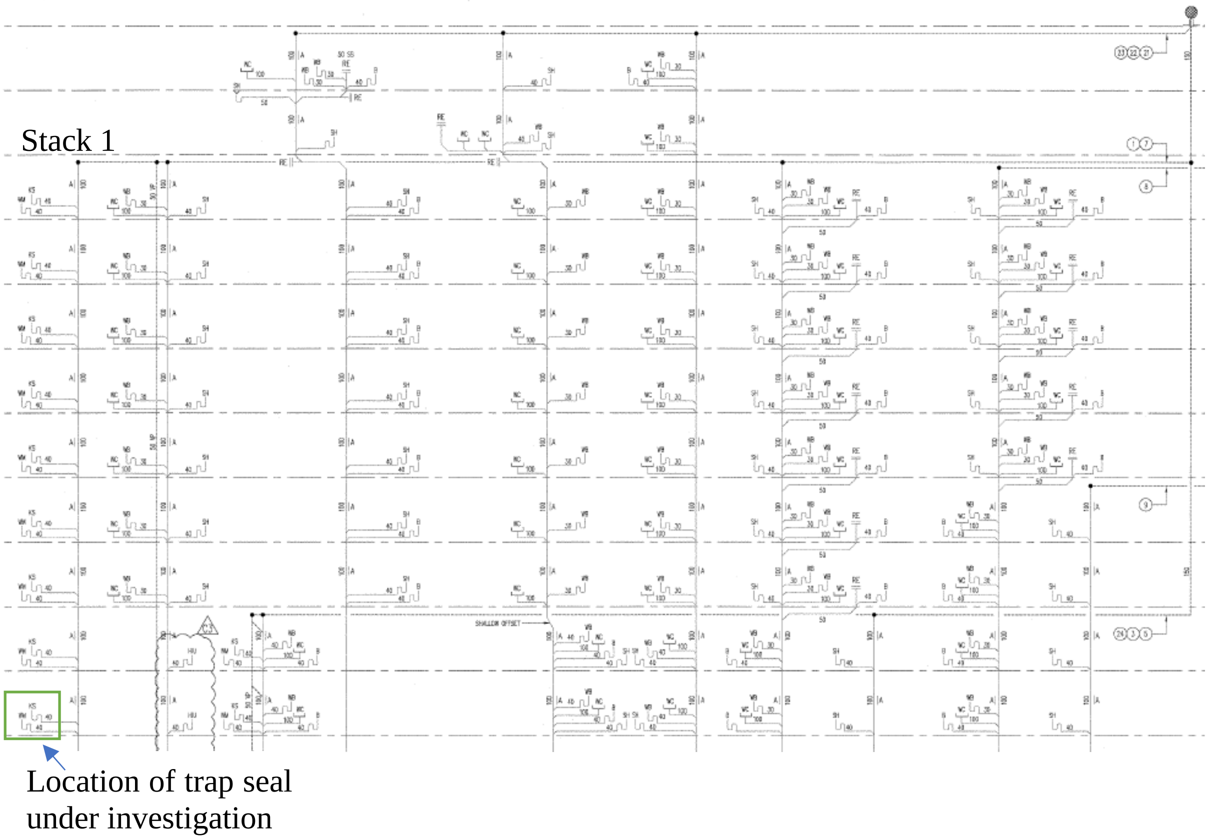

Figure 4. Partial schematic of the building drainage design showing linked vents at the top

It can be seen from Figure 4 that in this building 10 stacks have been cross linked to provide a single penetration through the roof.

An AIRNET analysis of this building was carried out to see what would happen if the system was loaded to its design capacity. The building was designed to EN12056:2000 and so the maximum loading would be 5.2 l/s. If one of these stacks was loaded to its maximum and there was some other activity in other stacks, would the single vent pipe be capable of proving the complex air requirements of the system?

The best way to assess the issue is to look at water trap seal retention in parts of the building which might be vulnerable under heavy usage load conditions.

Three loading profiles were used in the simulations: 5.2 l/s peak, 1.5 l/s peak, 2.5l/s peak and 1 l/s peak. This is shown in Figure 5. The flow rate is allowed to steadily increase over a period of 10 seconds to mimimize the risk of pressure transient generation due to rapid increase in flow rate rather than the loading itself.

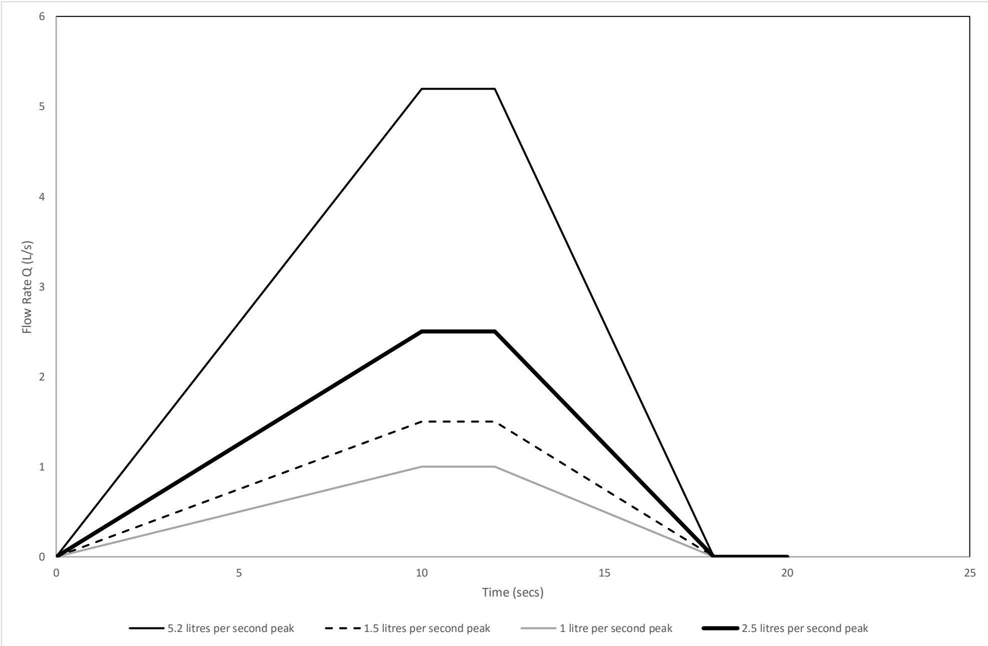

Figure 5. Water input profiles (note, this is the total water input to the system, accumulated across the height of the building to give the peak flowrate at the base of stack 1

Simulations were run in AIRNET to ascertain the vulnerability of the trap at the bottom of Stack 1. This was considered to be a worst case scenario, since it is the furthest away from the vent pipe and so the effectiveness of any venting capability will be at its minimum.

The results are shown below in Figure 6. It can be seen that only the lowest flowrate (1l/s) results in a system which is not vulnerable to seal loss. Even at 2.5 l/s there is significant seal depletion, but the trap has still some water left after the event. It can clearly be seen that this system cannot cope with the fully loaded 100 mm pipe at 5.2 litres per second under these venting arrangments

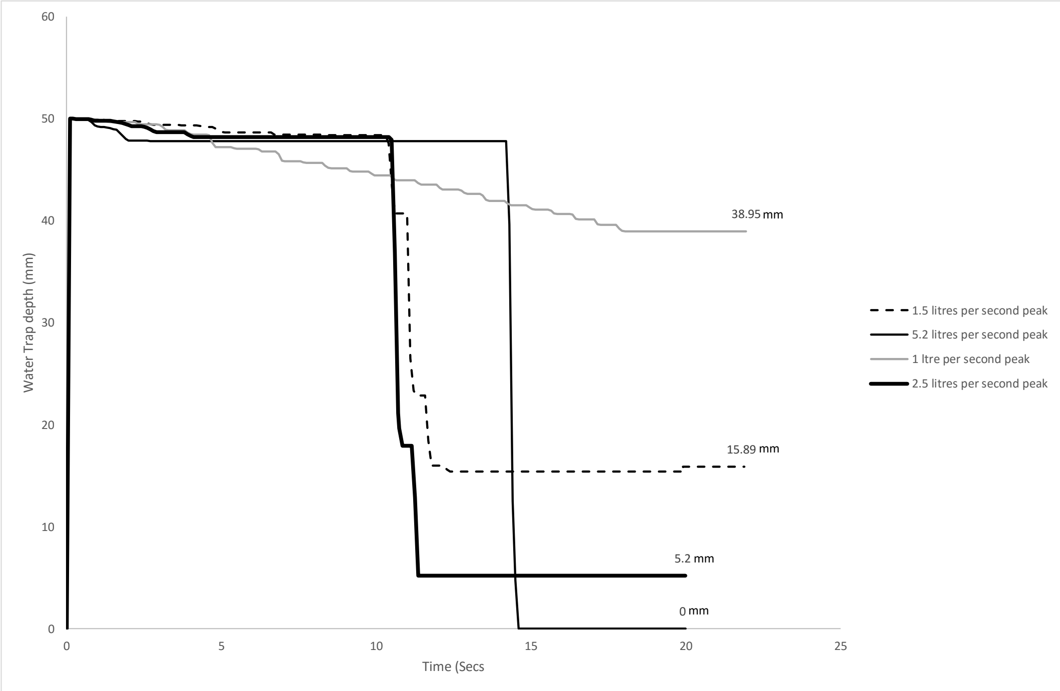

Figure 6. Water seal retention after the system operation was simulated in AIRNET

It can clearly be seen from Figure 6 that there are issues with this arrangement. Further local venting using air admittance valves or other venting arrangement.

3 Side Venting

In taller buildings the linked drainage vents and the individual drainage vents do not penetrate to atmosphere at the top of the building. In many cases they are side vented, typically behind louvered screens to hide them Figure 3. The wind speeds around taller buildings is higher and in structural calculations it is not uncommon for wind speeds to be calculated at 37.8m/s to 70m/s or more in their calculations.

This raises potentially other issues for the protection of the water trap seals, this being wind and the direction of the wind into the side vents. Wind speed at 12.5m/s will generate +- 180Pa of pressure

Wind effect around the side vents will lead to trap oscillation and the loss of water trap seals.
The changes in the external conditions around the vents will propagate transients into the drainage and vent system and will affect trap seal retention and generate entrained airflows.

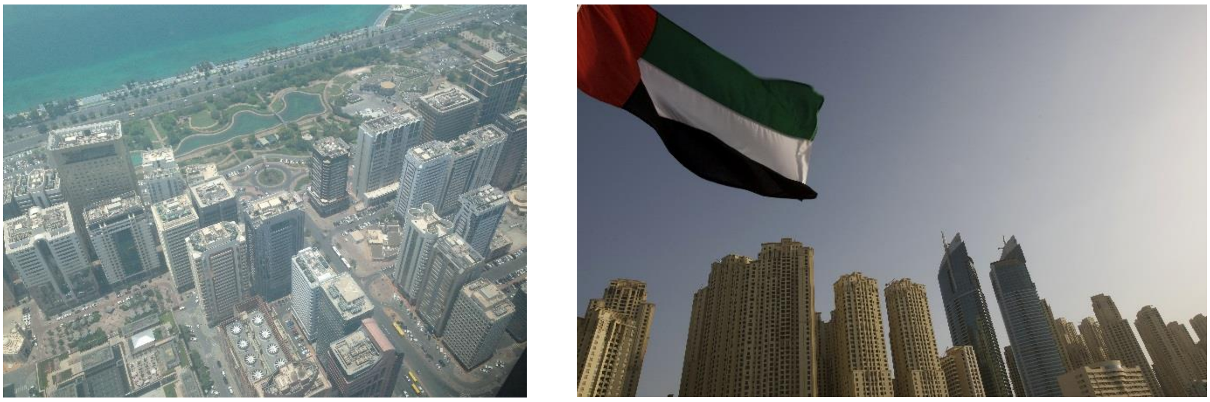

Figure 4 Abu Dhabi

An example of a building that has issues, with side venting and wind is the Burj Mohammed tower, a 381 meter, 88 floor building. When the world's 4 largest flag pole (123 meters) flag blows in the direction of the tower, water trap seals are lost.

4 Active Drainage Ventilation

The **active drainage ventilation** principle works by local intervention to remove or attenuate an incoming transient that, if left, would lead to trap seal depletion. This is achieved by placing AAVs and the P.A.P.A™ onto the standard pipes of the system to limit the surge pressures adjacent to the traps by reducing the rate of local changes in flow conditions.

The placement of the P.A.P.A™ must be positioned between the source of the transient and the base of the stack; offsets are typical points to generate positive transients.

Active drainage ventilation reduces the effects of the negative and positive transients, balancing the pressure within the drainage system – if the system pressure exceeds +/- 40mm WG (400Pa) the water trap seals can be lost by induced or self siphonage:

- **Negative pressure** (transients) are dealt with through the introduction of local airflow using AAVs on the branches. Air is allowed in through the AAV as required, which then seals tight to prevent sewer gases from leaking out into the habitable space.
- **Positive pressure** (transients) are absorbed by the P.A.P.A.™, slowing them down from the speed of sound (320m/s) to a harmless 12m/s, which is then released back into the system to naturally dissipate.

Active venting versus traditional "passive" venting

Active venting should be considered as functionally "superior" over traditional "passive" venting:

- The removal of long, and possibly, convoluted vent connections to atmosphere reduces the time taken before local relief can be applied – allowing the pressures to be balanced quicker with active venting.
- Local suppression prevents transient propagation throughout the network prior to relief – removing the risk of the siphonage of multiple traps.

With traditional "passive" venting, reliance on roof penetrating open terminations allows transients to travel the whole system prior to any remedial action. The fundamental issue being that a transient should be dealt with between its source and the first appliance trap seal in order to prevent trap seal depletion.

5 Conclusion

Public health engineers and MEPs have to find solutions to meet the architectural requirements for their clients. In many case they are trying to limit the drainage vents to atmosphere as well as hiding them from view. The approach of passive drainage venting can lead to the loss of water trap seals.

The architectural requirements can be met, only when active drainage ventilation is used. Linked venting arrangements seem to offer the perfect solution and a compromise between aesthetics and practical venting, however simulations show that this venting arrangement is lacking in that it increases water trap seal vulnerabilities. Maximum safe loadings reduce drastically (to about 1.5 litres/second peak) when this venting arrangement is used on its own.

In tall buildings the use of PAPA™ and AAV's provide the protection throughout the interconnected stacks, and limit the requirement for roof pentation's for the building. This allows engineers to place the vents to atmosphere away from locations that interfere with the use of the building and do not affect the external aesthetic of the building.

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7 Authors

***1*. Steven White**, is Technical Director for Studor Limited. His responsibility is the development of new markets and codes in the Middle East, Europe and Asia as well as supporting code issues for Studor worldwide.

2. Dr. Michael Gormley is Director of Research at the School of Energy, Geophysics, Infrastructure and Society at Heriot-Watt University in Edinburgh, Scotland. He has been active in research on pressure transient generation, propagation and alleviation since

joining Heriot-Watt University in 2000. His recent work has focussed on pressure transients in tall buildings.

***3*. Peter White**, CEng MCIBSE FSoPHE, is a Director of Public Health Design Consultants Limited, a UK company that he founded in 2015 to offer specialist public health advice to the construction industry. He is a Chartered Engineer, a Member of the UK Chartered Institution of Buildings Services Engineers and a Fellow of the UK Society of Public Health Engineers.

D13 - Study about vent cap air flow around buildings and the drainage stack internal pressure of the stack vent system by a numerical analysis

S. Tanaka (1), T. Endo(2),M. Otsuka(3)
1. m16J3005@kanto-gakuin.ac.jp
2. endo@kanto-gakuin.ac.jp
3. dmotsuka@kanto-gakuin.ac.jp
(1)Graduate Student, Graduate School of Engineering, Kanto Gakuin University, Japan
(2)Associate Professor, Dr. Eng., Department of Architecture and Environmental Design, College of Architecture and Environmental Design, Kanto Gakuin University, Japan
(3) Professor, Dr. Eng., Department of Architecture and Environmental Design, College of Architecture and Environmental Design, Kanto Gakuin University, Japan

Abstract

In Japan, trap seal breakings in drainage pipes have been reported in recent years. In Japanese drainage system, a vent pipe is connected to drainage stack to keep the drainage performance. One of the ventilation systems is the stack vent system. A stack vent pipe is connected to the upper part of the drainage stack in this system. The stack vent pipe is open to the outdoor, and it reduces the drainage stack loads in draining. A vent cap is also installed to the stack vent pipe opened to outdoor to prevent rainwater invasions. A stack vent pipe is basically installed to reduce the drainage load. However, it makes the airflow field at the building roof complicated. At a roof, the vent cap openings can be influenced by positive or negative pressure because of the bouncing air currents from the roof floor surface and the detaching air currents at the building edge. Depending on the magnitude of the outdoor wind pressure, the air currents breaking into the stack vent pipe can influence on the drainage stacks, the horizontal fixture drain branch, and sealed water. This study considered the influence of the vent caps opened to outdoor air currents on drainage stacks and horizontal fixture drain branch by using of a numerical analysis of CFD (Computational Fluid Dynamics). The result shows that the vent caps were greatly influenced by the outdoor air currents when a gale more than 25 m/s of wind velocity in the summer in Japan blew, and that the unstable air currents blew into the drainage stacks. It can be said that this can cause trap seal breakings in drainage pipes.

Keywords

Vent pipe, Vent cap, Drain internal pressure, Stack vent pipe, Numerical analysis, Computational Fluid Dynamics

1 Introduction

Buildings are recently required to have high properties in energy-saving, comfortability, sound insulation, and so on. This leads to the technology developments in construction and high airtightness in buildings. High airtightness in buildings improves comfortability in the thermal conditions and decreases the whole energy consumption of the building. However, it brings a bigger difference between indoor and outdoor air pressure, and this can cause difficulties in opening and closing doors, noises from drain pipes of air conditioner, and seal breaks of the trap seal water in the drain pipes. Regarding the seal breaks of trap seal water in drain pipes, negative pressure brought by high airtightness of a building is not the only reason for it. Other reasons can be the outdoor air flow conditions around vent caps (VCs), or vent pipes to reduce drain loads of drain pipes. Vent pipes are open to outside, and VCs are installed at the connections between vent pipes and outside. VCs and vent pipes are basically installed to reduce drainage loads, but some outdoor air flow conditions negatively influence on VCs and it transfers into the inside of vent pipes. In such condition, the inside of vent pipes has strong negative pressure, and seal break in the drain traps can happen. Especially, a unique wind of over 25 m/s which blow in summer season in Japan can cause the bigger difference between indoor and outdoor air pressure, and increase the possibility of seal break in drain traps. In sum, to solve the problems regarding the seal break of trap seal water in drain pipes needs a consideration from both of the following point of views: drainage facility and outdoor air flow condition. Therefore, this study considers the influence of airflow field around VCs and outdoor air flows on the pressure distribution inside vent pipes by using of Computational Fluid Dynamics (CFD).

2 Preliminary Check in CFD analysis

Before the main CFD analysis, this study needed to check whether this CFD analysis sufficiently reproduced the phenomenon in the wind tunnel experiment. In the preliminary check, the wind tunnel experiment was conducted, and the wind pressure coefficient distribution in the wind tunnel experiment was measured. Then, the CFD analysis was conducted, and its distribution was compared with that in the wind tunnel experiment. Figure 1 shows the VC type wind pressure model used in the window tunnel experiment. Table 1 is the outline of wind tunnel devices. The incoming air flow in the CFD analysis was the same as the measured values in the wind tunnel experiment. The other calculation conditions were the followings: SST k-ω model for the turbulent flow model, and wall function for the boundary condition of the numerical wind tunnel floor surface and the wall of the object buildings. The discretization scheme for the advection term was set as QUICK. The computational algorithm was SIMPLE method. Figure 2 shows the distribution charts of the wind pressure coefficient in the results of the CFD analysis (left side) and the wind tunnel experiment (right side). As a VC has a symmetrical shape, only the values measured in the half of the VC were compared between the wind tunnel experiment and CFD analysis in this preliminary check. In the

Figure 2, the results in the upper half of the target area were copied and turned over, and it was considered as the results in the lower half. As shown in the figure, both results in the wind tunnel experiment and CFD analysis had the greatest positive pressure at the windward side of the VCs. Positive pressure was switched to negative pressure around the center of the VCs. The areas from the center to the leeward side had the negative pressure distribution because of the peeling off influences. According to the comparison of these two results data, the values of the maximum wind pressure coefficient were from 2.1 to 2.3 [-], and it shows a slight difference between them. However, it shows the distributions of the wind pressure coefficient on the surface and back side were both generally the same. Therefore, it can be judged that the CFD analysis in this study adequately reproduced the phenomenon in the wind tunnel experiment.

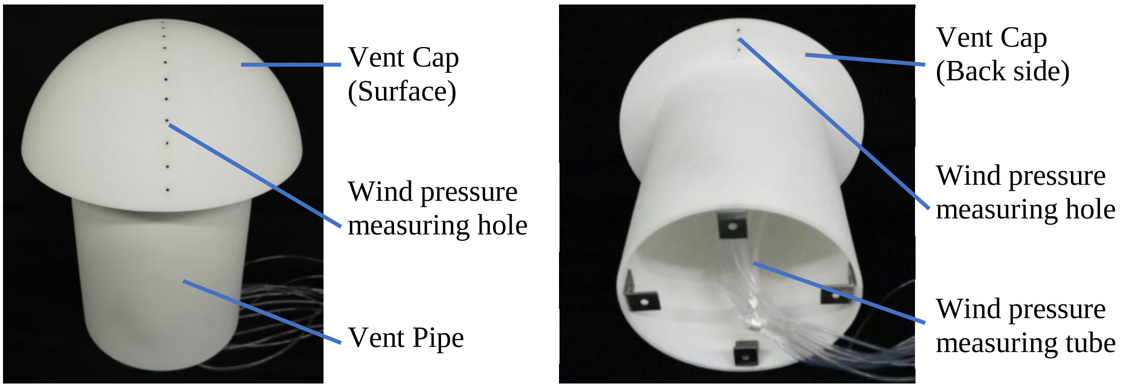


Figure 1 VC type wind pressure model

Table 1 Outline of wind tunnel device

Wind tunnel type	Indoor rotary type Eiffel type
Wind tunnel total length	22,400 mm
Wind tunnel measurement length	14,000 mm
Boundary layer length	14,000 mm
Wind tunnel measurement cross section	height 1,000 mm width 1,200 mm
Contracted flow ratio	1/5
Settable range of wind speed	0.5 ～ 18 m/s
Intensity of turbulence	Less than 0.2%

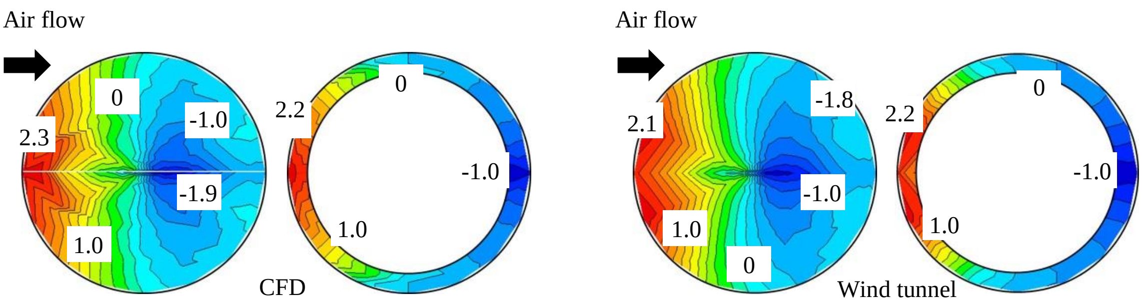


Figure 2 Wind pressure coefficient distribution chart of VC

3 Method

The analysis area and the object building for the main CFD analysis were shown in Figure 3. The analysis area had 38 meters of width, 68 meters of depth, and 50 meters of height. The object building was a 7-story highrise apartment building above the ground, and it had 5.0 meters of width, 5.0 meters of depth, and 24 meters of height. The ventilation system was stack vent system. VCs were installed on the top of the vent pipe which was open to outdoor 0.2 meters above the ground. Figure 4 shows the 4 positions of VC installments. In addition to these 4 positions, this study examined other cases with the conditions where a penthouse was installed in the windward and leeward side. The penthouse had 5.0 meters of width, 2.0 meters of depth, and 3.5 meters of height. In the case with a penthouse, the vent pipes and the VCs were installed as Figure 5 shows. The incoming air flow in the numerical wind tunnel representing a natural wind followed the law of 1/4 power. The wind velocities were based on the weather data, and they were 2.4 m/s at the normal wind speed and 25.2 m/s at the strong wind speed. The other calculation conditions were the followings: SST k-ω model for the turbulent flow model, and wall function for the boundary condition of the numerical wind tunnel floor surface and the wall of the object buildings. The discretization scheme for the advection term was set as QUICK. The computational algorithm was SIMPLE method. All the examination cases were shown in Table 2, and the calculation conditions were shown in Table 3.

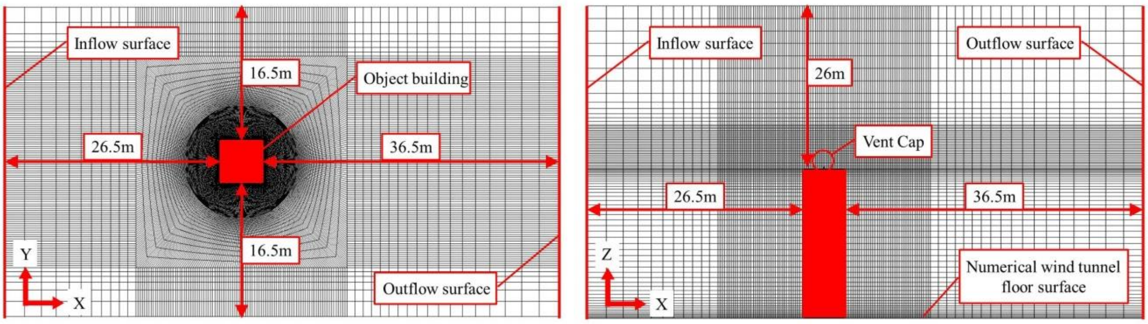


Figure 3 Analysis area (No pent house)

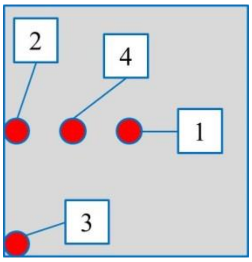


Figure 4 Position to install VC (No Pent house)

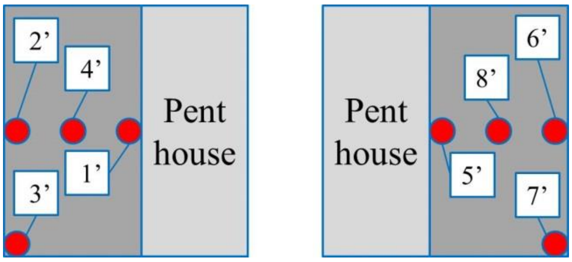


Figure 5 Position to install VC (Left: Windward side , Right: leeward side)

Table 2 Examination Case

Examination Case	Penthouse	Position to install VC
Case1	None	Center
Case1'	Leeward side	
Case2	None	Windward side Center
Case2'	Leeward side	
Case3	None	Windward side Corner
Case3'	Leeward side	
Case4	None	Midway between Case1・2
Case4'	Leeward side	
Case5'	Windward side	Center
Case6'		Leeward side Center
Case7'		Leeward side Corner
Case8'		Midway between Case5'・6'

Table 3 Calculation conditions

CFD code	OpenFOAM ver2.0.1
Analysis area	Analysis area X:Y:Z = 38m：68m：50m Object building X:Y:Z = 5m：5m：24m Penthouse X:Y:Z = 5m：2m：3.5m
Inflow condition	Follow the power law of 1/4 power
Outflow condition	Free flow
Turbulent flow model	SST k-ω model
Discretization scheme	QUICK
Computational algorithm	SIMPLE method
Wall boundary condition	Numerical wind tunnel floor surface ・Building surface：Wall function Other：slip

4 Results and Discussion

4.1 Without a penthouse

Figure 6 is the static pressure distributions of the building roof at the normal wind speed and the strong wind speed in Case 3. The wind velocity vector distributions were shown in Figure 7. They show that peeling offs were reproduced at the leading edge, and that bigger negative pressure area appeared at the roof and backward of the building. When the VCs were installed on the roof of the object building, they took an influence of negative pressure caused by a peeling off. The influence was outstanding at the strong wind speed.

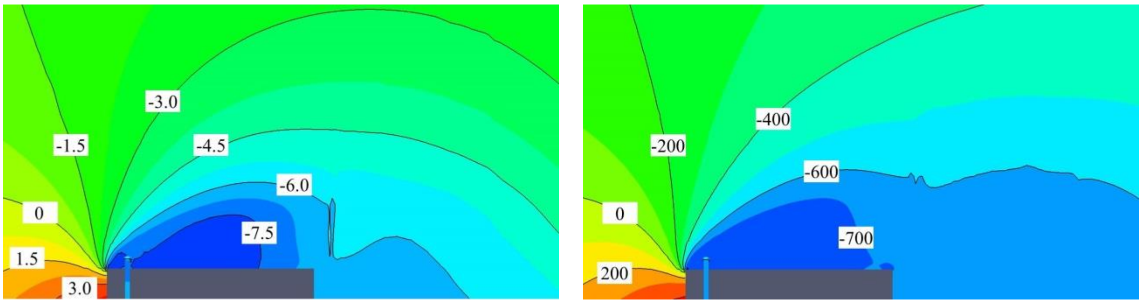


Figure 6 Case 3 static pressure distribution [Pa]
(Left: Normal wind speed , Right: Strong wind speed)

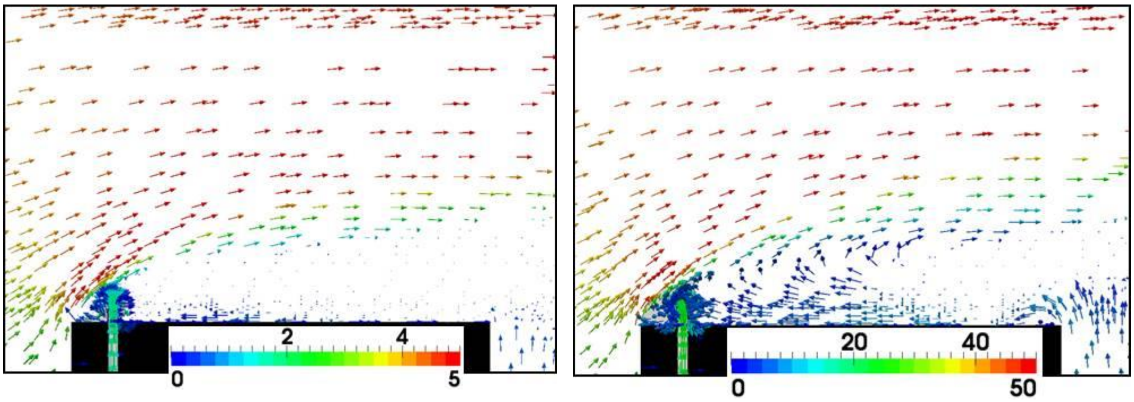
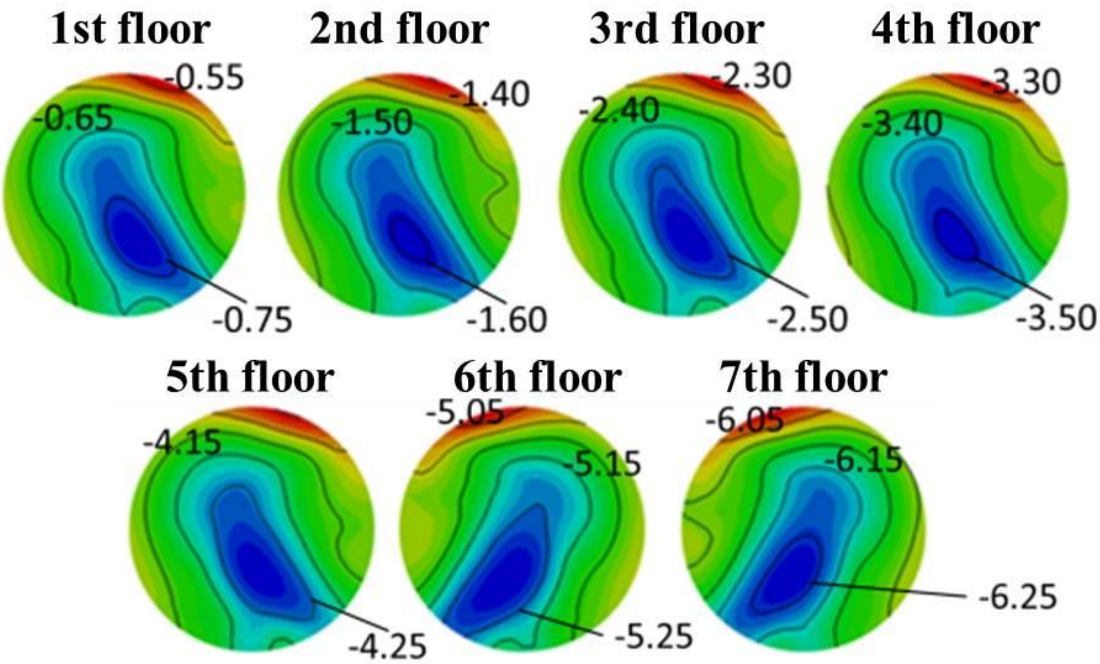
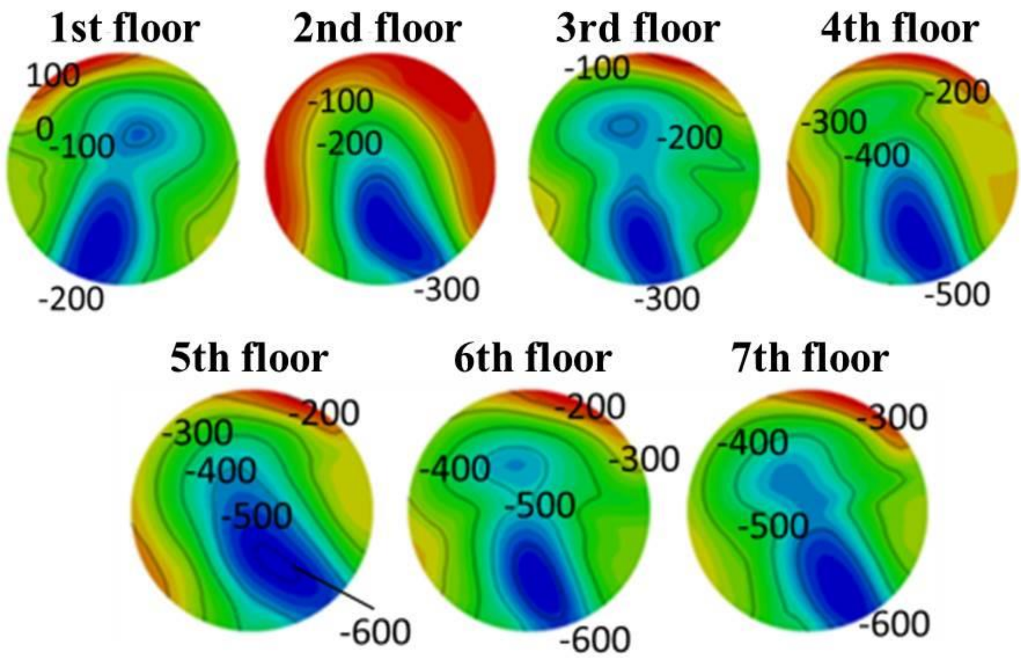


Figure 7 Case 3 wind velocity vector [m/s]
(Left: Normal wind speed , Right: Strong wind speed)

Figure 8 is the static pressure distribution of vent branch pipe section from 1st to 7th floor at the normal and strong wind speed. At the normal wind speed, negative pressure became bigger from lower stories to higher stories because of the peeling off influences in all the cases. In Case 1 and 4, when the VCs were installed near the center of the roof floor, the results of the static pressure distributions were alike each other. However, in Case 2, when the VC was at the windward side of the object building, the peeling off influence was small. The results in Case 3, when the VC was at the windward side corner, shows the greatest influence of the eddy produced by peeling offs. It also shows in the Case 3 that the static pressure distribution of vent branch pipe section was more complex. However, it can be said that the peeling off was not great enough to influence on the drainage performance in any case at the normal wind speed.At the strong wind speed as shown in Figure 8, negative pressure became bigger from lower stories to higher stories like in the case of normal wind speed. The influence of peeling off was outstanding at the strong wind speed. The bottom floor had 100 Pa of the static pressure distribution, but the top floor had -600 Pa of great negative pressure.



Normal wind speed [Pa]



Strong wind speed [Pa]

Figure 8 Case 3 static pressure distribution of vent branch pipe section [Pa]

When 3.5 L/ s constant flow of drainage load is given to a drainage stack of a stack vent system, the pressure inside the drainage stack is considered to be around ±400Pa, and then this can influence on the drainage performance. Figure 9 shows the result of wind velocity vectors in Case 3 at the strong wind speed, when the greatest influence of peeling off happened. As this figure shows, the VC was in the negative pressure area caused by the peeling off influence, the air flow inside the ventilation stand pipe rose as if it was sucked out. Figure 10 is the static pressure distribution of the ventilation stand pipe section in Case 3. It can be thought from the static pressure distribution of the ventilation stand pipe that the air flow invaded from the VC on the roof of the object building and descended inside the ventilation stand pipe winding its way. Due to this influence, it can be also thought that outdoor air flow coming in from the VC repeated an unstable invasion into the bent branch pipe. In the case of the strong wind speed, the drainage performance of the upper stories can be influenced by it.

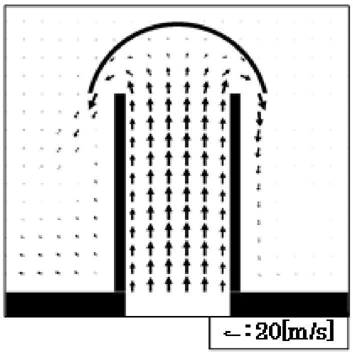


Figure 9 Case 3 wind velocity vector around VC at strong wind speed [m/s]

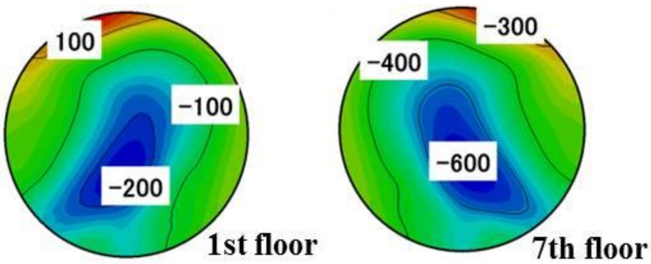


Figure 10 Case 3 static pressure distribution of Ventilation stand pipe section [Pa]

4.2 With a penthouse

This section deals with only the results of the cases showing greatest peeling off influences in the case of the strong wind speed. When a penthouse was installed in the leeward side, Case 2' shows the greatest peeling off influence. When it was installed in the windward side, Case 8' shows the greatest peeling off influence. Figure 11 is the static pressure distributions at the roof of the building, Figure 12 is the wind velocity vectors at the roof, and Figure 13 is the wind velocity vectors around the VCs. In Case 2', a big eddy of negative pressure appeared in front of the penthouse. In Case 8', a big eddy of negative pressure appeared at the back of the penthouse. Each case shows that the VCs on the roof floor were among the area of peeling offs. Figure 14 is the static pressure distributions of the vent branch pipe section in Case 2' and 8'.In Case 2' positive pressure became bigger from the lower stories to the higher stories, and the top floor had the biggest positive pressure. However, the positive pressure was below 400 Pa, and it can be thought that its influence on the drainage performance was small. In Case 8', the negative pressure became bigger from the lower stories to the higher stories. The bottom floor had about -25 to -75 Pa of negative pressure, and the top floor had -500 Pa of negative pressure. In this case, the pressure in the top floor can influence on the drainage performance when it is a load to the inside of the drainage stack.

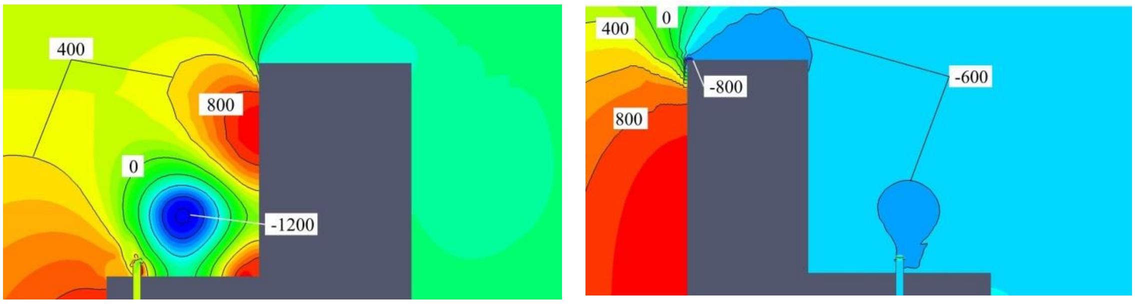


Figure 11 Static pressure distribution at strong wind speed [Pa]
(Left: Case2' , Right: Case8')

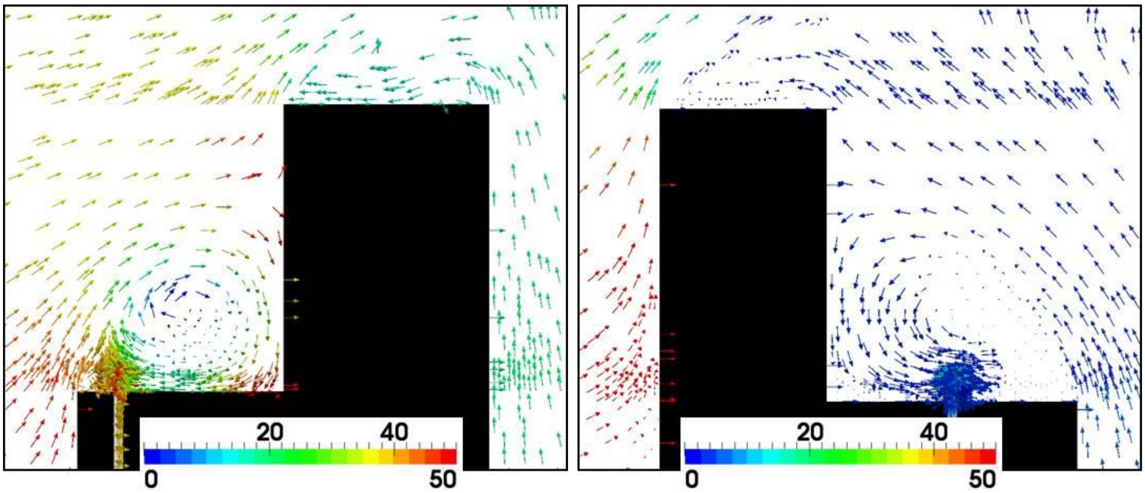


Figure 12 Wind velocity vector at strong wind speed [Pa]
(Left: Case2' , Right: Case8')

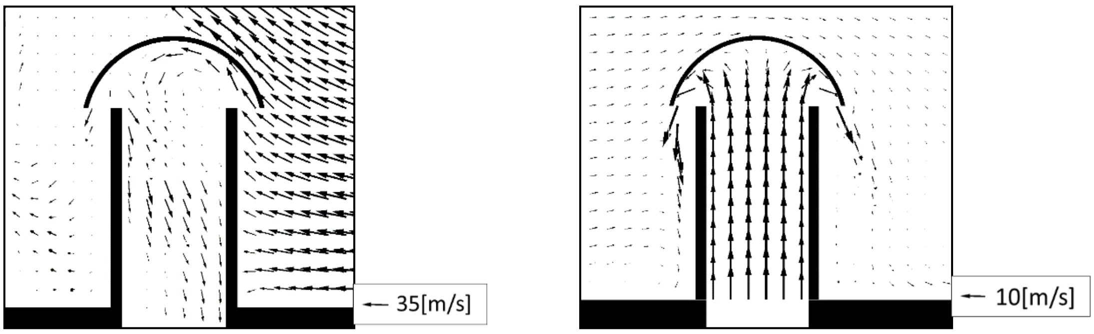
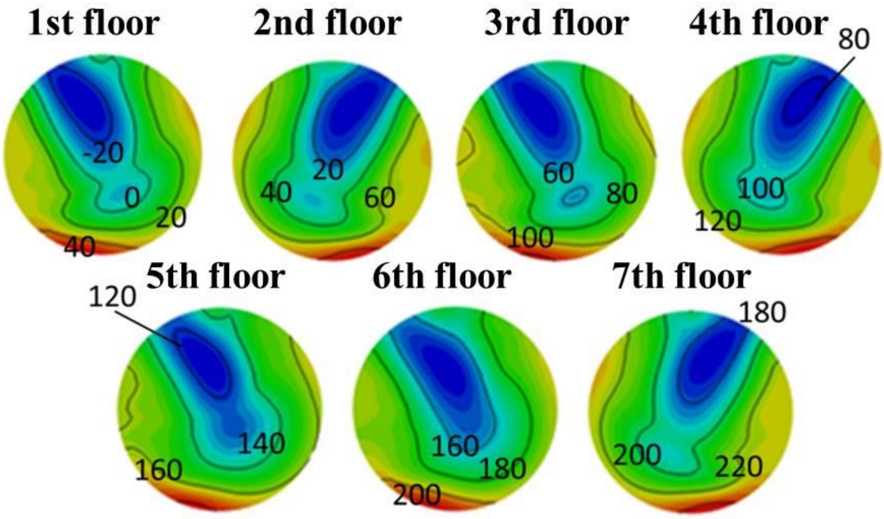
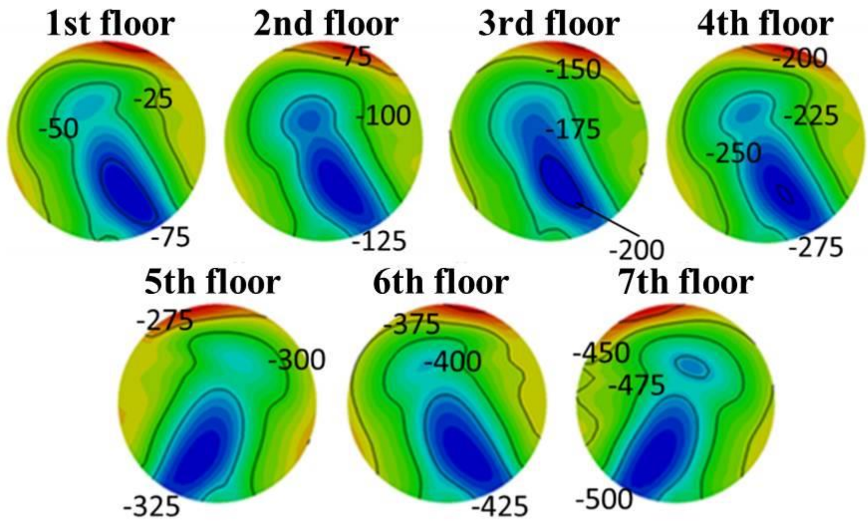


Figure 13 Wind velocity vector around VC at strong wind speed [m/s]
(Left: Case2' , Right: Case8')



Case2' static pressure distribution [Pa]



Case8' static pressure distribution [Pa]

Figure 14 Static pressure distribution of vent branch pipe section at strong wind speed [Pa]

5 Conclusion

This study conducted an air flow analysis with CFD, and examined the static pressure distribution in the vent pipes which VCs were installed at the top of drainage stacks. All the case without a penthouse shows that the negative pressure tended to be bigger from the lower stories to the higher stories of the object building. The static pressure distributions of the vent branch pipe sections were different around the roof edge and the center of the roof floor. When the analysis supposed the normal wind speed, there was no extremely big negative pressure inside the vent pipes, and it can be said that this is less likely to influence on the drainage performance. The results in the case with a penthouse shows the air flows into and out through the vent pipes generated by the static pressure distribution in the windward or leeward side of the penthouse. In addition, an airflow with a great wind velocity happened inside the vent pipes at the strong wind speed. Around the area, positive pressure and negative pressure switched because of changes in outdoor wind directions or airflow winding inside the vent pipes. This suggests that the areas of strongly positive and negative pressure constantly appear inside the ventilation stand pipes, and that this can bring about seal breaks because of the ups and downs of the seal water. This study conducted only a basic consideration with CFD steady calculations, and it still needs further examinations and considerations such as validations by experiments, examination of complex and integrated influences with other factors, unsteady calculation with seal water inside the drain pipes.

6 Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP25289201.

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8 Presentations of Authors

Suguru TANAKA is a graduate student of the Endo laboratory, Kanto Gakuin University. He is a member of AIJ(Architectural Institute of Japan) and SHASE(Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His current interest in research is to construct a prediction method of ventilation volume when doing natural ventilation in double skin building by wind tunnel experiment and CFD.

Tomoyuki ENDO is the Associate Professor at Department of Architecture and Environmental Design, Kanto Gakuin University. He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His current research interests are the prediction method of ventilation volume in natural ventilation and the development of highly-efficiency ventilation system.

Masayuki OTSUKA is the Professor at Department of Architecture and Environmental Design, Kanto Gakuin University. He is a member of AIJ(Architectural Institute of Japan) and SHASE(Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His current research interests are the hybrid drainage system that uses both force feed type and gravity type drainage methods compatible with commercial building conversion.

D14 - A numerical investigation on the hydrodynamic impact loads of the solid waste transport inside main drains

L.Y. Cheng (1), L.H. Oliveira (2), P.H.S. Osello (3), R.A. Amaro Jr (4)
1. cheng.yee@usp.br
2. lucia.helena@usp.br
3. pedro.osello@usp.br
4. rubens.amaro@usp.br
(1), (2), (3), (4) Department of Construction Engineering of Polytechnic School, University of São Paulo, Brazil

Abstract

Reduction of flow rates due to adoption of water saving practices is a great concern to assure the self-cleaning performance of building drainage networks. Thus, experimental and analytical studies on the topic have been published recently. A previous study on the complex fluid-structure interaction (FSI) problem of solid waste transport has showed that the hydrodynamic process can be divided in two phases: the first one is dominated by high impulsive hydrodynamic loads of relatively short duration. The second phase is predominated by gravity effects, such as waves, hydrostatic heads, weight and friction. In the present work, further investigation focused on the hydrodynamic impact loads and the behaviors of the solid waste due to the variation of its initial location is carried out by using a particle-based numerical modeling. For this purpose, a cylindrical solid transported by transient flow inside drain with 90º elbows is considered. The modeling and simulation of the FSI problem represent a step toward the understanding of the complex flows inside building drainage systems.

Keywords

Building drainage system; waste transport; fluid-solid interaction; nonlinear hydrodynamics; simulation; particle method.

1 Introduction

Reduction of flow rates due to adoption of water saving practices is a great concern to assure the self-cleaning performance of building drainage networks. Thus, experimental and analytical studies on the topic have been published recently, such as [1], [2] and [3].

Recent studies on the complex fluid-structure interaction (FSI) problem of solid waste transport [4] have showed that the hydrodynamic process can be divided in two phases: (i) the first one is dominated by high impulsive hydrodynamic loads of relatively short duration when the incoming wave front hits the solid and (ii) the second phase is predominated by gravity effects, such as waves, hydrostatic heads, weight and friction. Aiming further investigate the effects of the reduction of flow rate on the waste transport performance, the present work is focused on the investigation of the factors that affect the impulsive hydrodynamic loads. In the previous works, a particle-based computational fluid dynamic method, denominated Moving Particle Semi-implicit (MPS), has been adopted by the authors to model the solid transport by a transient free surface flow in horizontal drainage pipelines [4]. In the present work, the hydrodynamic behaviors of the solid waste transport due to the variation of the initial location of the solid waste inside a horizontal pipe is investigated by using the numerical modeling. For this purpose, a cylindrical solid transported by transient flow inside drain with 90^{o} elbows is considered.

For sake of simplicity, the solid wastes are assumed as rigid bodies with free motion. Also, considering the relatively low flow rate, the air entrapped inside the pipes and the pressure variation due to the entrapment is neglected.

2 Numerical method

2.1 Moving Particle Semi-implicit

The numerical method adopted in the present study is based on the Moving Particle Semi-implicit (MPS) method. It is a fully Lagrangian meshfree particle-based approach originally proposed by Koshizuka et al. [5] for the simulation of incompressible flow with free surface. It solves the governing equations of continuum by replacing the differential operators with discrete operators derived from a particle interaction model based on a weight function.

The solution algorithm of the MPS method is a semi-implicit one divided in two main parts. The first part is the explicit estimation of the fluid particle's velocity and position by using viscosity and external forces terms of the momentum conservation. After that, in the second part, the pressure of the fluid and wall particles is calculated implicitly by using the Poisson equation for the pressure. The RHS term of the Poisson equation is proportional to the deviation of particle number density, which is a parameter proportional to the density of the fluid in the vicinity of the particle. Finally, the velocity of the fluid particles is updated by using the pressure gradient term of the momentum conservation and the updated positions of the particles are obtained. More detailed description of the MPS method, including the numerical treatment of the boundary conditions, can be found in [5] and in the previous works of the authors [6,7].

2.2 Free solid modeling

The numerical modeling of the solids considered three different types according to their motions: fixed solid, solid with forced motion and a free floating solid. The velocity of the fixed and the forced motion solids are imposed as Dirichlet boundary conditions. The motion of the free floating solid are calculated based on forces and moments obtained from the integration of the pressure on the solid surface, i.e., the pressure of the wall particles, , and interactions among solids, as explained in the next section. On the other hand, the center of gravity, the mass and the moment of inertia used for the motion calculation of each free floating solid are input parameters.

2.3 Collision among solids

The simplified numerical model for the collision between two rigid bodies is the same as adopted in the previous study [4]. The collision is detected when the distance between the wall particles of the solids is smaller than 1.225 l_o, where l_o is the initial distance between particles.

The solid normal repulsion force resulting from the collision is calculated by summing all the components of the force from each individual particle. The components of the normal repulsion force are calculated based on a damped harmonic oscillator with linear spring force and damping force proportional to the relative velocity between colliding particles [8]. Both the spring and damping constants were obtained through numerical tests and calibrated to achieve critical damped motion with minimal oscillation. On the other hand, the tangential friction force between the solids is also calculated as a summation of the contributions from the particles, which are proportional to the relative tangential velocity between the particles of the different solids. The calibration of the friction coefficient was carried out through a block sliding on a sloped surface.

In the present study, following [9], the interaction between the solid and the pipe wall is modeled by using a spring with constant of 350000 N/m and a damping constant of 145 Ns/m. A numerical friction coefficient of 0.22 Ns/m was also introduced to simulate the dynamic friction coefficient of 0.26.

2.4 Validation of the numerical method

The particle-based numerical model for nonlinear hydrodynamics has been extensively tested and validated in the previous works that show its ability of reproducing complex fluid solid interaction with transient surface flows and free floating bodies. The validation of the simplified numerical model for the collision between solids was carried out in [4], where good agreement with the experimental and numerical results of [10] for the motion of a free solid in dam-break flow is shown. Nevertheless, in order to improve the prediction of the contact forces, mainly the friction between the solids that is critical in long simulations, new contact models are being investigated by the authors.

3 Descriptions of the case

Figure 1 shows the configuration of the cases. They consist of a horizontal pipe, which represents a drain pipe of a 6 liters water closet, with 2.5 meters in length, diameter of 100 mm and slope of 0.0%. The pipe has a 90^o elbow in its upstream end, with annular inflow, and open downstream end [6]. Fig. 1 also shows the position of the sections S1 to S5, in which the wave height and the fluid velocity are monitored.

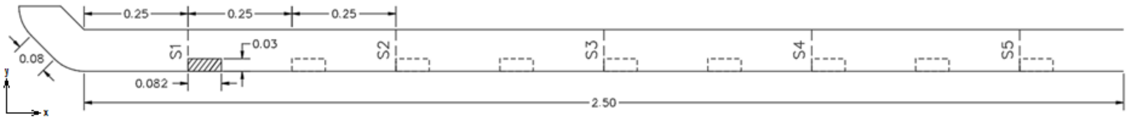


Figure 1 – Configuration of the horizontal drain pipe of a 6 liters water closet

There are total of 9 cases, each one with the solid initially placed with its upstream face 0.25 m, 0.50 m, 0.75 m, 1.00 m, 1.25 m, 1.50 m, 1.75 m, 2.00 m and 2.25 m from the upstream section of the horizontal pipe. Tab. 1 shows the denomination of the case. The initial position of the solid for case B025 is shown in Fig. 1 with hatched pattern. The initial positions of the solid in the other cases are shown in dashed lines. Following [4], the solid waste was modeled as a homogeneous circular cylinder. The cylindrical solid has 0.03 m in diameter and 0.082 m in length, and it is initially in rest inside the pipe with its axis parallel to the axis of the pipe. As the initial conditions for the simulation, the pipe is dry. The density of the fluid is 1000 kg/m^3. The mass of the cylindrical solid is 0.059 kg, homogeneously distributed with density equals to 1010 kg/m^3.

Table 1 Denomination of the cases and the initial position of the respective solid

Cases	B025	B050	B075	B100	B125	B150	B175	B200	B225
Initial position (cm)	25	50	75	100	125	150	175	200	225

Figure 2 shows the flow rate discharge as a function of time of the 6 liters water closet provided by Cheng *et al.* [4]. The hypothetical flow rate was also used by [4] and [6].

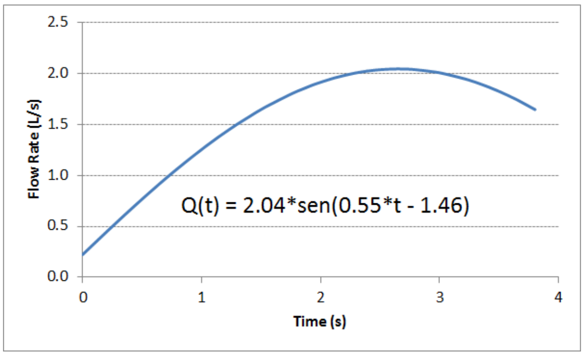


Figure 2 – Water closet flush profile [6]

For all the cases simulated, the initial distance between particles (l_0) is 0.002 m, which leads to models with about 850 K particles. The time step adopted was 5 x 10^{-5} s, which leads to processing time of about 3.5 days for 5 seconds of simulation.

4 Results and discussion

Figure 3 and 4 gives a sequence of images obtained from the computational simulations of the cases B025 and B075, respectively. In the figures, section views of the horizontal pipe are shown, and the color scale represents velocity magnitude.

Case B025

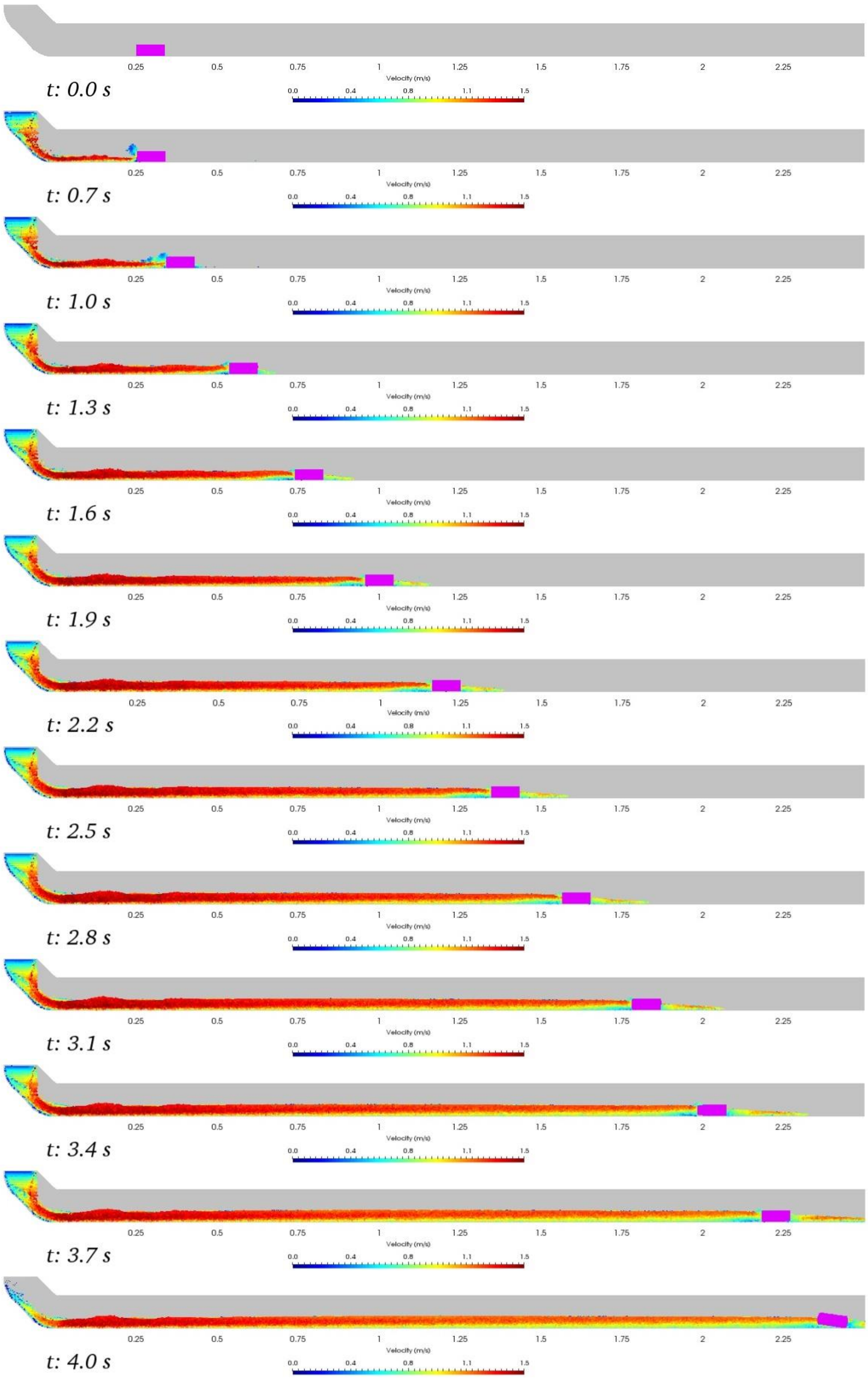


Figure 3 – Sequence of images obtained from the simulations of the case B025

Case B075

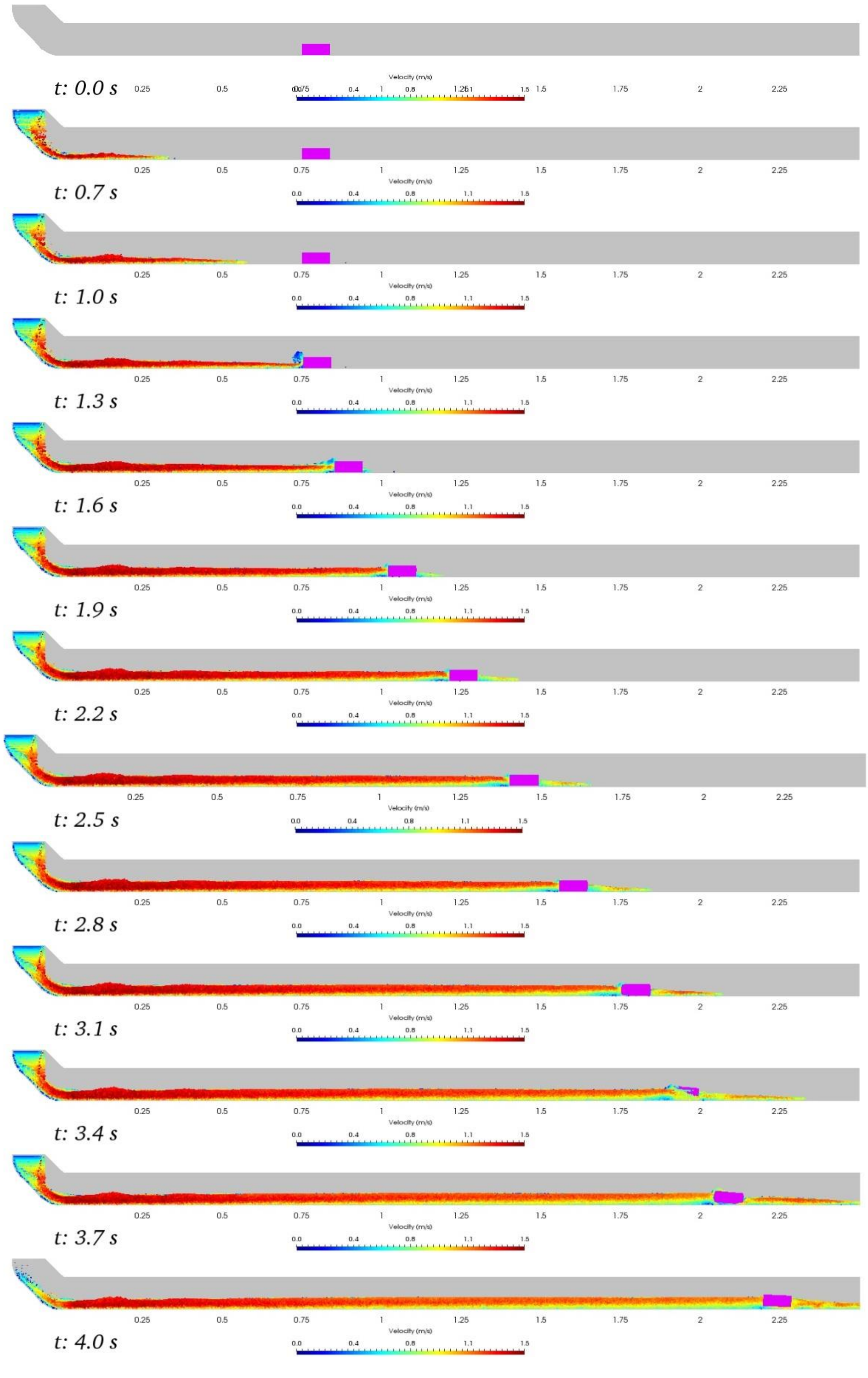
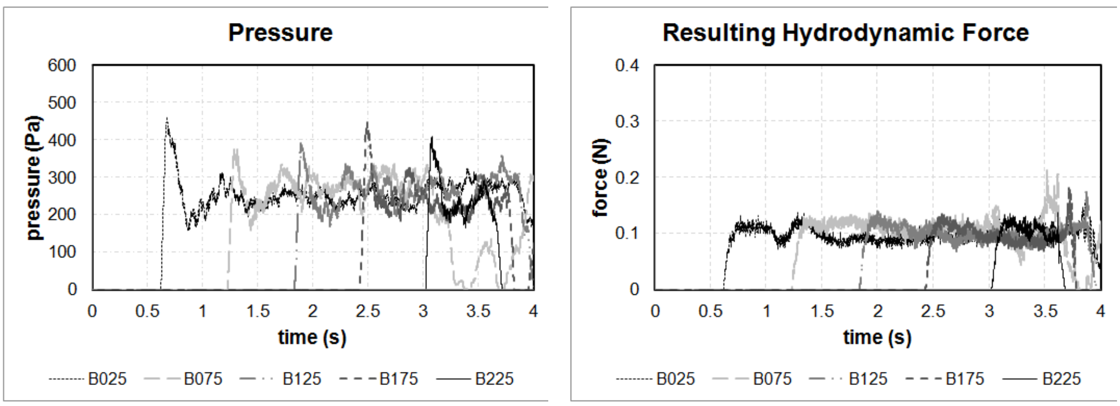


Figure 4 – Sequence of images obtained from the simulations of the case B075

From Fig. 3, the inflow from the elbow hits the solid located at 25 cm from the upstream section of the horizontal pipe at approximately *t*=0.7 s. An upward splash is generated followed by the formation of a wave, which is clear shown at *t*=1.0 s, on the upstream face of the solid. As the 6 liters discharge continues up to *t*=3.8 s, the solid displaces steadily pushed by the flow. Also, a hydraulic jump can be observed near 20 cm downstream the beginning of the horizontal pipe. Finally, it is interesting to point out that, in this case, floating and pitching of the solid occurs near *t*=4.0 s.

As an example showing what occurs in case of a solid located further downstream, Fig. 4 provides the sequence of images of the case B075. In this case, the flow hits the solid at approximately *t*=1.3 s. After that, considering the time lag, the wave and flow patterns of B075 in subsequent instants are quite similar to those of B025. However, it is clear that soon after the impact, the water level upstream the solid is higher than B025 and the flow continuously tends to overtop the solid. By *t*=3.1 s, floating and pitching of the solid occurs and the motion of the solid becomes relative unstable.

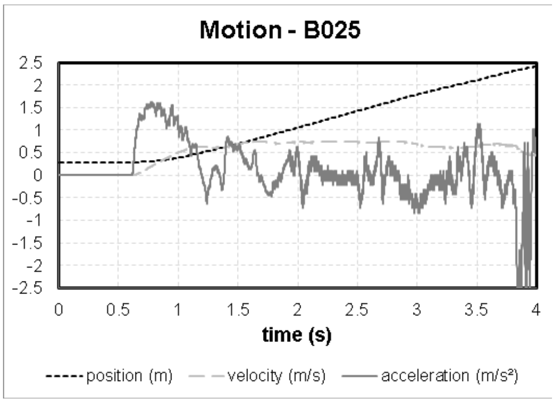
Figure 5 gives computed hydrodynamic pressure and force on the solid. To make easy the visualization, only the results of 5 cases are shown. Fig. 5 (a) provides pressure computed near the lowest point of the solid's longitudinal center plane of symmetry. As spurious oscillations of pressure were computed, the results were filtered applying moving average. As shown in Fig. 5 (a), the pressure patterns of the cases are quite similar, mainly close to the instant when the flow hits the solids, with a pressure spike followed by a relatively stable value despite the peak value of the pressure are slightly lower for B075, B125 and B225. For the case B075, near *t*=3.3 s, the pressure drops down due to the floating and pitching, as already shown in Fig. 4, and consequent emergency of the pressure gauge. The pressure drop due to the floating and pitching of the solid also can be observed in the other cases, but at different instants.
The time series of the computed hydrodynamic force given in Fig. 5 (b) show that in general the change of the initial position of the solid does not affect remarkably the hydrodynamic forces at least in the initial phase of the solid motion. In the present study, as the relatively short horizontal pipe is considered and the simulation stops near the discharge ends, the global effects including the change of the flow regimes could not be evaluated.



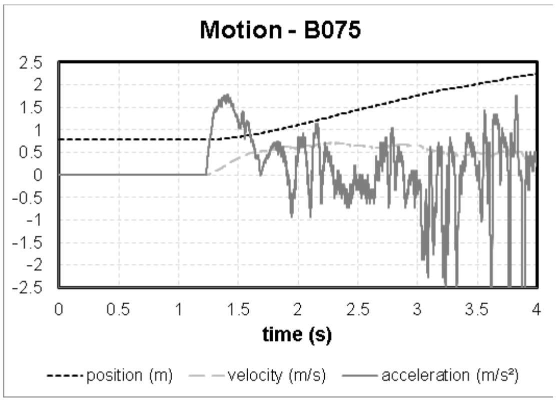
(a) (b)

Figure 5 – Computed time history of (a) pressure near the lowest point of the solid's upstream face and (b) time history of the resulting hydrodynamic pressure

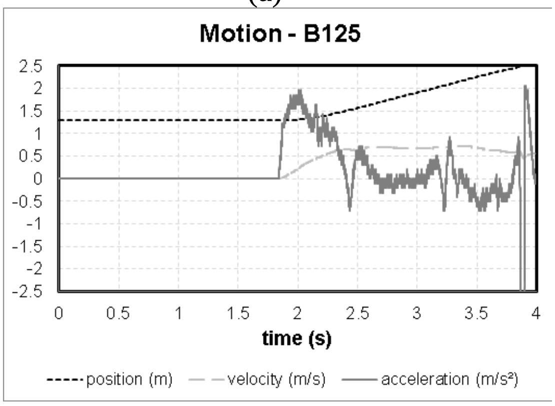
The time histories of the position, velocity and acceleration of the solids computed for the cases B025, B075, B125 and B 175 are shown in Fig. 6 (a), (b), (c) and (d), respectively. The comparisons among the time histories show that the velocity in case B025 is slightly higher than other cases. It might be attributed to slightly lower fluid energy loss due to smaller distance from the inflow boundary to the initial position of the solid and slightly larger momentum transfer to the solid. However, the graphs show that the patterns of position, velocity ad acceleration are similar for different initial position of the solids. The initial accelerations due hydrodynamic impact are very similar for the four cases, with slightly variation in the peak magnitude. The curves of the solid velocity show similar rise up patterns. After that, despite some oscillations in the acceleration, the solid velocity remains quite stable. Larger oscillations of acceleration are associated to the floating and pitching motion of the solid, and it is especially evident for B075. Finally, as the 6 liters flush ends by *t*=3.8 s, the duration until the velocity drops down varies and seems to be shorter as the solid is initially located at downstream.



(a)



(b)



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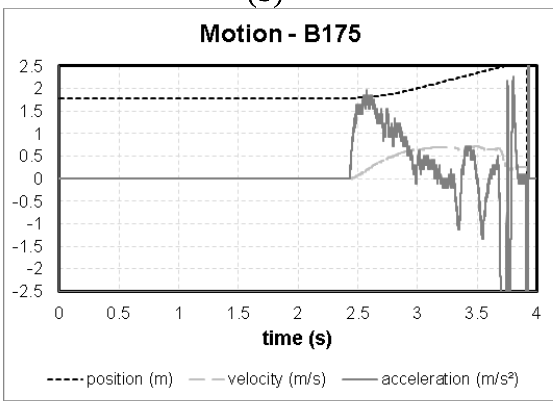
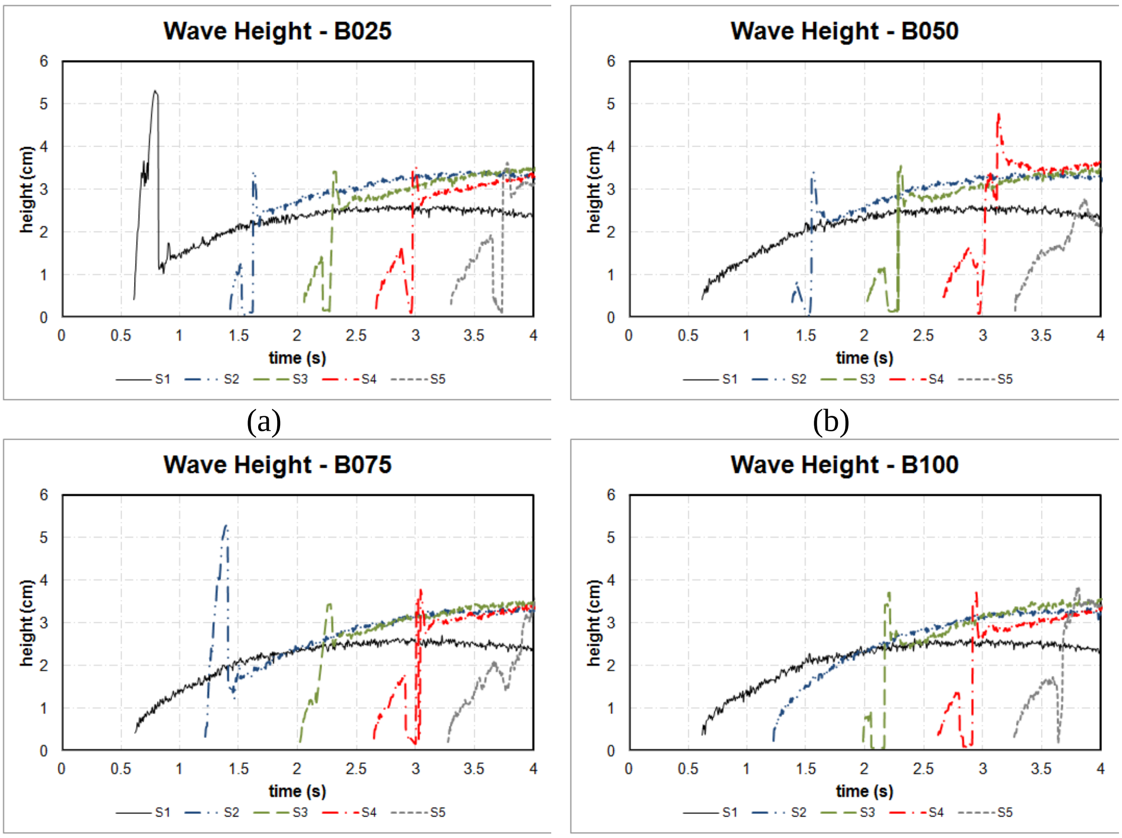


(d)

Figure 6 – Computed time history of the positions, velocity and acceleration of the cylindrical solid for the cases (a) B025, (b) B075, (c) B125 and (d) B175

Finally, in order to provide insights about the fluid flows that involves the transportation of solid, Fig. 7 and 8 show, respectively, the wave height (water level) and fluid velocities across the sections of the pipe. In Fig. 7, the wave heights (water levels) at the sections of the horizontal pipeline for four cases are shown: B025, B050, B075 and B100. In Fig. 7 (a), as the solid is initially located at S1, when the flush hits the solid, peak water level height associated to the splash produced by the fluid impact on the upstream face of the solid is recorded at S1 at *t*=0.7 s, approximately. After the peak due to the initial impact passes through S1, the water level at the sections increases again slowly and starts to reduce slowly due to the reduction of the incoming discharge flow rate. In the subsequent sections, for example, S2, the wave front reaches the section at about *t*=1.4 s. Initially, relatively shallow water downstream the solid reaches the section. Then, at nearly *t*=1.5 s, the water level at S2 drops suddenly to zero, and rises again shortly later. This abrupt change of water later is associated to the solid crossing the section. Following the passage of the solid, the higher water level upstream the solid is recorded at S2. In Fig. 7 (b), as section S1 is 25 cm upstream the initial position of the solid in case B050, the flow across S1 is almost undisturbed and does not present the initial peak wave height. However, the patterns of the time histories at the subsequent sections are quite similar to those shown in Fig. 7 (a), except at S5, where pitching motion of the solid occurs in this case. In Fig, 7 (c), as the initial position of the solid in B075 is at S2, the peak wave height pattern similar to that of S1 in Fig. 7 (a) is obtained. In addition to this, the shape of the curve associated to S5 also indicates that, in this case, the unstable motion of solid due to its floating and pitching motion occurs near this section. Finally, the comparison among the water levels in the sections show that the height increases remarkably from S2, and might surpass 0.3 m, which is the diameter (and height) of the solid. Mainly in S4, where the peak water height is much larger than 0.3 m, and might increase the probability of the unstable solid motion.

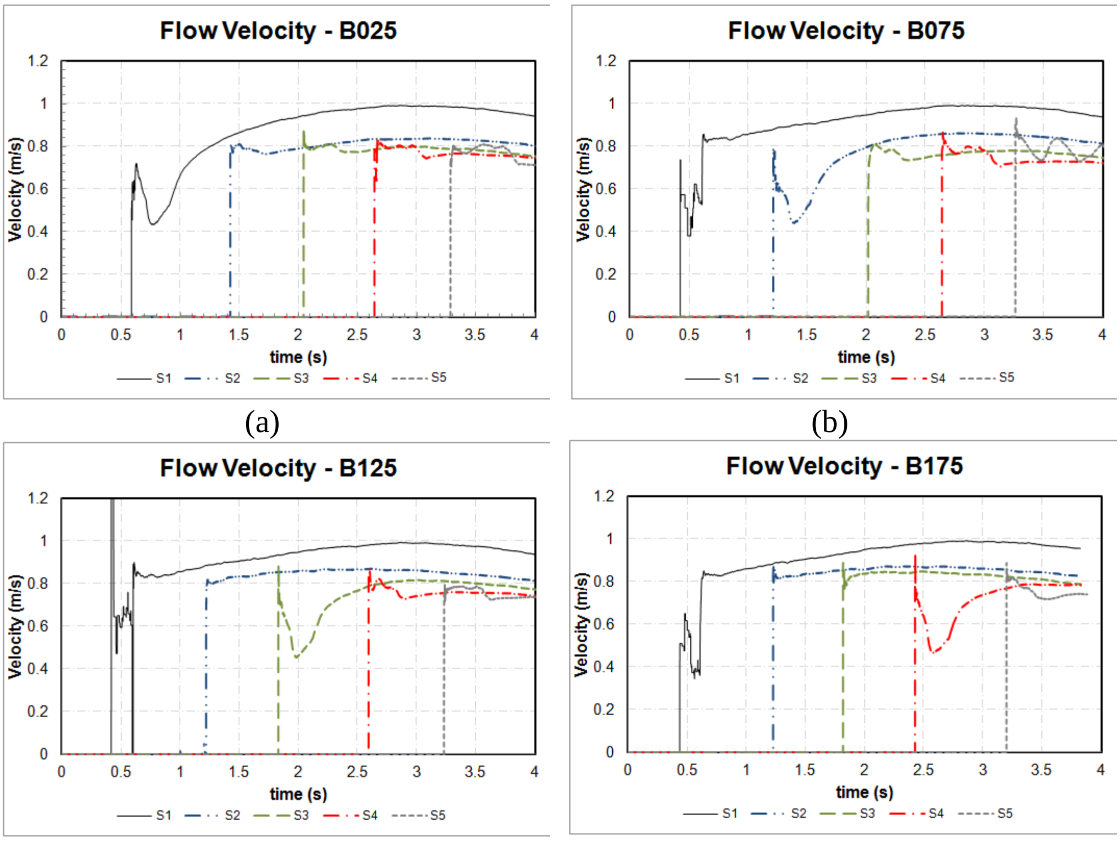


(a) (b) (c) (d)

Figure 7 – Computed time history of the wave heights (water levels) at the sections of the horizontal pipeline for the cases (a) B025, (b) B050, (c) B075 and (d) B100

Figure 8 shows the flow velocity across the sections for the cases B025, B075, B125 and B175, of which the upstream faces of the solid are initially located at S1, S2, S3 and S4, respectively. From the graphics, it is clear that when the wave front reaches the section where the upstream face of the solid is located, the solid is suddenly pushed by the hydrodynamic impact and then a sharp rise up of the flow velocity is recorded at the section. Soon after, a slightly drop down followed by smooth increase of flow velocity are computed. In the other sections, before the end of the flush, the time histories of the flow velocity are similar to those without the presence of the solid, with abrupt rise followed by almost constant values.

Another highlight of Fig. 8 is the decrease of the flow velocity along the sections of the pipeline is observed in all the cases. This is expected due to fluid kinetic energy loss and, at the same time, the slightly increase of the water level in subsequent sections that may increase the probability of the unstable solid motion associated to floating and pitching.



(a) (b) (c) (d)

Figure 8 – Computed time history of the flow velocity at the sections of the horizontal pipeline for the cases (a) B025, (b) B075, (c) B125 and (d) B175

5 Concluding remarks

In the present work, focusing on the hydrodynamic impact loads and the behaviors of the solid waste due to the variation of its initial location, particle-based numerical simulations were carried considering a cylindrical solid transported by transient flow of a hypothetical 6 liters flush inside drain with 90^o elbows.

The computed results show that the patterns of the initial hydrodynamic impact phase are almost similar, disregard the initial position of the solid taken into account in the present study. The variation of the hydrodynamic pressures and forces on the solid are almost negligible. However, the duration for the momentum transfer from the fluid to the solid seems to reduce as the solid is initially placed downstream and further studies using longer pipes and longer simulations are required to assess the effective displacement of the solids regarding its initial position. On the other hand, the computed time series of the water level show that it increases remarkably from S2, and might surpass 0.3 m, which is the height of the solid. Mainly in S4, where the peak water height is much larger than 0.3 m for the case B050, the solid is more susceptible to the unstable motion. Finally, the decrease of the flow velocity and, at the same time, the slightly increase of the water level along the sections of the pipeline, is observed in all the cases, as it should be expected due to fluid kinetic energy loss.

The modeling and simulation of the FSI problem, despite the simplifications assumed, represent a step toward the understanding of the flows inside building drainage systems by providing effective means to investigate basic issues of the complex hydrodynamics.

Acknowledgments

The author would like to express their gratitude to Petrobras S.A. for financial support on the development of MPS/TPN/USP simulation system, PRP/USP and FDTE for the undergraduate research scholarships, and CAPES for the doctor degree scholarship.

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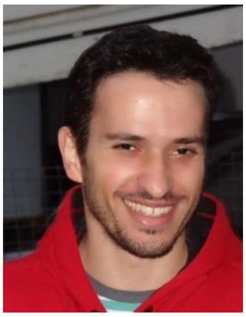
Presentation of Authors

Liang-Yee Cheng is an assistant professor at Department of Construction Engineering of Escola Politécnica of University of São Paulo where he teaches and conducts researches on fuzzy analysis applied to designs, CFD simulations and graphical geometry for engineering.

Lúcia Helena is an associate professor at the Department of Construction Engineering of Escola Politécnica of University of São Paulo, where she teaches and conducts researches work on building services.

Pedro Henrique Saggioratto Osello is an undergraduate student of Civil Engineering of Escola Politécnica of University of São Paulo with scholarship granted by FDTE for the undergraduating research on numerical simulation of flows in building drainage systems.

Rubens Augusto Amaro Junior is a doctor degree student in the Graduating Program in Civil Engineering, Escola Politécnica of University of São Paulo, where he is the performing researches on particle-based numerical simulations.



D15 - A transformative change to UK flood management: Domestic garden adaptation and retrofit

D.A. Kelly
d.a.kelly@hw.ac.uk
The Water Academy, Heriot-Watt University, Edinburgh, Scotland, UK.

Abstract

In recent years, government policy within the UK has emphasised the need for sustainable solutions to flood management, whereby the focus is to maintain and restore natural processes within the urban landscape to reduce flood risk. Yet, there is one land type which, despite forming a major component of the urban land mass, currently remains untapped in terms of urban flood risk management. Domestic gardens cover up to 36% of the total urban area, and constitute up to 63% of urban green space. The natural vegetation and permeable soil surfaces in domestic gardens help to intercept, store, and infiltrate rainwater where it falls and so provides a valuable asset in terms of surface water management. However, this asset is slowly being eroded due to growing urban densification and the desire for off-street parking and low-maintenance gardens.

Whilst domestic gardens are currently outside the immediate control of local government, they present a potentially valuable tool for helping control surface water within the urban environment. This paper proposes a transformative change to current flood management in the UK, based on the adaptation and retrofit of domestic gardens for localised surface water control. Sustainable drainage systems incorporated at the individual houseplot, could help to improve urban resilience to flood risk, particularly within the context of issues such as climate change and urban densification.

Keywords

Domestic gardens, climate change, flood risk, adaptation, retrofit, SuDS, towns & cities.

1 Introduction

Flooding is the most significant threat facing the UK from the effects of climate change (Defra, 2012). The projected increase in the frequency and magnitude of extreme rainfall are expected to pose major future challenges in terms of surface water management and urban resilience. Throughout the country, around 6 million properties (approximately one in six) are currently at risk of flooding. On average, flooding causes £1.4bn in damage per year in the UK, however, the cost of extreme events can be considerably higher (the 2007 floods cost more than £3bn) and the cost of future flood damage is expected to be even greater (up to £4.5bn per year by the 2050s, rising to £6.2bn by the 2080s).

In recognition of the challenges facing the country, government policy has begun to emphasise the need for sustainable solutions to flood management. The *Flood and Water Management Act 2010* promotes the use of natural processes to minimise flood risk, whilst the *Flood Risk Management (Scotland) Act 2009* encourages the use of space in urban landscapes to store and slow rainfall. The approach now is to control runoff at source using natural flood management and green infrastructure which promotes multifunctionality of land use and delivers a wide range of benefits for biodiversity, amenity, health and wellbeing, water quality, and of course, flood risk (CIWEM, 2010). This new approach is becoming more widely adopted worldwide and is known as sustainable drainage systems (SuDS) in the UK, water sensitive urban design (WSUD) in Australia, and stormwater best management practices (BMPs) and low impact development (LID) in the USA (Fletcher, 2015).

Whilst SuDS are now mandatory for most new developments in the UK, their widespread implementation and success are hindered by a number of barriers largely associated with a lack of governance addressing their effective adoption and long-term maintenance (Hoang and Fenner, 2015). Fragmented responsibilities and relational complexities between the agencies and authorities involved mean that SuDS solutions within the urban environment are currently having limited impact.

This paper proposes a transformative change to flood management in the UK by presenting a vision based on the adaptation and retrofit of domestic gardens for stormwater control. The extent and coverage of domestic gardens within towns and cities make them ideally suited to help minimise flood risk by providing distributed spaces within the urban landscape that could be used to slow and store rainfall through appropriately designed houseplot-SuDS solutions. Such an approach would help to build resilience into urban stormwater management systems whilst providing a potentially effective way of avoiding the governance issues currently hindering SuDS at the urban scale.

2 The UK domestic garden: then and now

In the rapidly expanding cities of the industrial revolution, gardens were a luxury with many of the terraced housing and tenements that were built at the time having no front garden, and only having backyards if they were fortunate. The garden city movement in the early 1900s (Howard, 1902) and the start of the new town movement in the 1940s following World War II, were a direct response to the overcrowding and lack of green space within the industrial cities. Gardens became a strong component of the planning layout, with each house having its own front and back garden (Jacob and Vanstiphout, 2014). The quintessential British garden became characterised by neatly trimmed hedges, manicured lawns, and beautiful rose-beds, see Figure 1. Over the course of the twentieth century, garden culture evolved with the renewed interest in growing vegetables and using the garden as a place for recreation (Murphy, 2007).

Figure 1: Immaculately kept gardens at the Becontree Estate, built 1921-1935, where tenants were obliged to keep the gardens neat and cultivated, and annual prizes were awarded to the best-kept garden (source: Low and Heyden, 2015)

Domestic gardens now make up a significant proportion of the urban land mass, contributing between 22-36% of the total urban area (Gaston *et al.*, 2005; Mathieu *et al.*, 2007) and between 35-63% of urban green space (Loram *et al.*, 2007; Greenspace Scotland, 2012). However, over the past decade or so, many domestic gardens within the UK have fallen victim to the growing demand by householders for off-street parking or low-maintenance gardens whereby planting and vegetation are replaced with hard impermeable surfacing. Front gardens are particularly affected, see Figure 2.

Figure 2: Domestic front gardens after vegetation has been replaced with hard impermable surfacing to create off-street parking (Street View ©2015 Google)

A study of land coverage in the city of Leeds, found the area of paving in domestic front gardens had increased by 138% between 1971-2004 (Perry and Nawaz, 2008). Similarly, in London the area of impermeable cover in front gardens had increased by 26% between 1998-2008 (Smith *et al.*, 2011). In Southampton, impermeable cover was found to have increased by almost 23% between 1991-2011 (Warhurst *et al.*, 2014). The Royal Horticultural Society (RHS) suggests 1 in 4 UK front gardens are now completely paved and nearly 1 in 3 has no vegetation (RHS, 2015).

The increase of impermeable cover in domestic gardens, and the subsequent decline of vegetation impacts rainwater runoff volumes, peak flows, and water quality and is linked to increased incidences of flooding (Lee and Heaney, 2003; Kelly 2016). The UK's

Committee on Climate Change prioritises limiting the paving of front gardens as a key surface water management strategy for minimising the country's vulnerability to flooding [CCC, 2015). The loss of vegetation from domestic gardens also reduces their multiple other benefits, including ecosystem services and stimulation of social interactions (RHS, 2006).

3 The houseplot-SuDS concept

In the UK, SuDS consist of a range of techniques and technologies used to manage stormwater by replicating natural hydrological processes in order to reduce the quantity and pollution of runoff from a site and help manage downstream flood risk (Woods-Ballard *et al.,* 2015). SuDS are, therefore, designed to harvest, infiltrate, slow, store, convey, and treat stormwater on the surface rather than underground through a combination of components – landscaped features, planting and vegetation, and manufactured products. The SuDS approach provides the opportunity to provide multiple benefits to communities in terms of water quantity, water quality, amenity, and biodiversity, particularly when designed to deliver and enhance vegetation and greenspace. The use of SuDS, designed to Scottish Water standards, have been mandatory for most new developments in Scotland since 2003 (WEWS, 2003), whilst in England and Wales SuDS are only required for developments of ten homes or more.

However, new developments form only a very small part of the current urban environment meaning that for towns and cities to build resilience in order to cope with climate and other changes in the urban environment, the retrofitting of SuDS will provide a flexible and cost-effective way of increasing stormwater drainage capacity. While advances in retrofitting SuDS have been modest in the UK, achievements in other countries, such as the USA, are significantly ahead (NRDC, 2011).

The adaptation and retrofit of houseplot-SuDS concept provides an opportunity for a transformative change in how stormwater management is tackled in the UK. Whilst the intended function of domestic gardens is for social infrastructure, they could also be used to help contribute to localised flood management (as well as providing other multiple benefits such as enhancing urban biodiversity, aesthetics, and temperature regulation). The houseplot-SuDS concept would help to establish a sense of social responsibility towards stormwater management amongst householders and within communities; moving away from the usual belief that flood risk should always be managed by local authorities, water authorities, and government. It would also provide an effective way of avoiding governance issues surrounding the adoption and maintenance of large-scale SuDS instillations. Table 1 provides an assessment of selected SuDS techniques potentially appropriate for houseplot adaptation and retrofit. A clear distinction in the range of benefits provided by each SuDS technique can be seen between those that are based around, or incorporate, vegetation and those that are not. Maximum benefits are attributed to "green" SuDS solutions.

Table 1: Evaluation of SuDS components for potential houseplot application. Diameter of ball identifies degree of positive impact.

SuDS technique	Water quantity			Water quality		Amenity						Biodiversity			
	Delay runoff	Reduce runoff volume	Reduce peak flow	Increase infiltration	Increase groundwater	Improve air quality	Reduce urban heat island	Reduce atmospheric carbon	Improve recreation	Improve aesthetics	Improve health & wellbeing	Support habitat & wildlife	Improve ecosystem	Applicability to houseplot-SuDS	Maintenance
Tree planting	●	●	●	●	•	●	●	●	●	●	●	●	●	●	•
Detention basins/ponds	●	●	●	●	•	●	●	●	●	●	●	●	●	●	●
Bioretention/ rain gardens	●	●	●	●	•	●	●	●	●	●	•	●	●	●	•
Grass swales/ filter strips	●	●	●	●	●	●	●	●	•	•	•	●	●	•	•
Green roofs	●	●	●	·	·	●	●	●	·	•	•	●	●	•	•
Downpipe disconnection	●	●	●	●	●	·	·	·	·	·	·	·	·	●	●
Permeable pavements	●	●	●	●	•	·	•	·	·	·	·	·	·	●	●
Enhanced topsoil	●	●	●	●	●	·	·	·	·	·	·	·	·	●	•
Rainwater harvesting	●	●	●	·	·	·	·	·	·	·	·	·	·	●	•

3.1 Growing evidence

The cumulative effect of adapting individual gardens has the potential to significantly reduce runoff from a much wider area, helping reduce flood risk and improve water quality. However, whilst knowledge and policy in this area is sparse, particularly in the UK, there is a international evidence-base of particular SuDS techniques which are, or have potential to be, used as components of houseplot rainwater drainage systems incorporating SuDS.

Successful houseplot-SuDS should be able to achieve improved stormwater management whilst also delivering an enhanced garden space for recreation, biodiversity, and streetscape aesthetics. To retain the character and form of a domestic garden, successful houseplot-SuDS should be based on techniques that incorporate, where possible, enhanced planting and vegetation that will allow the rainwater to be dealt with naturally. Where greater management of stormwater is needed, or sufficient vegetation is not possible, light-engineering solutions such as landscape features and manufactured products can provide benefit.

3.1.1 Enhanced vegetation

In comparison with impermeable surfaces, planting and vegetation helps sustain natural hydrological processes by intercepting rain and increasing soil infiltration. Whilst reducing surface runoff, planting and vegetation also delivers a wide range of benefits for biodiversity, amenity, and health and wellbeing. Whilst there is a lack of studies into the benefits of planting and vegetation for stormwater management specifically in domestic gardens, studies of other landforms have found significant relationships between rainwater runoff and vegetation cover.

Studies on agricultural land have found that relatively moderate rainfall events (<40 mm depth) can be totally infiltrated into vegetated soil due to the effects of stemflow and reduced soil compaction, yet a reduction in vegetation cover can result in decreased soil infiltration and excessive runoff and erosion (Greene and Ringrose-Voase, 1993). Tree canopies have been found to intercept as much as 45% of annual rainfall (Mansell, 2003), with average interception being a function of tree size and leaf surface area (McPherson *et al.,* 2006). Additionally, soil infiltration rates have been found to increase by a factor of 100 within 6 years of tree planting due to root development and reduced soil compaction (Bird *et al.,* 2003).

3.1.2 Light-engineering solutions

Domestic garden adaptation for stormwater management is gaining growing attention around the world. In the USA, for example, evaluation studies have been conducted to assess garden-level solutions for tackling urban stormwater challenges by incorporating engineered landscape features similar to those used on large-scale developments. A study carried out in 2006 in the City of Burnsville, Minnesota, evaluated the effectiveness of constructing 17 new rain gardens within existing domestic gardens. Each rain garden was designed to accept the first 23mm of rainwater runoff from adjacent streets and impervious surfaces. When compared to a control catchment, the rain garden catchment was found to generate up to 92% less runoff (Barr Engineering, 2006). In 2007, the city of Milwaukee evaluated the ability of selected garden adaption measures to reduce combined sewer overflows (CSOs) in a typical 6-acre residential area. The study found that, CSO volume and peak flow could be reduced by up to 38% and 36%, respectively, through employing practices such as porous pavements, rain barrels, rain gardens, trees, enhanced compost, and downspout disconnections. A pilot project where 38 downspout disconnections, 38 rain gardens, and four cisterns were installed is estimated to divert 552,000 gallons each year from the sewer system to infiltrate naturally (NRDC, 2010). A 2013 study of residential catchments in Toronto evaluated the hydrological benefits of the widespread application of two "lot level" stormwater management approaches: (i) increasing topsoil depth to enhance permeability, and (ii) installing infiltration trenches to receive additional runoff. In comparison with a control catchment, the gardens with increased topsoil depth were observed to consistently generate lower mean runoff coefficients, exhibiting a considerable 20-60% reduction in overall runoff during some of the most intense storm events, with a corresponding reduction in peak flow. The catchment with infiltration trenches installed in each garden produced around 14% less runoff than the control catchment during large storm events (Young et *al.*, 2013). Whilst still to gain attention in the UK, these studies indicate the potential impact that domestic garden adaptation could have on urban stormwater management in helping to capture and store increased volumes of rainwater.

4 Conclusion

The need for a new and transformative approach in managing stormwater will be vital for the avoidance of surface water flooding within the urban environment, particularly due to the expected impacts of climate change on precipitation. Vegetated domestic gardens provide source control functions by intercepting, infiltrating, and slowing rainfall. Their extent within the urban environment make them ideally suited to providing distributed and localised contribution towards stormwater control.

The development and incorporation of houseplot-SuDS provide an opportunity to enhance the impact that domestic gardens can have on urban flood risk. A number of established SuDS techniques have the potential to be applied to the scale of the domestic garden whilst providing addition multiple benefits for householders and communities. The houseplot-SuDS with the greatest potential to provide multiple benefits, whilst retaining the character of the domestic garden, are those that incorporate vegetation and planting.

The adaptation and retrofit of houseplot-SuDS in domestic gardens could offer significant and sustainable solutions to reducing urban flood vulnerability.

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6 Presentation of author

Dr David Kelly is Assistant Professor of Architectural Engineering at Heriot-Watt University. His research interests include the monitoring and prevention of cross-contamination from building drainage systems, the impact assessment of climate change on rainwater systems, the use of green infrastructure and sustainable drainage systems (SuDS) for stormwater management, and the promotion and analysis of water efficiency measures within buildings.

Paper 62 - System solutions in the fight against infection caused by bacteria *Legionella*

Z. Vranayova (1), D. Kaposztasova (2),
1. zuzana.vranayova@tuke.sk
2. daniela.ocipova@tuke.sk
1. Faculty of Civil Engineering, Technical University of Kosice, SK
2. Faculty of Civil Engineering, Technical University of Kosice, SK

Abstract

As we know, the main cause of outbreaks of Legionnaires' disease is from contaminated water sources. About 3 in 10 cases of Legionnaires' disease are due to poorly maintained water storage and air conditioning systems in buildings. The primary aim of this paper is to present our research focused on theoretical and experimental analysis of potable water and building water distribution systems from the point of view of microbiological risk on the basis of confrontation between the theoretical analysis and synthesis of gathered information in conditions of the Slovak Republic. We have no regulations on how to maintain water supplies systems used in large buildings as in other countries. This mainly involves keeping the water temperature at less than 20°C or more than 60°C. The water supply should also be kept clean and kept moving so that it doesn't stagnate. All of this reduces the chance of legionella germs (bacteria) breeding. However, it is very difficult to destroy (eradicate) this bacterium completely. The goal of this paper is to show the necessity of prevention and regulations for installations inside buildings by exploring the system solutions in two phases. To assess the potential public health impact of *Legionella* colonization in potable water and in building distribution a study was undertaken to identify and qualify the levels of the microorganism in hospitals.

Keywords

hot water; Legionella pneumophilla; water distribution systems; thermal disinfection; temperature; water samples

1 Introduction

Microbiological contamination of water and air and health risks caused by germs that colonize technical systems causes various problems and illnesses. Among these conditions is Legionnaires' disease - *Legionellosis*. Caused by ubiquitous water bacteria *Legionella pneumophila*, having a diameter of 0.2 to 0.7 microns which is dangerous in the form of contaminated aerosol, which may be formed, for example during showering

by inhalation. *Legionella* bacteria are widespread in natural water systems, e.g. rivers and ponds. However, the conditions are rarely right for people to catch the disease from these sources. Outbreaks of the illness occur from exposure to *Legionella* growing in purpose-built systems where water is maintained at a temperature high enough to encourage growth, e.g. cooling towers, evaporative condensers, hot and cold water systems and spa pools used in all sorts of premises (work and domestic) [1].
Are we taking Legionnaires' disease seriously enough? The summer 2015 outbreak in New York City that killed 12 people and sickened over 100 more underscores the danger to your building occupants if Legionella risk isn't managed carefully. Because *Legionella* is a building water problem, health officials agree that managing building water systems properly is the key to prevention [2]. The presence of the bacteria Legionella in water systems, especially in hot water distribution system, represents in terms of health protection of inhabitants the crucial problem which cannot be overlooked. *Legionella* pneumophila discovery, its classification and its influence on installations inside buildings are relatively new [3].

2 Legislation

Our previous measurements showed that *Legionella* is present in the distribution of water [3] and air in Slovakia. For the water supplier and the operator of the building is an obligation in the water system to ensure the prescribed quality and temperature at each sampling site, as well as providing air ducts from a hygiene point of view. Health flawless drinking water is provided for in the Act of NR SR 355/2007 Z.z. on protection, support and development of public health and on amendments to certain laws, which is valid from August 2007 [4]. Health risk is evaluated according to the quality indicators and hygienic limits. The quality of supplied drinking water to the public water supply and sanitation are responsible in our water companies. The quality of water supplied to consumers is monitored by regional public health within the meaning of Slovak Government Regulation no. 354/2006 Coll. [5]. Sample sites should be selected in areas or buildings where water flows from outlets that are normally used for human consumption. For domestic hot water use standard STN 83 0616 Hot water quality [6] is valid for that bacteriological and biological indicators. Hot water quality must meet the criteria for drinking water. Designers should respect the STN EN 806-2 Internal water supply for drinking water, Part 2 - Design [6] and as well as technical management TC 164 WI 164353 - Recommendations for prevention of Legionella growth for installations inside buildings conveying water for human consumption which specifies a standard in view of the presence of Legionella pneumophila [7]. These fundamental rules are valid in all member states of the European Union.
In the Czech Republic they apply the decree of the Ministry of Health. 252/2004 Coll. showing the desired parameters of the hot water, which should be supplied to the distribution points of over 50 ° C, preferably above 55 ° C.
United Kingdom adopted as a national standard method for assessing the impact of materials in contact with drinking water test MDOD (The Mean Dissolved Oxygen Difference) and is governed by regulations BS 6920. Safety quality and suitability of procedures accepted for safeguarding of system performance according EN 1717 should be regularly controlled. Conditions of installations operation have to be compared with conditions of design and assembly in order to insure their functionality [8].

Potable water is safeguarded by the basic formula:
- Cold water must remain cold
- Hot water must remain hot
- Water must not stagnate in water pipes longer than it is necessary.

Among the possibilities for water protection against *legionella* we include for example: the ensuring sanitary water with chlorine dioxide, ozone, UV radiation, thermal disinfection, physical methods such as the use of filters and much more.
It is necessary to examine other possible methods to eliminate bacteria in addition to freight thermal disinfection, also is in the world a general need to define both efficient and safe technical measures in domestic hot water systems and air conditioning.

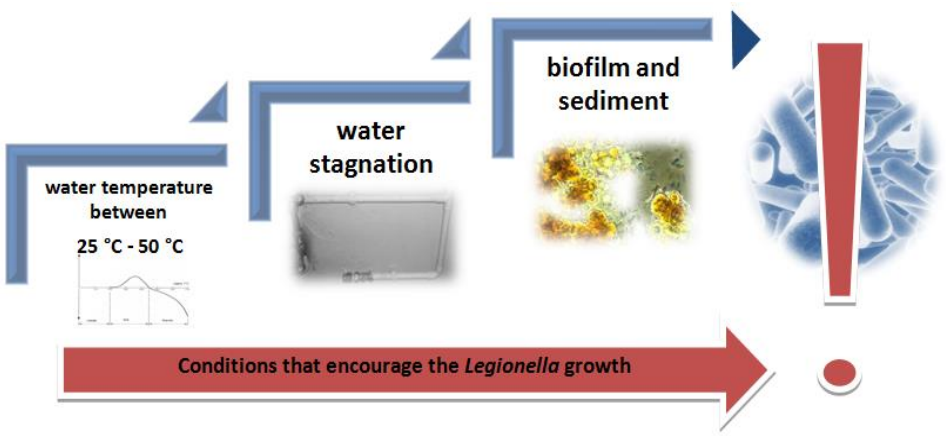

Fig. 1. Conditions that encourage the Legionella growth

3 Aims and Methods

The main aim is to show the necessity of prevention and regulations for installations inside buildings by exploring the system solutions in 2 phases.
First phase included the simulation of temperature and risk management proposal for boiler house and phase 2 started in 2015 with fist sample collection to complete the specific aim 1.

We addressed 3 specific aims:
1. to estimate the frequency of *Legionella* colonization and severity of contamination at different levels (first phase - boiler houses, second phase - hospitals)
2. to define relative role of each risk factor (temperature, material base, etc.) and suggest possible remediation
3. to identify potential the risk factors for contamination relative to distribution systems and water characteristics (Critical control points, proposal of so called *Water audit scheme*).

Lastly, risk for *legionellosis* will retrospectively evaluated by collecting information about pneumonia symptoms recorded by residents at buildings and hospitals.

2.1 Boiler houses survey

Our last investigation in past years was aimed at **phase 1**. *Legionella* contamination was represented by collection of 46 water samples from private homes, hospitals and boiler houses of Kosice, representative city of Eastern Slovakia. Selection was made on the basis of the water distribution systems inside the town and buildings and heater types in each area. After we identified each building, we asked a random family, or work collective to participate in the study, i.e. to complete our questionnaire and give informed consensus for water collection.
Laboratory examinations and Legionella analysis were made by Regional health office – referential centre for potable water in Kosice according to STN ISO 11731 - part 2 [9]. Water and aerosols samples survey to *Legionella* presence according their outcomes is connected with saprophytic and thermotolerant amebas presence monitoring.
In waters for human consumption (potable water cold - PWC) volume of *Legionellas* were detected, from sporadic colonies 20 CFU/200ml up to massive colonizationist in the quantity 6700 CFU/200ml of a sample. Legionellas presence was detected in 8 samples of drinking water samples analysis. In waters for human consumption (potable water hot - PWH) volume of legionellas were detected, from sporadic colonies 200 CFU/100ml up to massive colonizationist in the quantity 14600 CFU/100ml of a sample. Legionellas presence was detected in 8 samples of PWH samples analysis, i.e. in 17,4 %.
The thermal disinfection was proposed as the immediate reaction to this situation. The subject matter is periodic rising of temperature per specific time in the whole hot water network including outlet points with a certain time of flushing these points at increased temperature over 71 °C. Important is the temperature level and time of flushing the outlet points. We repeated sampling after thermal disinfection in contaminated places. After 12 days the level of *Legionella* colonies was almost the same as before this measure. The measures have proved that the thermal disinfection is not a suitable system treatment. New strategies are tend to permanent disinfection due to the fact that spasmodic disinfection is not enough reliable to ensure the required standard and of course it is not possible to apply temperatures above 71 °C in old pipes and systems without their damage. From the energetic point of view the thermal disinfection is very expensive and reliable only if it is done periodically. Much worse results were obtained at similar survey in Italy or Germany [10]. In this case 36 - 68 % of samples were positive. In case that thermal disinfection in contaminated places was not done, the concentration of bacterias will have exponential character – will continually increase. By collecting the samples we verify that thermal disinfection is not systemic solution and it is needed to find a new complex solution.
We explored deeply also the impact of temperature change by simulating the temperature and water velocity in software Fluent 6.3 (Fig.2) [11] and the virtual water tank was proposed as the tool for managers to avoid the growth of *Legionella* in water tanks [12].

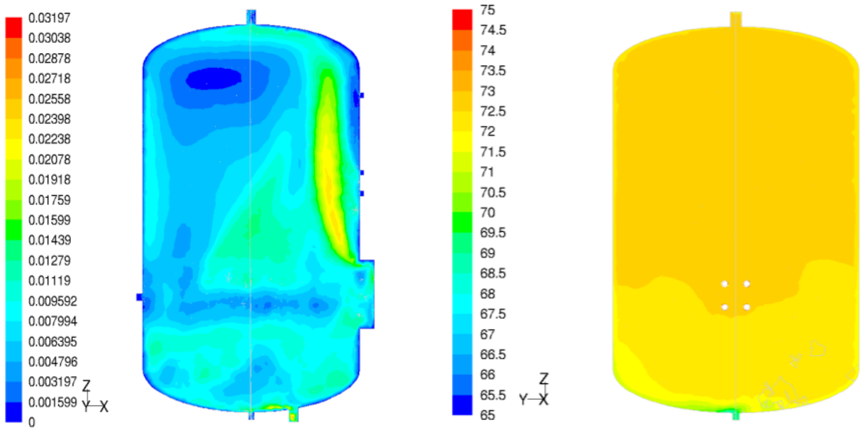

Fig. 2. Example of experimental hot water tank - water velocity – temperature layering

2.2 Risk analysis

Risk analysis was chosen as one of the methodological procedures in **phase 1** to identify possible contamination threats by Legionella pneumophila in water distribution systems. It is an analysis of problems based on the latest scientific and technical knowledge to make basis and inferences for effective decisions. The goal was to estimate necessary precautionary measures since specific risk assessment is essential for their successful implementation. Risk analysis evaluated specific conditions on the ground of information about current contamination that comprises the assessment of possible ways of proliferation, exposure risk, and the target group risk in each situation. Risk analysis involves risk assessment and risk management. Building owners, landlords and managers are responsible for assessing sources of risk in water distribution systems. Risk analysis included four parts: system assessment -identification of risk sources and groups, risk assessment, risk management, conclusions of risk analysis. As a part of the risk assessment, it is significant to determine level of risk from the exposure to Legionella bacteria. It is a tool for choosing the proper preventive measures in order to reduce the risk to acceptable level [11]. As a result of risk management is a document that ensures safe and correct operation of hot water at the end of distribution systems for users. The interesting and very important part in risk assessment was identification of critical control points of the system. Conclusions of risk analysis involve summary of risk assessment together with risk management as well as a scheme of precautionary measures to reduce risk (Fig. 3) [13].

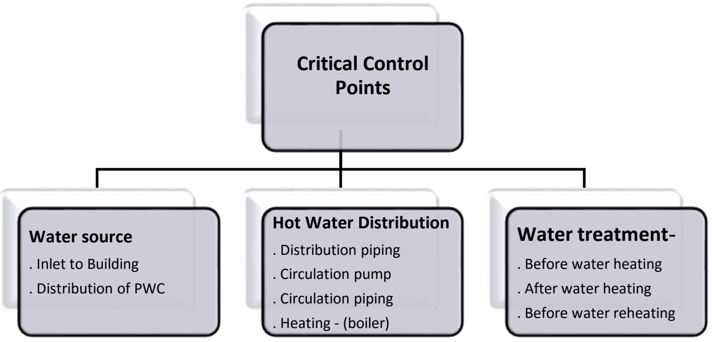

Fig. 3. Critical points of the system [11]

2.3 HOSPITALS SURVEY

In 2015 we started with **phases 2** - water sampling in hospitals. The main goal is to find out the *Legionella* contamination level in selected health facilities. The selection was directly targeted at risky departments in hospitals (geriatrics, gynecology clinic, clinic of pneumoniae etc.) where the factors that encourage bacteria growth can occur and be dangerous for patients with weakened immunity.
The totals of 20 water samples of potable water hot - PWH were collected in 4 health facilities (5 water samples per clinic) as described in the table 1.

Table 1. Sample collection

	Water samples	**18.9.2015**	**source**
Hospital 1	1	Department of long-term illness	shower- for immobile patient
	2	Department of Internal Medicine	shower
	3	Department of Gynecology	shower
	4	Department of Gynecology	shower
	5	Centre for Burn Injuries	shower
	Water samples	**14.10.2015**	**source**
Hospital 2	1	Department of Gynecology	shower
	2	Department of Neurology	shared shower
	3	Clinic of Infectious Diseases	shower
	4	Clinic of Pneumonia	shower
	5	Department of Internal Medicine	shower
	Water samples	**2.10.2015**	**source**
Hospital 3	1	Department of Gynecology	shower
	2	Department of Hematology	shower
	3	Department of Balneology etc.	shared shower
	4	Department of Psychiatry	shower
	5	Department of Internal Medicine	shared shower
	Water samples	**24.11.2015**	**source**
Hospital 4	1	Geriatrics and Gerontology	shower
	2	Geriatrics and Gerontology	shower- for immobile patient
	3	Department of Long-term illness	shared shower
	4	Department of Long-term illness	shower
	5	Institute of Preventive Medicine	shower - after ergometry

All 20 samples were tested according to STN ISO 11731 - part 2 [9] for Legionella presence. Hospital 1, 2, 4 were in all cases negative. In hospital 3 all 5 samples were positive. Results are presented in table 2.

Table 2. Positive findings

Positives samples				*Legionella species*	
Hospital 3	**Water samples**	**2.10.2015**	**source**	**CFU/100ml**	**Serotype**
	1	Department of Gynecology	shower	3400	3
	2	Department of Hematology	shower	1200	1
	3	Department of Balneology etc.	shared shower	1600	3
	4	Department of Psychiatry	shower	4600	3
	5	Department of Internal Medicine	shared shower	2800	3

The next step is the identification of contamination before recommending the corrective measures. We have to differ between local and system colonisation. The local colonisation of *Legionella* species can be easily removed by replacing the contaminated showerheads. Very dangerous is system colonisation where immediately measures need to be taken because of health risk of patients.

3 Discussion and future research

Future research and measures are planned from April 2017. After the collection of all samples, proposed methodology of risk assessment will be applied in risky hospitals as described in Figure 4.

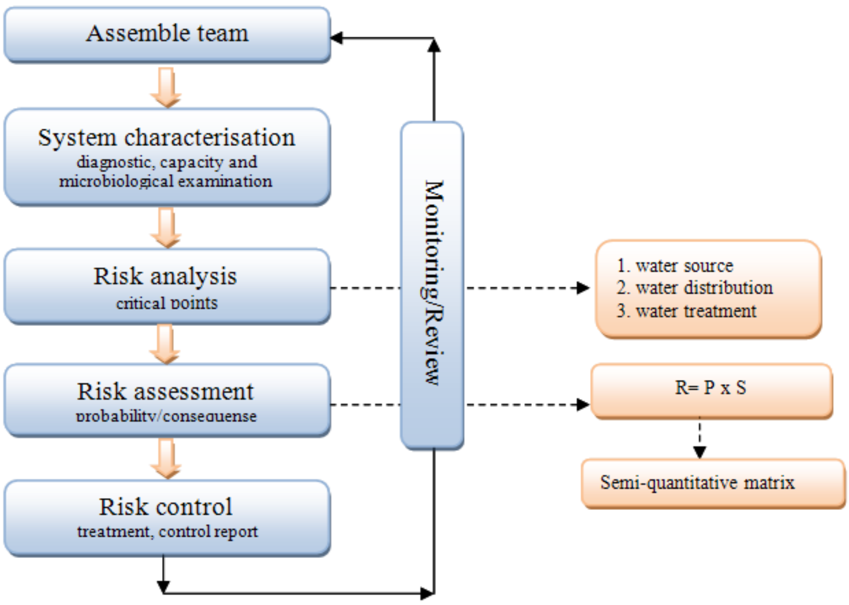

Fig. 4. Flow diagram - Proposed Risk Analysis

This method will enable us to distinguish between significant and less significant risks as well as to establish priorities in terms of implementation of measures to reduce or

eliminate the contamination on technical level. The proposed methodology is described in [14].
At the end of the **phase 1** a list of precautionary measure we recommended to the supplier of PWH to implement the proposed changes, and to avoid possible recolonization in the future.
The main of them are as follows:

- removal of disused pipes (“dead legs”)
- circulation pumps replacement – in this exchange the system was discharged
- hydraulic regulation of system
- immediate sludge blow off and cleaning of heaters, ensuring periodical sludge blow off
- flushing the pipe by drinking water – the whole distribution system
- thermal disinfection of the system at 75°C (partial –local overheating of the system)
- replacement of damaged insulation on the pipes and water heater tanks
- proper placement of temperature sensors in the tank.

As we know that each system is unique, it is inevitable to evaluate system and to record as much information as it is possible to ensure contaminated water distribution systems against *Legionella* colonization. These inputs allow us to prepare a new concept of Water audit scheme to reduce the risks from water systems.

4 Conclusions

A wide range of factors support growth of *Legionella* and other microorganisms in a distribution system. For the health significance given to these organisms it is necessary to pay particular attention to issues of design and implementation of preventive medical and technical measures. While respecting the basic parameters of hot water, it is required for a water supplier and operator of a building to ensure the prescribed quality and water temperature at each sampling site. The measures have proved that the thermal disinfection is not a systematic solution (periodically use is effective but in some cases it is not possible to use this treatment, there to it raises the energy consumption and costs). By application of preventive measures and the use of risk management we can get a secure system which eliminates costly solution’s by implementing the technical guideline or standard in Slovak republic that will intend the designers and construction companies to build systems in a way to avoid the *Legionella* growth it will be not to late to control the *Legionelae bacteria* at the end user and ensure the distribution network from “source-to-tap”. The outputs of our goals will be transformed to the *hygienic Water audit scheme* as a tool in the fight against *Legionella* contamination in the future.

Acknowledgments

This work was supported by the Slovak Research and Development Agency under the contract No. VEGA 1/0697/17 Hygienic water audit platform as transition tool to Legionella free water and HVAC systems in hospitals.

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6 Presentation of Authors

Zuzana Vranayova is the professor at the Faculty of Civil Engineering, Technical University in Kosice, Department of Building Services. She is conducting various researches on her major field of study of water supply and drainage system in buildings. She is also actively involved in governmental and academic institutions and committees related to her field of study as chief coordinator and board member..

Daniela Kaposztasova is an associate professor at the Faculty of Civil Engineering, Technical University in Kosice. She is specialised in Water supply and drainage systems. Recently she has been concentrated on the field of hot water distribution systems, grey and rainwater reuse. She is a vice dean for education.

Poster Presentations

PP01 - Evaluation of unit design water supply amounts and characteristics of water consumption based on measured building use

Toyohiro Nishikawa
t-nskw@cc.kogakuin.ac.jp
Professor, School of Architecture, Kogakuin Univercity, Japan

Abstract

Droughts, floods and heavy snow are occurring more frequently in Japan as the global climate changes. In Japan, we seem to have to change how to catch precipitation to be said to the rain once in several decades or several years. New conditions dictate that rainwater drainage plans should also be reconsidered to prepare for emergency flood control and drought, and those plans should include buildings as well as water supply infrastructure. It should also be noted, however, that there is a trend toward decreasing water consumption in buildings, brought about through the spread of water conservation devices and lifestyle changes [1]. This study investigated the standard unit design water supply for an existing office building based on measured BEMS data and evaluated the water supply reduction that could be achieved by using rainwater. In Japan, design water supply requirements can look forward to a downward trend thanks to the spread of water saving technologies [2]- [4]. In addition, changing precipitation characteristics brought about by recent climate changes has led to a need to change the criteria upon which domestic water systems are designed.

Keywords

Water consumption; Unit design water supply amounts; Rainwater utilization; Fungible ratio of potable water

1 Introduction

In Japan, the discharge from an increasing number of buildings is being measured automatically by Building Energy Management System (BEMS), but there are few examples for which the measured data can be reflected in design standards. This research investigates the real water consumption in a recently constructed building using measured data and estimates environmental performance based on unit design water supply standards and rainwater utilization. In this paper, we examine the interaction between the design water supply set using the unit water supply standards, rainwater utilization, and potable water replacement rates, based on actual measurements of water use in an existing building.

2 Study building and data collected

2.1 Study building

The building we used in this investigation is a high-rise office building in Niigata Prefecture that uses a booster pump water supply system. Table 1 outlines some main features of the building and Figure 1 diagrams its water supply distribution system.

The water supply in the building is divided into one system for the upper stories and another for the lower floors. A third, non-potable system provides water for toilet flushing and watering.

Rainwater is used to replenish a miscellaneous use tank, and the system is designed to help control water usage.

Water supply data was measured automatically at one-hour intervals in six places. These monitors measure flows to the upper stories, the lower floors, amounts required for make-up water for miscellaneous uses and the cooling towers, and make-up water to the non-potable water tank as shown in Figure 1.

Table 1 Outlines some main features of the building

Building locations		Niigata
Building use		Office, Hall, Restaurant, Store
Gross floor area		Approximately 30, 000m^2
Gross floor area		Booster pump water supply system
Water use	Potable water	Washbasin, Kitchen, taps
	Non-potable water	Toilet flushing, Watering

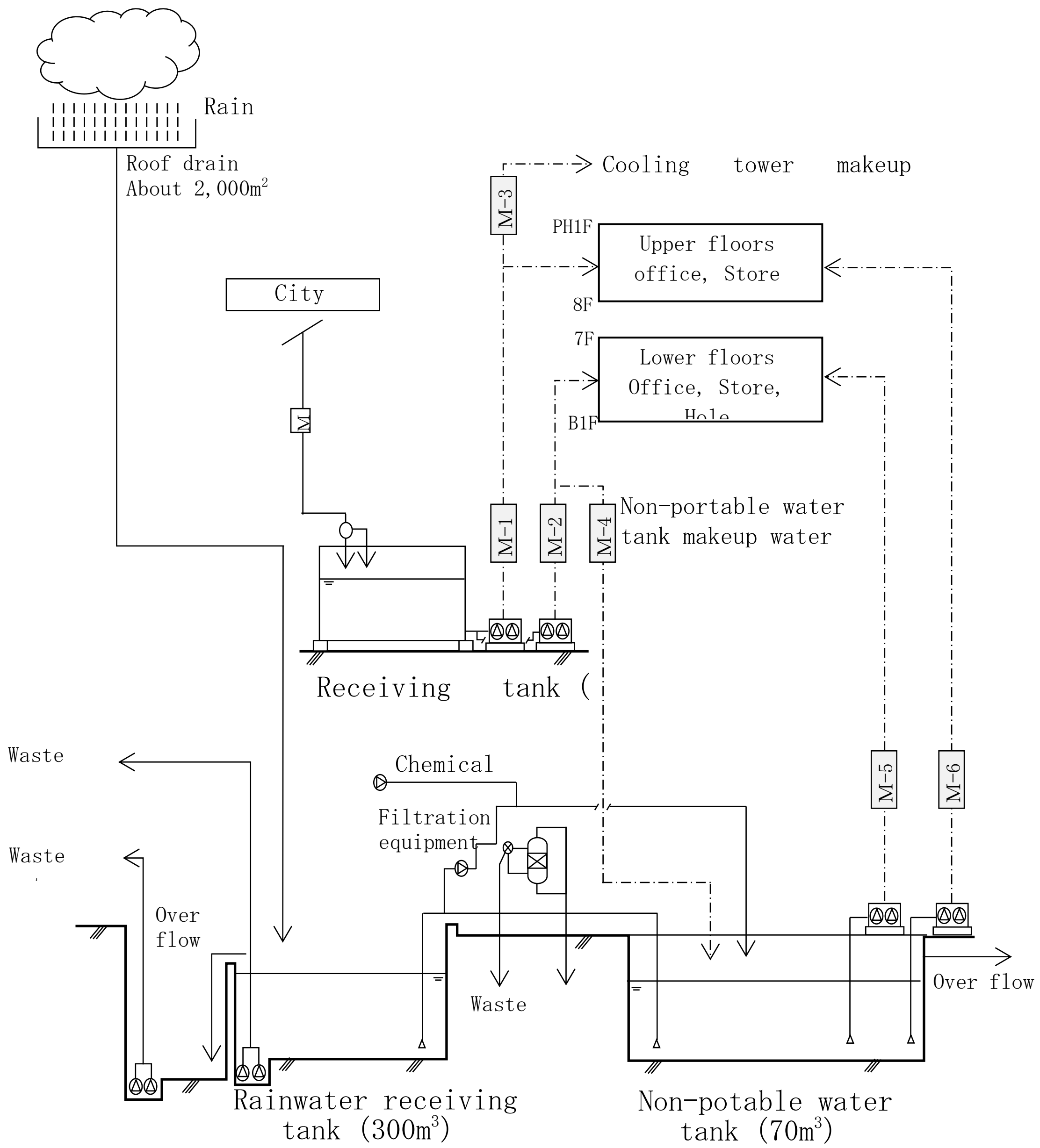


Figure 1 Water supply system diagram

2.2 Data collection

Figure 2 shows rainfall and the water drawn by the building per day during the evaluation period (April 2013 to March, 2016). During that period, the total yearly precipitation for fiscal year 2015 was 1,584 mm. In fiscal year 2014 the total was 1,953 mm, and fiscal year 2013 had 1,584 mm. The average yearly precipitation was 1,821 mm, with a variation of about 20%.

The amount of city water consumed peaks in July and August because of increased cooling tower operation. Figures 3 show potable and non-potable water usage in the upper and lower floors. The non-potable water use is quite constant, though it is somewhat elevated in the warmer months of the year.

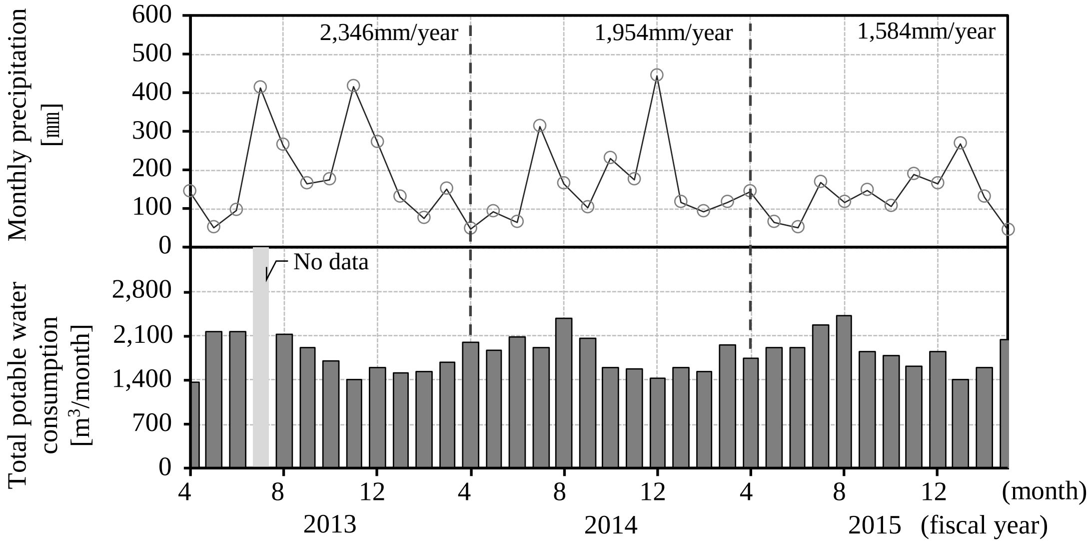


Figure 2 Monthly precipitation and total portable water consumption

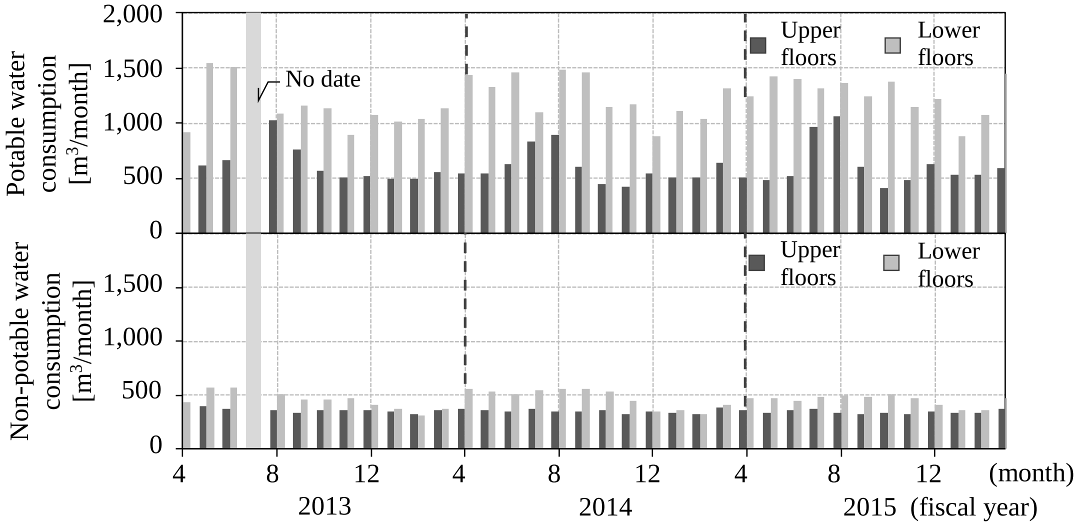


Figure 3 Consumption of Potable water and non-potable water

3 Water usage in the study building

3.1 Potable and non-potable water supply trends compared to monthly precipitation

Figure 4a shows the relation between monthly rainfall and the volume of water drawn by the building (all water except cooling tower make-up). When rainfall increases, the amount of the water drawn tends to decrease somewhat.

Figure 4b shows the relation between monthly precipitation and the water supplied to the non-potable miscellaneous use tank. The amount of make-up water going to the non-potable water tank tends to decrease when rainfall increases, and the trend is much stronger than with the potable water. This leads to the conclusion that rainwater is recycled as non-potable water.

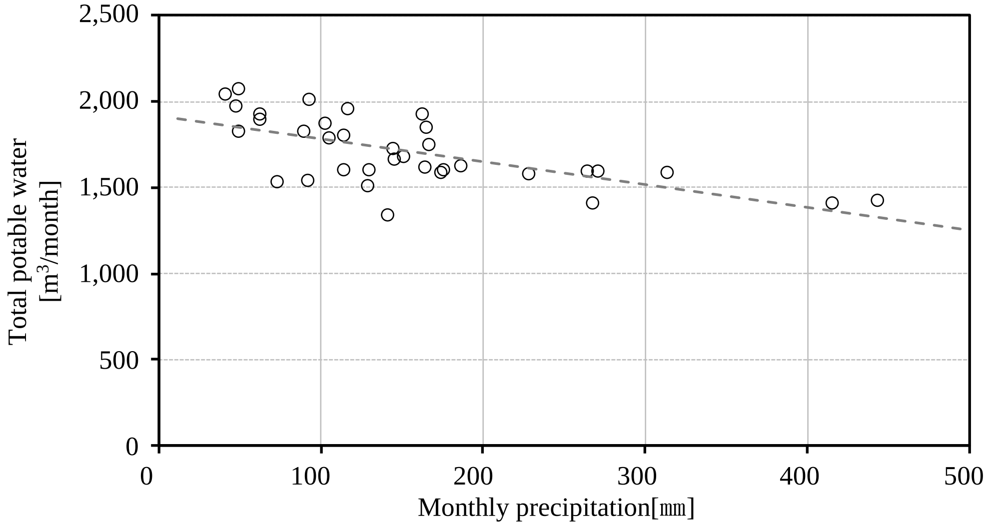


Figure 4a Comparison of Rainfall and total potable

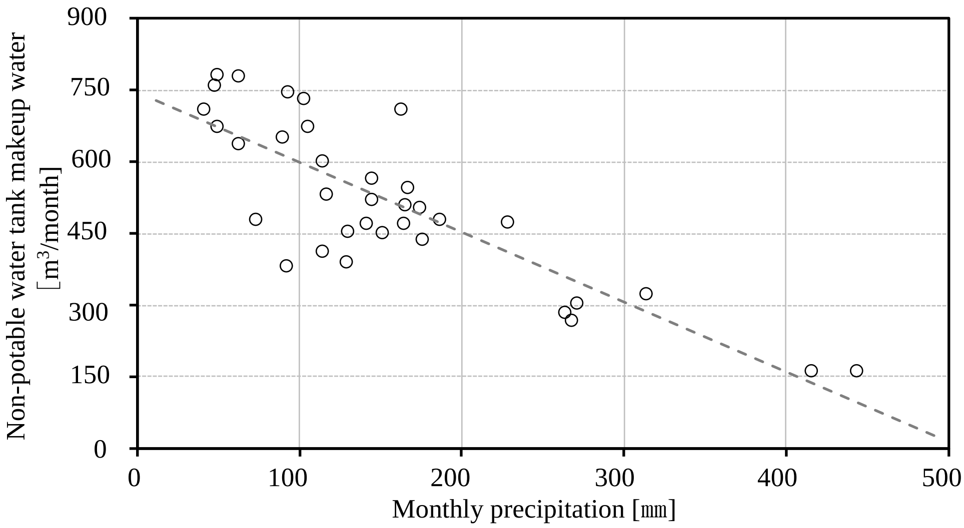


Figure 4b Comparison of rainfall and non-potable water tank makeup water

3.2 Ratio of potable to non-potable water consumption

Figure 5 shows the ratios of annual average daily water consumption by each of the potable water supply systems (excluding water consumption to the cooling towers) to that drawn by the non-potable water supply system. Because the upper floors are mainly used as offices, comparatively more non-potable water is used on weekdays than on holidays. On the other hand, water consumption on weekdays and holidays is very similar on the lower floors because a hall and a store are the main uses of that part of the building. Figure 6 compares potable and non-potable water consumption by the upper and lower floors. On the upper floors, the ratio of potable to non-potable water consumed was 54:46. This is a typical ratio for a general office building in Japan. On the lower floors, the ratio of potable to non-potable water used was around 60:40, including weekdays and holidays. It should be noted that the reason the holiday ratio for the upper floors was 70:30 is that a restaurant (a heavy potable water user) came to use two of the upper high-rise floors, becoming the primary use for those floors.

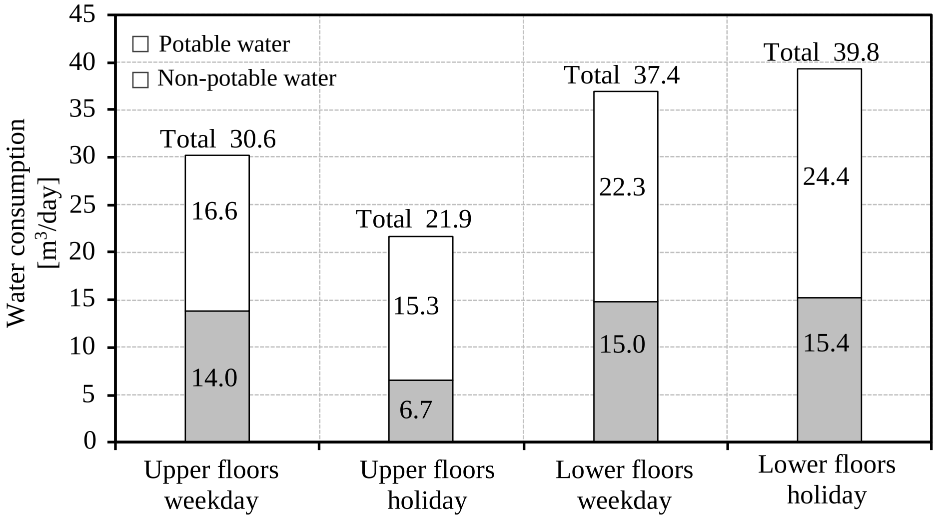


Figure 5 Weekday and holiday of daily water consumption by water use

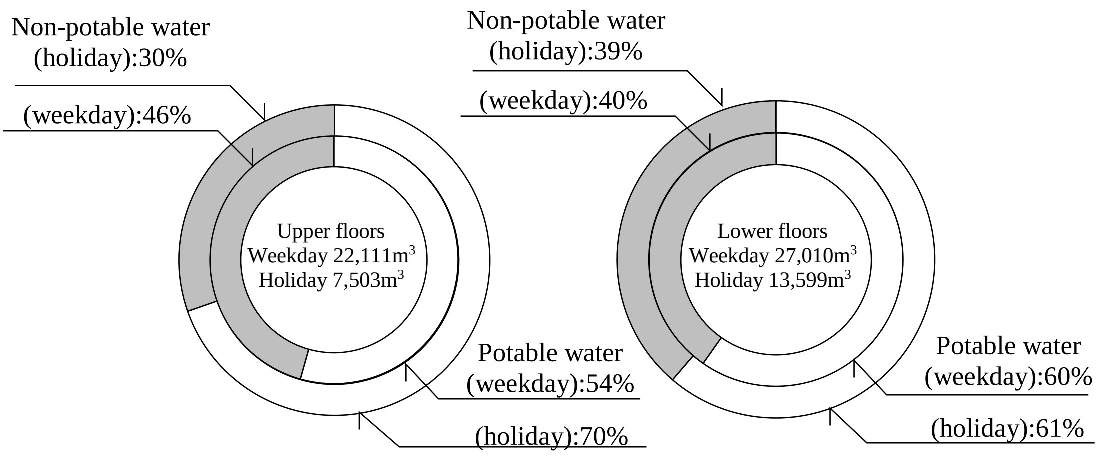


Figure 6 Water use rate of upper and lower floors in study building

3.3 Design water supply for the study building

Figure 7 shows the unit design ranges and yearly averages for the potable and non-potable water supplies for the upper and lower floors for weekdays and holidays. Based on the maxima of the ranges, the upper floor supply system would need to be designed for a weekday water usage of 2.8 liter/m^2/day (1.7 liter/m^2/day potable + 1.1 liter/m^2/day non-potable) and the system supplying the lower floors would need to provide weekday water usage of 4.8 liter/m^2/day (2.7 liter/m^2/day potable + 2.1 liter/m^2/day non-potable). Similarly, for holidays the design units would require 2.2 liter/m^2/day (1.5 liter/m^2/day potable+ 0.5 liter/m^2/day) on the upper floors and 4.9 liter/m^2/day (2.8 liter/m^2/day potable + 2.1 liter/m^2/day non-potable) on the lower floors.

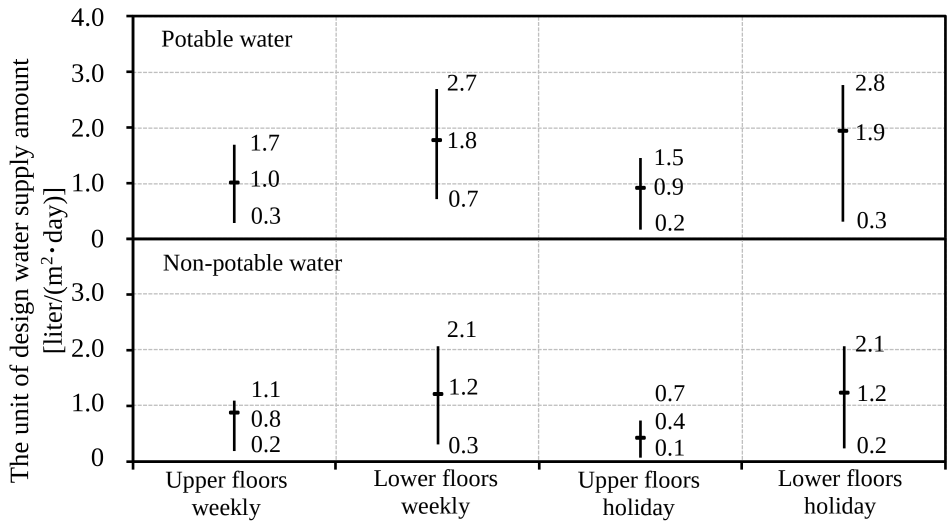


Figure 7 Unit of design water supply amount

4 Evaluation of unit design water supply based on the fungible ratio of potable water

4.1 Relation of monthly precipitation to fungible ratio of potable water in the building studied

In the building we studied, rainwater is used as part of the non-potable water. Figure 8 shows the relation between monthly precipitation and the fungible ratio of potable water (rainwater used/ (rainwater use + makeup water)). As precipitation increases, the fungible ratio of potable water tends to rise, and captured rainwater is used effectively. The fungible ratio of portable water averaged 37% over the three years of the evaluation period (fiscal years 2013-2015), and the monthly averages ranged from 10% to 80%.
To evaluate how rainwater use compares overall to non-potable water use, we assumed that the water level was controlled and used the data collected for the non-potable water tank to simulate the quantity of rainwater uses and the overflow.
Figure 9 compares the calculated values of the monthly volumes of potable water supplied and rainwater captured in the non-potable water tank with actual survey data to confirm the reliability of the computed values. Because such uses as affusion and the

use of cleaning water in building maintenance were not included in the assumptions, the calculated values did not match the actual survey data exactly, but the coefficient of correlation between the two was over 0.90, showing very good correlation.

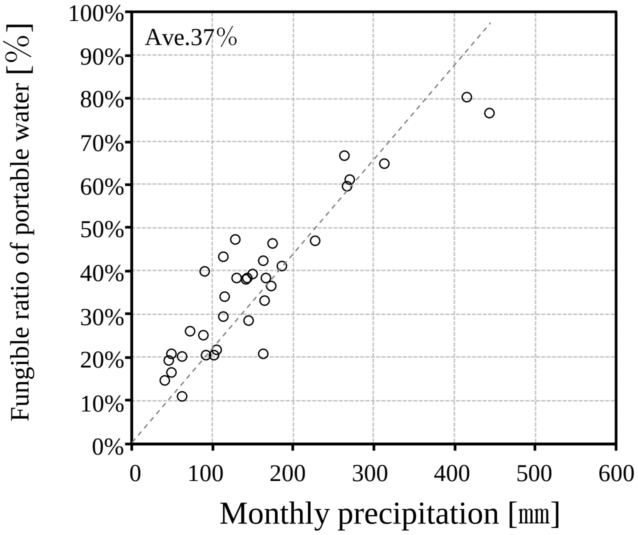


Figure 8 Fungible ratio of portable water and rainfall

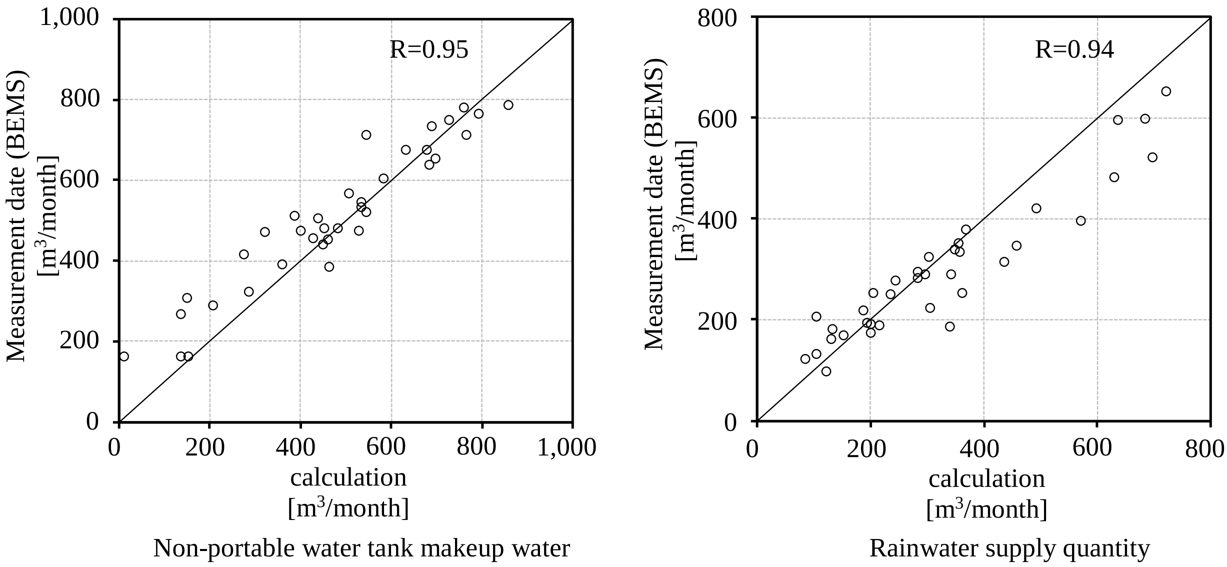


Figure 9 Comparison between measurement date and calculation

4.2 Comparison of monthly precipitation to fungible ratio of potable water

(1) Comparison based on rainwater receiving tank capacity

Figure 10 presents estimates from our numerical simulations of the relationship between monthly precipitation and the fungible ratio of potable for rainwater receiving tank capacities of 50 m^3, 100 m^3, 200 m^3, and 300 m^3. The fungible ratio of potable water was estimated at 31% for 50 m^3, the capacity of the rainwater receiving tank. For 100 m^3, 200 m^3, and 300 m^3 capacities, the fungible ratio of portable water was 37%, 39%, and 40%, respectively. In this evaluation, we determined that the preferable capacity for a rainwater receiving tank would be 200 m^3–300 m^3.

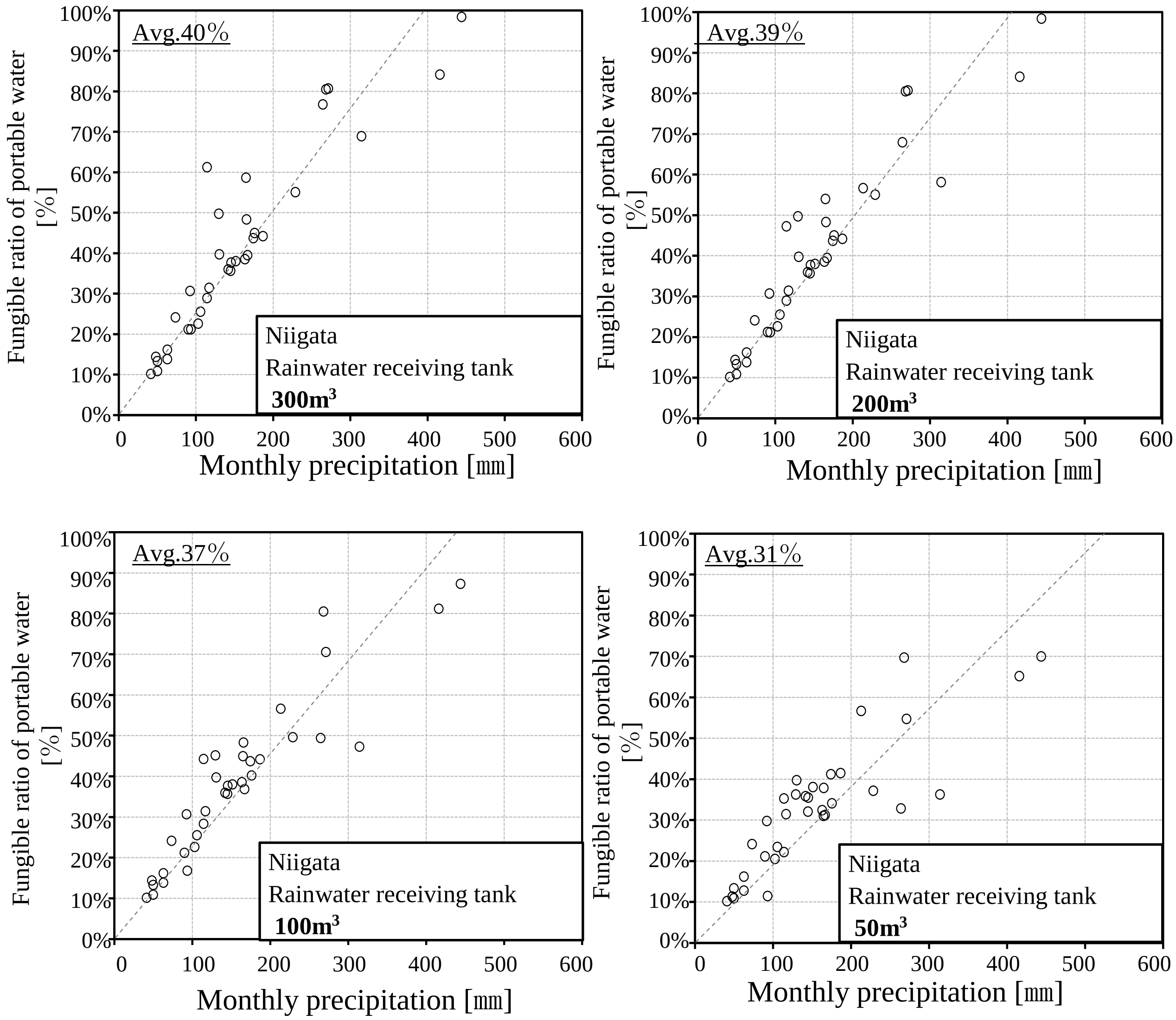


Figure 10 Comparison based on rainwater receiving tank capacity

(2) Comparison by rainfall characteristics (for Niigata and Tokyo)

In Figure 11, we consider the influence that rainfall characteristics may have on the fungible ratio of potable water using monthly precipitation in Tokyo provided by the Japan Meteorological Agency. The fungible ratio of potable water for a building like the one we studied, but with a 300 m^3 rainwater tank, was 39.8% in Niigata and 34.2% in Tokyo. In Niigata, where the study building is located, there is precipitation (both rain and snow) throughout the winter, and rainfall throughout the year is anticipated to show this in Figure 12. On the other hand, in Tokyo, the fungible ratio of potable water is lower because of the difference in its wet and dry seasons. Torrential rains and the heat island effect likely affect the ratio.

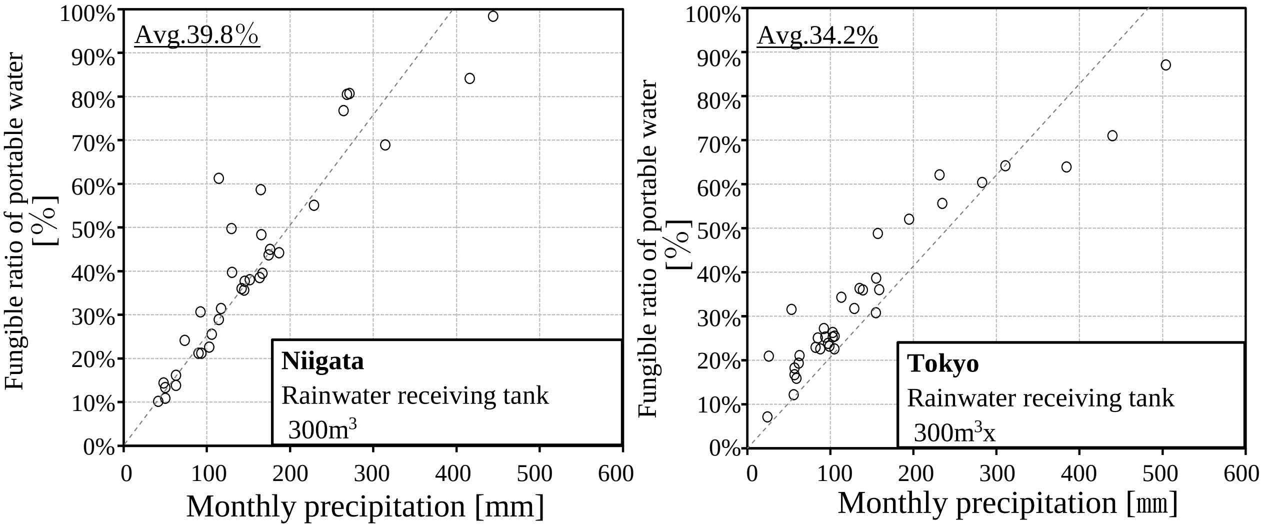
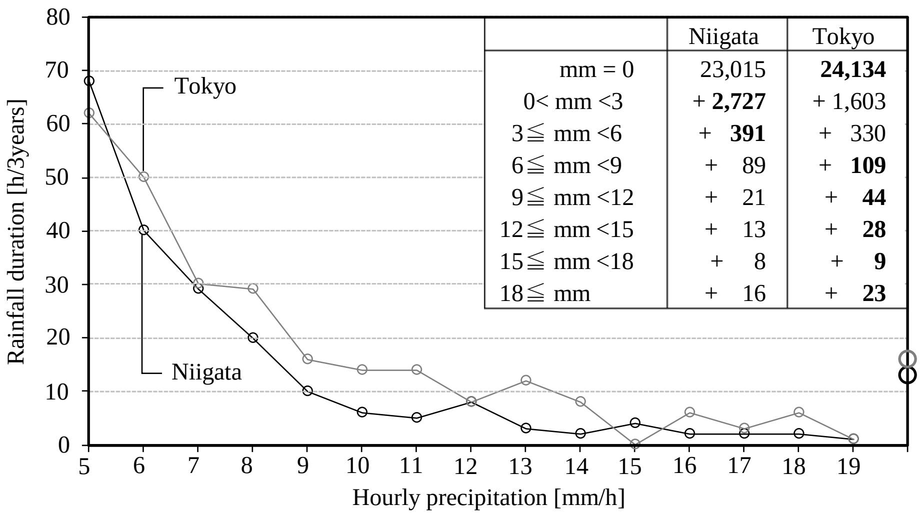


Figure 11 Comparison by rainfall characteristics (for Niigata and Tokyo)



	Niigata	Tokyo
mm = 0	23,015	**24,134**
0< mm <3	+ **2,727**	+ 1,603
3≦ mm <6	+ **391**	+ 330
6≦ mm <9	+ 89	+ **109**
9≦ mm <12	+ 21	+ **44**
12≦ mm <15	+ 13	+ **28**
15≦ mm <18	+ 8	+ **9**
18≦ mm	+ 16	+ **23**

Figure 12 Rainfall characteristic of Niigata and Tokyo in evaluation period

4.3 Reducing the design water supply standards to account for rainwater use

Figure 13 shows rainwater retention tank capacities and how design water supply requirements can be reduced by rainwater use. The results show that the unit design water supply could be reduced by 14.4% (from 3.0 liter/m^2/day to 2.6 liter/m^2/day) in Tokyo, and by 15.9% (from 3.0 liter/m^2/day to 2.5 liter/m^2/day) in Niigata by using part of the available rainwater as toilet stool flush water.

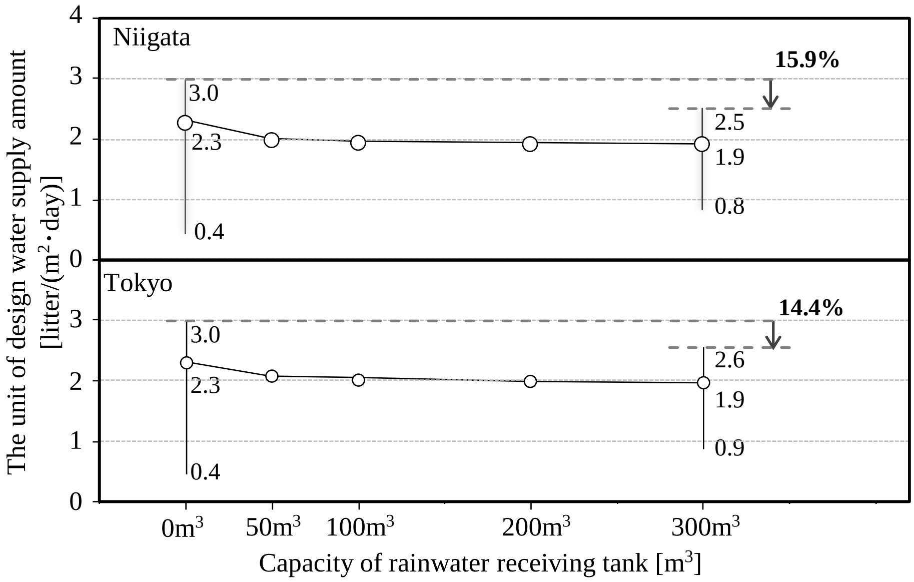


Figure 13 Reducing the design water supply standards to account for rainwater use

5 Conclusion

This study investigated the standard unit design water supply for an existing office building based on measured BEMS data and evaluated the water supply reduction that could be achieved by using rainwater. In Japan, design water supply requirements can look forward to a downward trend thanks to the spread of water saving technologies. In addition, changing precipitation characteristics brought about by recent climate changes has led to a need to change the criteria upon which domestic water systems are designed. Our hope is that this paper, which is based on real-world data, will be useful in optimizing the capacity of domestic water systems in buildings where rainwater use facilities are installed.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Number JP16K06618.

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7 Presentation of Author

Toyohiro NISHIKAWA is the Professor at School of Architecture, Kogakuin Univercity,Dr. Eng.
He is a member of AIJ (Architectural Institute of Japan) and SHASE (The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His current research interests are Performance verification of next generation air-conditioning systems, Development of high-performance outer wall, and Analysis of water environment in urban buildings.

PP02 - CFD Analysis on Flow Characteristics of WC Discharge in Horizontal Drain Using Particle Method

S. Watabe (1), K. Sakaue (2), T. Mitsunaga (3), K. Fujimura (4)
1. ce63045@meiji.ac.jp
2. sakaue@isc.meiji.ac.jp
3. mitunaga-t@yamashitasekkei.co.jp
4. kazuya.fujimura@mj-sekkei.com
(1), (2) Dept. of Architecture, School of Science and Technology, Meiji University, Japan
(3) Yamashita Sekkei Inc, Japan
(5) Mitsubishi Jisho Sekkei Inc, Japan

Abstract

Analysis by CFD (Computational Fluid Dynamics) makes it possible to reproduce the behavior of a fluid in a virtual space created by a computer, to assemble a drainage model and to reduce the time and construction cost required for installing measurement equipment. Analysis based on the grid method for simulation, which is one of the discretization methods of CFD analysis, which has been conventionally used, has become widespread in the field of air conditioning equipments, and air conditioning efficiency in natural ventilation, building wind and large-scale space. There are a number of analysis cases such as verification of. On the other hand, in the field of water supply and sanitation facilities, the analysis object is often a two-phase flow of water and air, and since the free surface that becomes the boundary has a complicated shape, the number of lattices increases for analysis , It took a lot of time to analyze and few opportunities to utilize it. In the "particle method" proposed by Koshizuka, the above disadvantages are improved, and it is expected as a new discretization method for CFD analysis. Attempts to apply to drainage systems have already been tried, but the effectiveness of such systems has not yet been sufficiently verified. Therefore, in this study, we aimed to examine the adaptability of CFD analysis using particle method, comparing and examining measured values and analytical values.

Keywords

Computational fluid dynamics; fixture drain; characteristic of fixture discharge; particle method

1 Introduction

Analysis by CFD (Computational Fluid Dynamics) makes it possible to reproduce the behaviours of fluid in a virtual space created by computer, and it helps assemble a drainage model and reduce time and construction cost required for installing measurement equipment. It is also promising as a new means of fluid measurement for it is suitable to check invisible fluid phenomena and measure forces applied to fluid. Analysis based on the grid method for simulation, one of the discretization methods of CFD analysis has been conventionally used and become widespread in the field of air conditioning equipment, producing many cases of successful analyses such as air conditioning efficiency in natural ventilation, building wind and large spaces. On the other hand, in the field of water supply and sanitation facilities, it has seen fewer opportunities for application since the object of analysis is often a two-phase flow of water and air with their boundaries having complicated shapes and a number of lattices for analysis, which requires time for analysis.

However, the "particle method"[1] proposed by Koshizuka has successfully overcome such disadvantages, and it is expected as a new discretization method for CFD analysis. Though its application to drainage systems has been tried[2],[3],[4],[5], but the effectiveness of such systems has not been sufficiently verified. In view of this situation, we examined characteristics of fixture discharge based on the measurement data obtained from horizontal branches of WC and compared them with analytical values, aiming to verify the adaptability of CFD analysis using the particle method to the drainage system.

2 Purpose

In planning WC and fixture drain, it is essential that a drainage system be designed in such a way that waste material is transferred to drainage stack by fixture discharge without fail. In fixture discharge from WC, the capacity to convey fecal matter depends on average flow rate from a fixture and average flow rate from a fixture connected to the drain pipe, and the performance evaluations of fixture discharge are described in SHASE-S220[6]. CFD analysis may replace such evaluations if it can reproduce characteristics of fixture discharge. Therefore we compared the discharge characteristics of various fixtures by conducting experiments and analyses to verify the adaptability of CFD analysis using the particle method to fixture discharge from WC.

3. Experiments on WC Discharge Flow

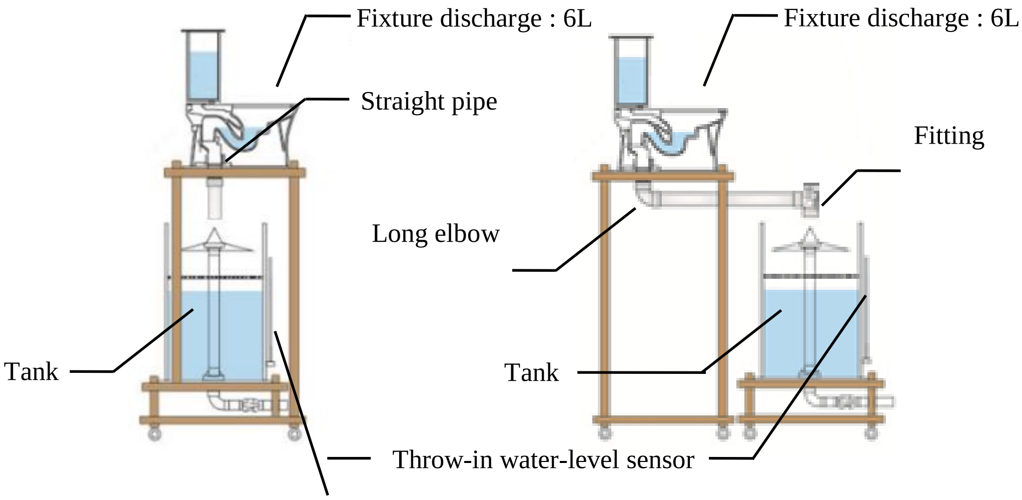
3.1 Experiments on fixture discharge characteristics of WC

3.1.1 Purpose

Flow rates from test WCs were measured to obtain basic data for CFD analysis.

3.1.2 Method

The diagram of an experimental apparatuses is shown in Figure 1-a) . 75A U-PVC pipe was connected to a test WC and discharge was made into a tank. Water level fluctuations for 30 seconds were measured with a throw-in water-level sensor at data output interval of 0.02 sec. Measurements were made each five times, and out of three measurements excluding the maximum and minimum values of average flow rates from the fixture, the data that approximated most to the average of the three measurements were used for analysis.



a） Straight pipe connection　　b） Fixture drain connection

Figure 1. Experimental apparatus

3.1.3 Results

Actual measurements are listed in Table 1. The average of average flow rates from a fixture was 2.36 L/s. Flow rate data that approximated the value were used for analysis. Discharge and flow rate data used for analysis are shown in Figure 2.

Table 1. Characteristics of discharge from fixture

	w[L]	td[s]	qd[L/s]	qmax[L/s]
1st time	6.06	1.54	2.36	2.84
2nd time	5.89	1.50	2.36	2.91
3rd time	6.32	1.64	2.31	3.00
4th time	6.07	1.50	2.43	2.92
5th time	6.01	1.54	2.34	2.93
Average	5.99	1.53	2.36	2.89

w : Flow rate from a fixture [L]
The total amount of water discharged by one drainage

t_d : Average drainage time [s]
The time taken from discharging 20% of the discharge amount until 80% discharge

q_{max}’: Peak drain flow rate from a fixture connected to the drain pipe [L/s]
The maximum flow rate of the drainage flow rate

q_d’ : Average flow rate from a fixture connected to the drain pipe [L/s]

$$qd' = \frac{0.6w}{td'}$$

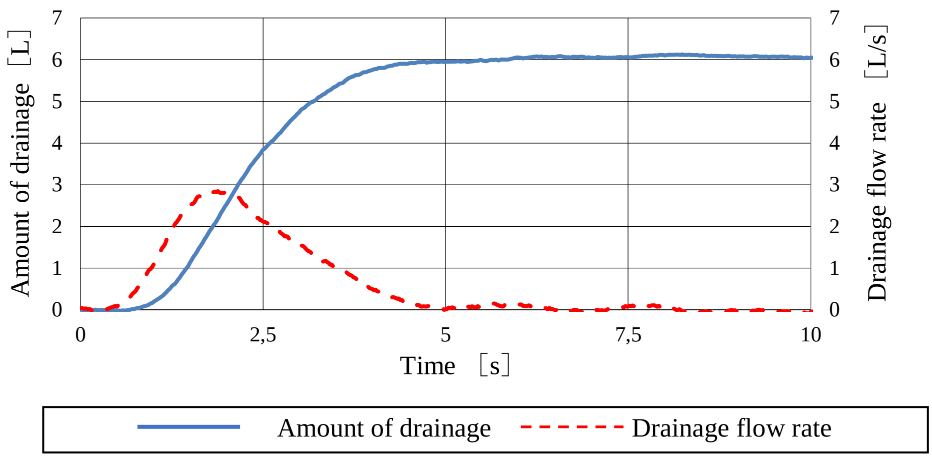


Figure 2. Amount of drainage and drainage flow rate

3.2 Flow Characteristics in WC Horizontal Pipes

3.2.1 Purpose

Fixture discharge characteristics were measured in fixture drains of 1 m, 4 m, and 8 m to elucidate the effects of horizontal branches on fixture discharge.

3.2.2 Method

The experimental apparatus used for measurement is shown in Figure 1-b. 75A U-PVC pipe was connected to a test WC with 1/100 pipe gradient and discharge was made into a tank. Straight pipes and horizontal branches were connected with long elbows, and fittings were attached at the second curves. Measurements were made at 1 m, 4 m, and 8 m from long elbows on the way to discharge outlets. Fluctuations of water level were measured for 20 seconds in 1 m and 4 m pipes, and 60 seconds in 8 m pipes with a throw-in water level gauge. Average flow rates from a fixture connected to the drain pipe were calculated based on SHASE-S220.

3.2.3 Results

Actual data for each horizontal pipe length are shown in Table 2. Discharge quantities measured with a throw-in water level gauge are shown in Figure 3 and discharge flow rates in Figure 4. Average flow rates from a fixture connected to the drain pipe at 1 m, 4 m, and 8 m were 2.43 L/s, 1.61 L/s, and 0.50 L/s respectively.

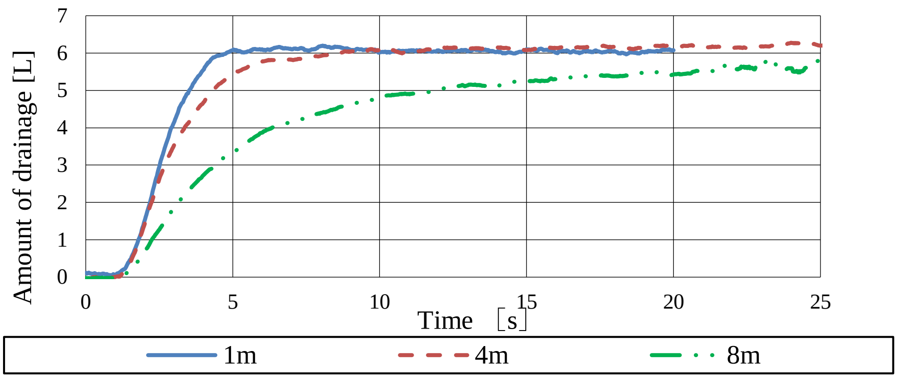


Figure 3. Cumulative discharge volume with each horizontal pipe length

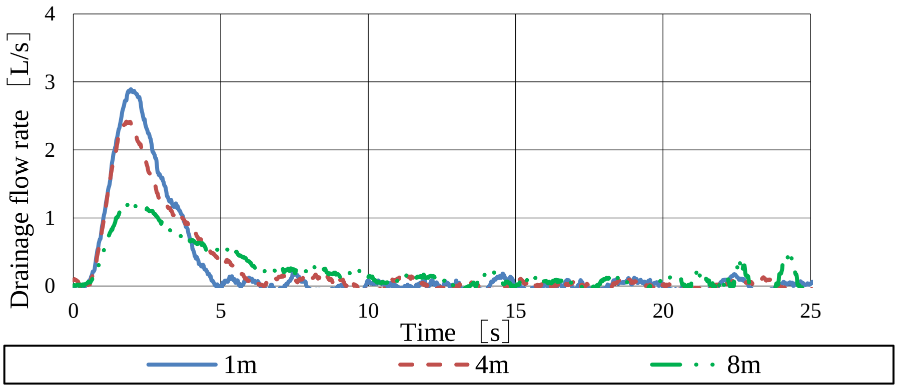


Figure 4. Flow rate from fixture with each horizontal pipe length

Table 2. Discharge characteristics of fixture connected with pipes

Horizontal pipe length	w [L]	td [s]	qd' [L/s]	qmax [L/s]
1m	6.05	1.49	2.43	2.88
4m	6.09	2.29	1.61	2.42
8m	5.99	7.13	0.50	1.26

w : Flow rate from a fixture[L] t_d : Average drainage time[s]
q_d' : Average flow rate from a fixture connected to the drain pipe [L/s]
q_{max}' : Peak drain flow rate from a fixture connected to the drain pipe [L/s]

4. Numerical Analysis of WC Drainage Flow

4.1 Purpose

Fixture drainage characteristics measured at 1 m, 4 m, and 8 m from the long elbows were numerically analyzed to see if CFD analysis based on the particle method is suitable for examining characteristics of drainage in horizontal branches from a WC.

4.2 Outline of analysis

4.2.1 Analysis model

The fixture drain connection model used for analysis is shown in Figure 5. 75Φ pipes were used with the pipe gradient of 1/100. An inlet opening was made at the upper part of the fixture drain, and inlet flow rates were determined based on inflow data measured in 3.1. The experimental model was designed in such a way that fluid could be freely discharged from horizontal branches. Measuring areas were set at points of 1 m, 4 m, and 8 m from the connection with the fixture drain and measurements were made.

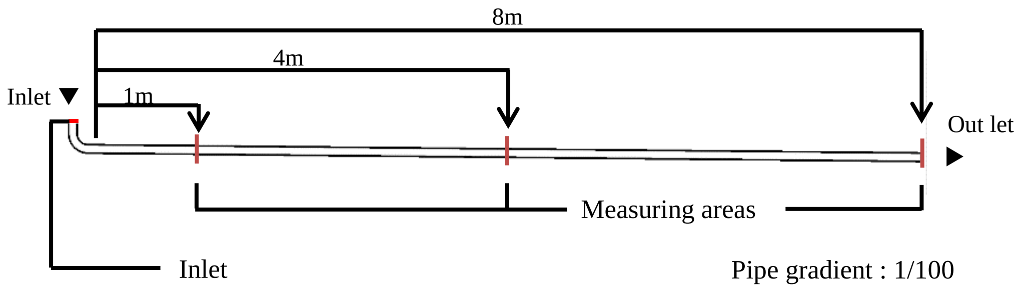


Figure 5. Analytical model (Elevation)

4.2.2 Analysis method

1) Computer used for analysis

A personal computer with intel (R) Xeon (R) CPU E5-2630 v2 128GB was used. CPU which had 8core used for Particle Works.

2) Conditions of analysis

The conditions of analysis are listed in Table 3. MPS method was used as a Lagrangian approach. An implicit method, which is suited to analyze static and semi-static physical phenomena, was used for pressure and viscosity conditions. The density of fluid, dynamic coefficient of viscosity, and coefficient of surface tension were approximated those at water temperature of 20℃. The particle diameter and primary particle distance were set at 2.0 mm and 2.0 mm respectively. The angle of contact made by the trap wall and fluid was determined 90° , slip condition at 4, which is an appropriate value for a circular pipe. The primary time step size was set at 0.5ms. (2,000 Hz) and data output interval at 20ms (50Hz) to make calculations accurate with flow velocity in drain taken into consideration. In order to make the fluid in pipe smooth, collision distance was set at 0.9 mm, influence radius at 3.1 mm, collision coefficient at 0.2 and coefficient of surface stabilization at 0.97 mm.

Table 3. Analytical conditions for the particle method

Type	Analysis conditions
Calculation method	MPS method
Solution (Pressure condition)	Implicit method
Pressure gradient blend ratio	0.9
β	1
γ	1
Solution (Viscous condition)	Implicit method
Solution (surface tension)	Potential method
Physical properties	Fluid : water（Fluid） Individual : Wall surface（Polygon）
Slip condition	4
Contact angle	90°
particle diameter	2.0mm
primary particle distance	2.0mm
primary time step size	0.5ms（2,000Hz）
Courant number	0.2
coefficient of surface stabilization	0.97
collision distance	0.9
Collision coefficient	0.2
influence radius	3.1
data output interval	20ms（50Hz）

4.3 Results of analysis and discussion

4.3.1 Results

It took 190 hours and 48 minutes for the CPU of a PC to make necessary calculations of 70 seconds worth of actual data, which means approximately 2 hours and 43 minutes was required to calculate 1 second worth of actual data.

Discharge volumes, discharge flow rates and discharge characteristics are listed in Figures 6, 7, and Table 4 respectively. Average flow rates from a fixture connected to the drain pipe with fixture drain of 1 m, 4 m, and 8 m calculated from discharge flow rates were 2.18 L/s, 1.61 L/s and 0.46 L/s.

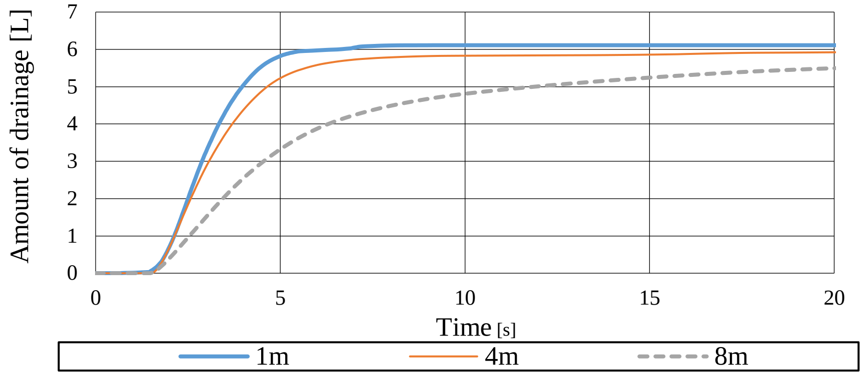


Figure 6. Cumulative discharge volume with each horizontal pipe length

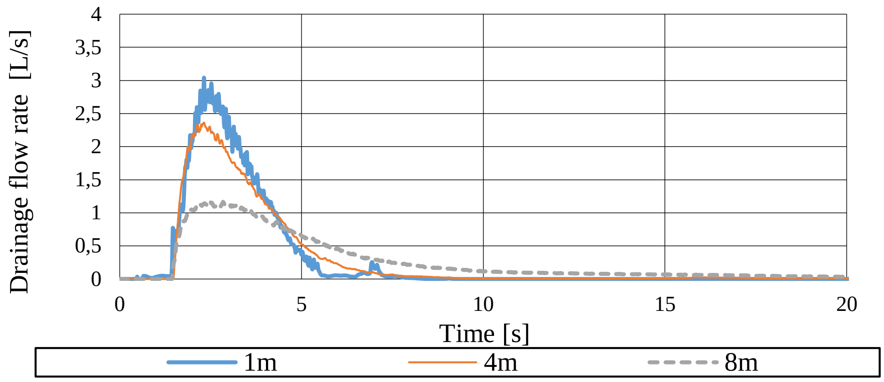


Figure 7. Flow rate from fixture with each horizontal pipe length

Table 4. Characteristics of discharge from fixture

Horizontal pipe length	w [L]	td [s]	qd' [L/s]	qmax [L/s]
1m	6.11	1.68	2.18	3.04
4m	6.11	2.28	1.61	2.36
8m	6.11	7.98	0.46	1.16

w : Flow rate from a fixture[L] t_d : Average drainage time[s]
q_d' : Average flow rate from a fixture connected to the drain pipe [L/s]
q_{max}' : Peak drain flow rate from a fixture connected to the drain pipe [L/s]

4.3.2 Comparison of analytical results with experimental results

Actual measurements and analytical values of discharge volumes and discharge flow rates with horizontal pipe lengths of 1 m, 4 m, and 8 m are shown in Figure 8, average flow rates from a fixture connected to the drain pipe in Figure 9, and peak drain flow rates from a fixture connected to the drain pipe in Figure 10. The comparison of actual discharge volumes and discharge flow rates with their analytical values based on Figure 8 indicated that they approximated on the whole. The comparison of actual average flow rates from a fixture connected to the drain pipe with analytical values based on Figure 9, on the other hand, showed that while the values approximated with 4 m and 8 m pipes, the difference between the actual measurements and analytical values of the average flow rates from a fixture connected to the drain pipe with 1 m pipes was 0.25 L/s indicating a greater difference than with other horizontal pipe lengths. The comparison between actual measurements and analytical values of peak drain flow rates from a fixture connected to the drain pipe based on Figure 10 showed that the values approximated with 4 m and 8 m pipes but the values with 1 m was 0.15 L/s indicating a greater difference than with other horizontal pipe lengths. This can be attributed to the fact that discharge was made manually, which led to varied average discharge flow rates with 1 m pipe that normally does not cause reduction of discharge flow. Therefore, the difference seen with 1 m pipe is considered valid.

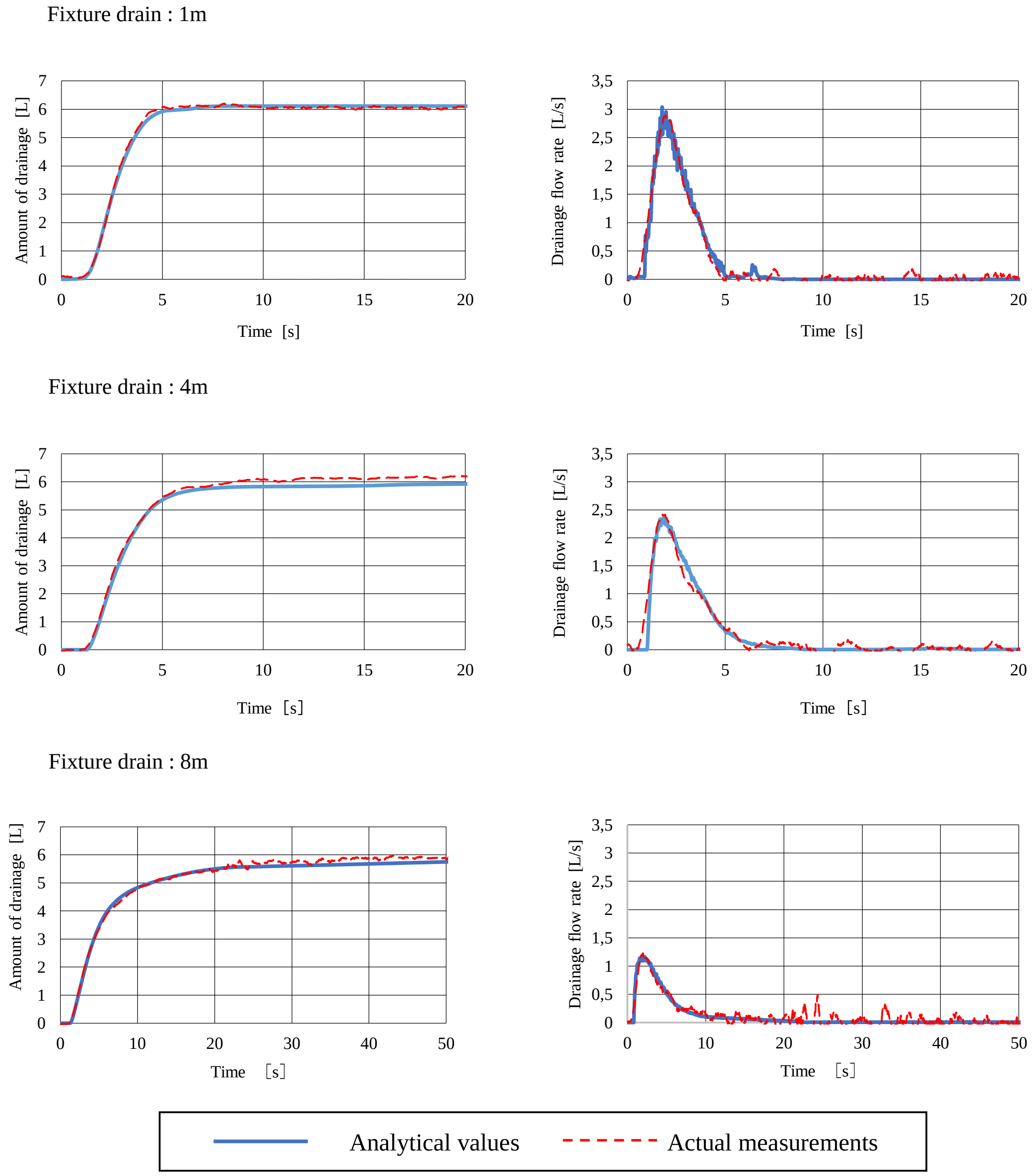


Figure 8. Time variation of discharge volume and discharge flow rate for each horizontal pipe length

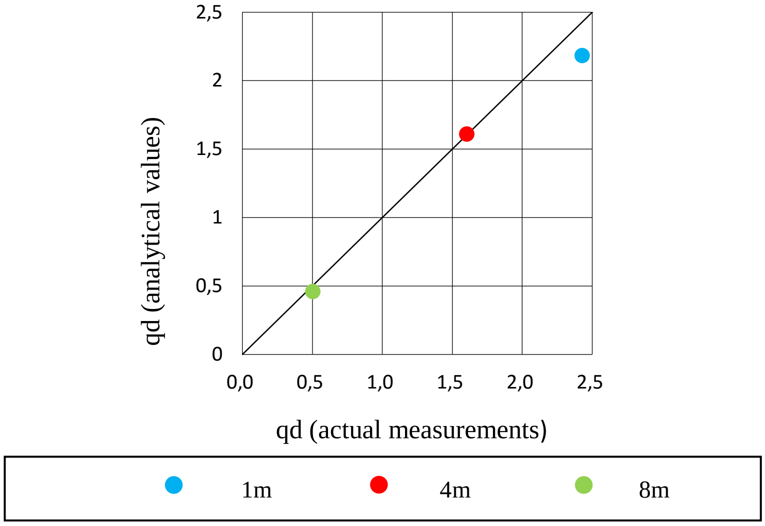


Figure 9. Analytical values and actual measurements of average flow rate from a fixture connected to the drain pipe

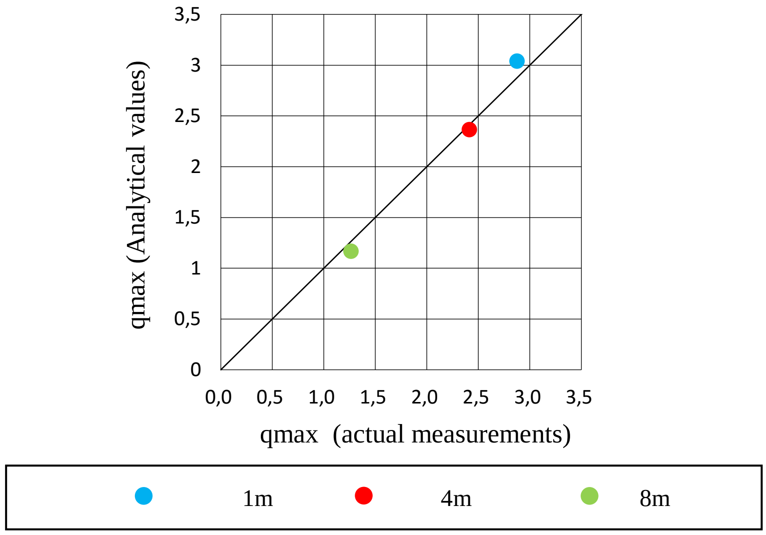


Figure 10. Analytical values and actual measurements of peak drain flow rate from a fixture connected to the drain pipe

5. Conclusion

In this study we analysed and compared actual measurements and analytical values of discharge flow rates from a fixture connected to the drain pipe based on the particle method of CFC analysis. The findings can be summarized as follows:

1) Actual measurements and analytical values of average flow rates from a fixture connected to the drain pipe and peak drain flow rates from a fixture connected to the drain pipe with each horizontal pipe length were found to be similar.

2) Actual measurements and analytical values of discharge flow rates were also found to be similar.

Though CFD analysis based on the particle method proved to be applicable to straight piping, its performance with fixture discharge with curved piping has not been confirmed. Therefore, it remains to be examined in the future studies.

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6. Presentation of Authors

Seiya Watabe is a master of student at the Sakaue laboratory, Department Of Architecture, School of Science and Technology at Meiji University in Japan

Kyosuke Sakaue (Dr. Eng.) is a professor at Department of Architecture, School of Science & Technology, and head of New Plumbing System Institute, Meiji University.
His fields of specialization include water environment, building services and plumbing system.

Takehiko Mitunaga (Ph. D.) is an engineer at Yamashita Sekkei Inc.
He belongs to Mechanical Systems Design Development.
He finished the doctoral course for coorker in Architecture at Meiji Universityin Japan.

Kazuya Fujimura (Ph. D.) is a mechanical engineer at Mitsubishi Jisho Sekkei Inc. He finished the doctoral course for coorker in Architecture at Meiji University in Japan.

PP03 - Current bathroom requirements in housing rehabilitation

Ines Meireles (1), Ana Velosa (2)
1. imeireles@ua.pt
2. avelosa@ua.pt
(1)Professor Auxiliar, RISCO, Department of Civil Engineering, University of Aveiro, Portugal
(2)Professor Associado, RISCO, Department of Civil Engineering, University of Aveiro, Portugal

Abstract

Nowadays it is possible to witness the growing global awareness to rehabilitation of old buildings, mainly due to the cost of new construction a change of mentality regarding the real estate sector and a sense of sustainability. However, even if rehabilitated, most housing in the 20th century is unsuited to the 21st century lifestyle.
It is a fact that old dwellings possess an insufficient number of bathrooms for the current requirements of comfort. Even during the 20th century many Portuguese urban buildings had only elementary bathrooms on the outside or on the balconies. The evolution on the number of bathrooms per dwelling occurred recently. In Portugal, was just in the 1950s that were established minimum requirements for the number and size of bathrooms inside private residences and it is from the 1980s that the number and size of these compartments gains relevance.
In this regard, the need to create additional bathrooms in old dwellings is undoubted. However, the diversity of existing buildings is relevant, both in terms of spatial division and construction system.
Thus, in order to meet a sustained growth of the building rehabilitation sector which fulfils the current bathroom requirements, this paper focuses on a new bathroom pod concept. The main characteristics are high versatility, possibility to be transported to and placed in small spaces, simple and quick installation, and high aesthetical performance.

Keywords

bathroom pod; rehabilitation; aesthetics.

1 Introduction

The construction sector is a major energy consumer, consuming40% of the materials entering the global economy, and generating 50% of the global output of greenhouse gases and the agents of acid rain every year (CIWMB, 2000).

Although it is usual to consider a life span of 50 years for buildings (e.g., Khasreen *et al.*, 2009), the building components often remain in good physical condition for longer periods. The nonconformity between housing conditions and the contemporary standard limits for comfort, quality and aesthetics usually dictates the end of life of the building as it is. Frequently, without adaptation to the evolution of these requirements, the buildings might lie empty, and unused and eventually be object of demolition.

In the European Union, 17% of the dwellings are unoccupied, either reserved for seasonal or secondary use, such as holiday homes, or vacant. The later include dwellings for sale, for rent, for demolition or simply empty and/or unused. Vacant buildings represent 11% of the total building stock for 12 EU countries (Czech Republic, Denmark, Ireland, Greece, France, Croatia, Cyprus, Luxembourg, Malta, Portugal, Romania and Finland) (Census Hub, 2011).

With the current European Union policies to reduce carbon footprint, reusing existing vacant buildings would contribute to sustainability by diminishing demolitions and new construction. In this regard, buildings that present structural and functional/comfort debilities need to be rehabilitated and renovated in conformity. In a recent study on the built heritage conservation in Portugal (PTCP, 2015), it was observed that historic buildings represent 25% of the total housing stock. From these, 55% need conservation and only 13% need extensive structural conservation measures. Considering buildings constructed between 1960 and 1990, which are about 44% of the Portuguese housing stock (LNEC-INE, 2013), only 2% require extensive structural conservation measures. The remaining buildings only need to improve the conditions of habitability and comfort to the present requirements.

In this study, an investigation is performed to determine if the number of sanitary facilities in the housing stock is consistent with the present society needs and is presented a new concept under development to fulfil the possible gap between demand and supply.

2 Housing stock characterization in terms of the number of sanitary facilities

In 1775, Alexander Cumming designed a toilet coupled with a siphon that, using water as the seal, allowed to keep the toilets inside the house and the odors out. However, about 100 years needed to pass before these toilets would be widely available inside the dwellings (Antoniou *et al.*, 2016). For instance, during the 20th century many Portuguese urban buildings had only elementary sanitary facilities on the outside or on the balconies.

The evolution on the number of sanitary facilities per dwelling occurred recently. In Portugal, it was just in the 1950s that were established minimum requirements for the number and size of the sanitary facilities inside private residences, which varied between 1 and 2, respectively for dwellings with less than 3 rooms or 4 or more rooms (RGEU, 1951). However, it is only from the 1980s that the number and size of these compartments gains relevance.

According to the Eurostat (2015) indoor toilets can be regarded as an indicator of housing quality. In 2011, 97.3% of the EU dwellings (excluding Croatia and Finland, since data was not available) had at least one indoor flush toilet facility. In Belgium, Luxembourg, the Netherlands, Sweden and the United Kingdom, 100% of the dwellings were equipped with at least one indoor flush toilet, against 80.6% in Latvia and Lithuania and 61.9% in Romania. In Portugal, the share of dwellings with at least one indoor flushing toilet was 98.4%.

The lack of an indoor flushing toilet, along with the lack of a bath or shower or problems in the overall condition of the dwelling (as leaking roof or dwelling being to dark) are indicators of housing deficiencies. In this regard, the numbers above allow to determine the extent of severe housing deprivation in the referred Countries. However they say nothing related to the relation between society needs and housing stock characteristics regarding the number of sanitary facilities per dwelling.

To fulfill this lack of knowledge 29 thousand dwellings presently for sale in Portugal and advertised online (Imovirtual, 2017) were studied. The sample was observed to be similar to the data from the the Portuguese *Population and Housing Census* conducted in 2011 (LNEC-INE 2013), in the framework of the EU Census 2011.
This similarity was observed in terms of average size of the dwellings (Figure 1a), distribution of the dwellings by number of rooms (Figure 1b), and distribution of the dwellings by number of rooms per period of construction (Figure 2). Consequently, a characterization of the housing stock in terms of the number of sanitary facilities was performed. It should be noted that, in accordance with the publication LNEC-INE (2013), to characterize the dwellings this survey did not count bathrooms nor kitchens with less than 4 m^2 as a room.

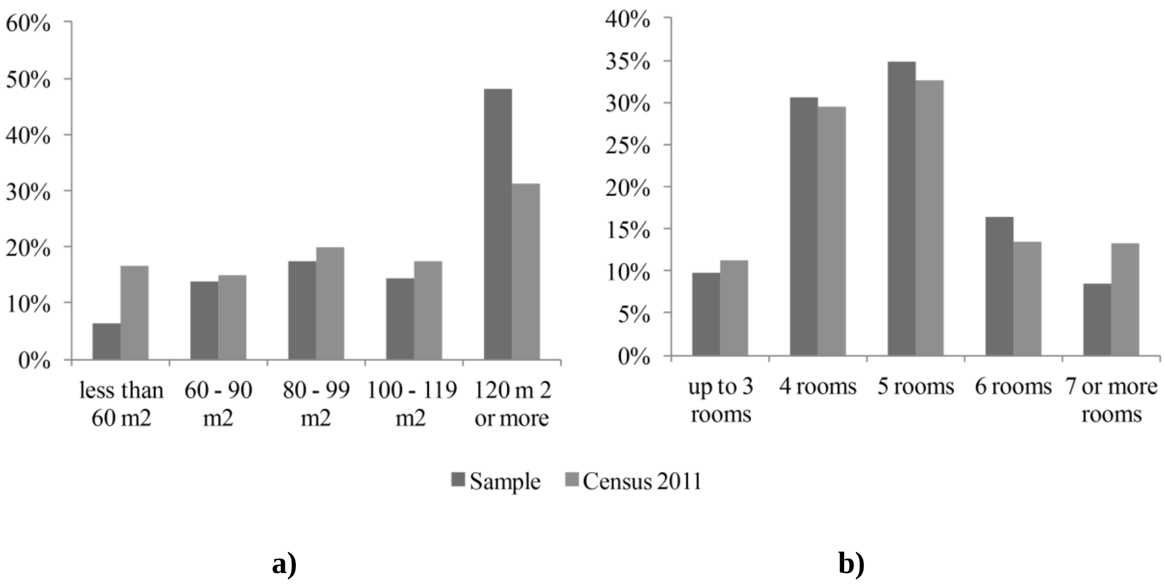


Figure 1 - Comparison between the sample and the Census 2011 in terms of: a) average size of dwellings, b) number of rooms.

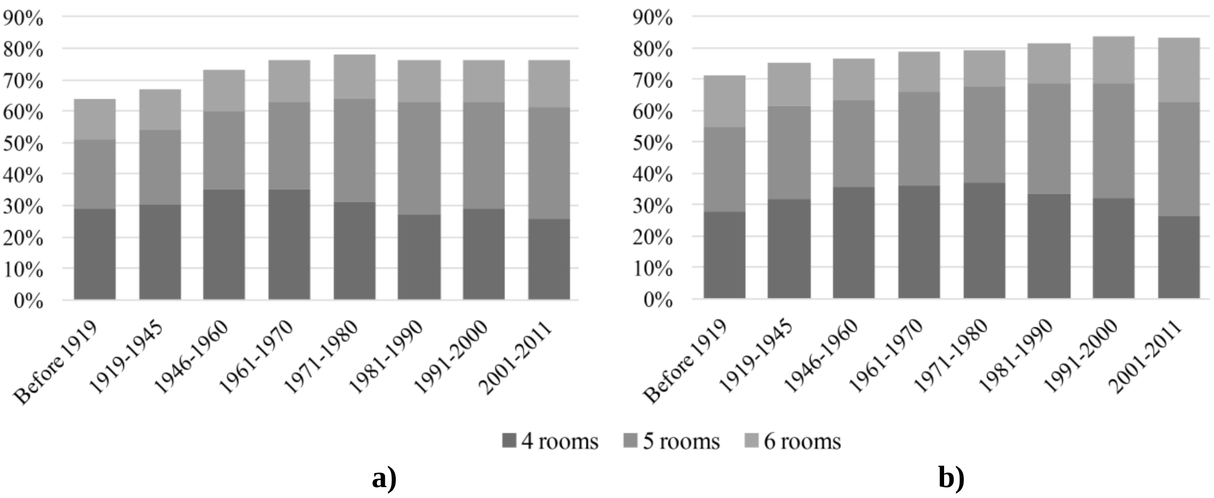


Figure 2 - Distribution of dwellings by number of rooms per period of construction: a) Census 2011; b) Sample.

Figures 3 to 5 present the historical evolution of dwellings in terms of number of sanitary facilities by number of rooms. It is noticed an evident increment in the number of sanitary facilities (SF) with the construction's year and the number of rooms of the dwelling for dwellings possessing 4 to 6 rooms, which represent about 80% of the housing stock. Since the most recently built dwellings have the largest share of sanitary facilities, it is plausible to conclude that this is a reaction of the market to the requirements/demand of the users. In this regard, one can observe that buildings with more than 10-20 years do not fulfill the needs of the users in terms of number of sanitary facilities. Therefore, solutions are required to tackle this specific problem.

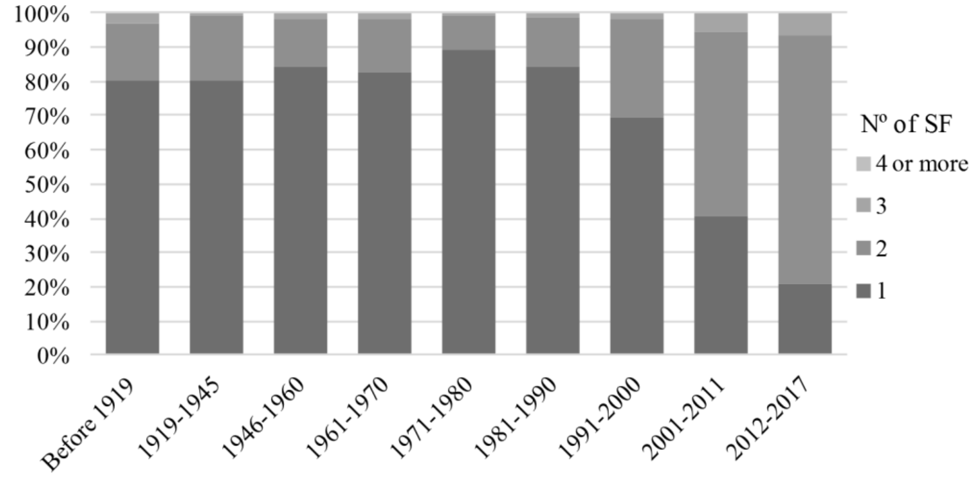


Figure 3 - Number of sanitary facilities (SF) in a dwelling of 4 rooms per period of construction.

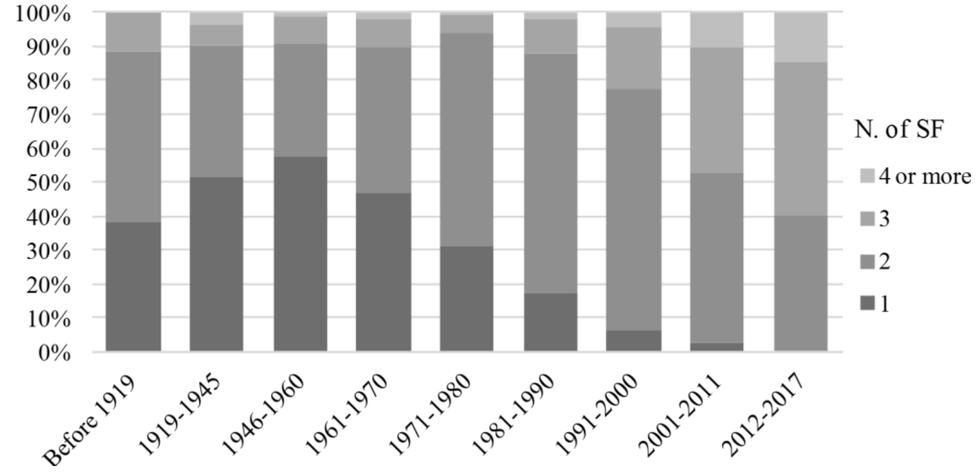
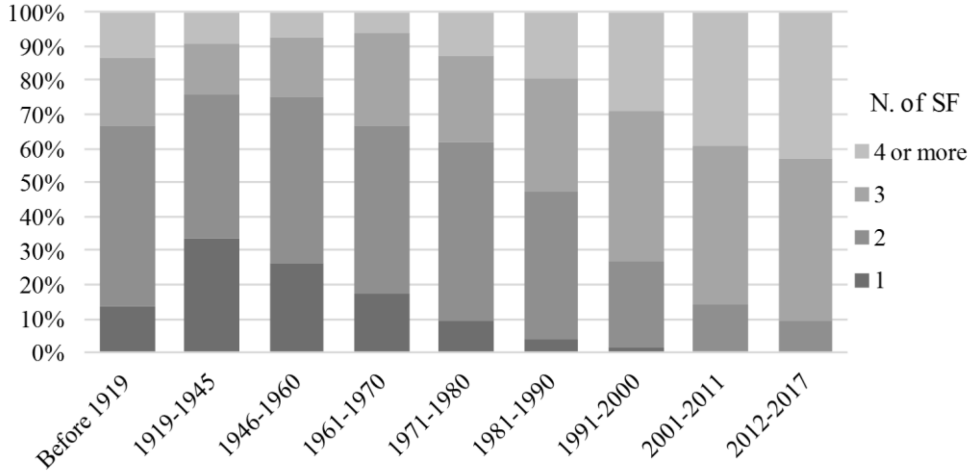


Figure 4 - Number of sanitary facilities (SF) in a dwelling of 5 rooms per period of construction.



c)

Figure 5 - Number of sanitary facilities (SF) in a dwelling of 6 rooms per period of construction.

3 The concept of bathroom pod for rehabilitation

In order to effectively improve the comfort and habitability of existing buildings in terms of number of sanitary facilities, the majority of the traditional interventions carried out are extensive, intrusive, timely, costly, with high amount of demolitions and waste production, and sometimes detrimental to the preservation of the building and corresponding image.

In this context, a sanitary facility for the rehabilitation of residential buildings of the 20th century should be:
- less intrusive,
- less time-consuming;
- cost-effective;
- more sustainable.

Since the construction of a bathroom on the site requires a lot of precautions regarding its installation, in particular due to the need to reconcile electrical and hydraulic networks with the construction of the walls, the search for alternatives, such as bathroom pods, has grown. The latter allow to optimize the process of building construction, namely in terms of execution time and cost. In addition, since bathroom pods are generally manufactured in industrial production lines, all stages of quality control, finishing and electrical and hydraulic networks are carried out in the factory, so that on-site errors and waste are minimized.

A detailed study on the bathroom pod industry in Europe was performed, in order to determine the weaknesses and strengths of the existing products when specifically used in the market of rehabilitation (Table 1).

Table 1 Number of studied bathroom pod manufacturers in Europe

Country	Nº of manufacturers
Belgium	1
Denmark	1
France	7
Germany	15
Ireland	1
Italy	6
Netherlands	1
Norway	2
Poland	3
Portugal	1
Spain	2
Sweden	2
United Kingdom	10
Total	**52**

From the analysis of the 52 bathroom pod manufacturers the following conclusions were drawn:

- The majority of the bathroom pods are costumer tailored, based on a specific project, which forces the ordering of a significant number of units to enable a competitive unit price. This limits the use in micro-scale rehabilitation/renovation, although 3 manufacturers present versatile bathroom pod models allowing to consider a specific setting of the devices at the time of acquisition. **Target 1**: to conceive a versatile bathroom pod model that can be assembled and disassembled in a vast number of settings.

- The majority of the bathroom pods require lifting equipment, due to weight and size restrictions, which may be a significant constraint in the context of building rehabilitation/renovation. However, 3 manufacturers have products that can be transported by parts. **Target 2**: to conceive a bathroom pod that may be transported by parts.
- All the studied bathroom pods are closed compartments. **Target 3**: to conceive a bathroom pod partially open, which can fit into spaces of smaller dimensions than the minimum area required to install the other bathroom pods without reducing user comfort.

- All the studied bathroom pods incorporate hydraulic, sanitary and electrical installations, as well as sanitary devices. **Target 4**: to conceive a bathroom pod that incorporates hydraulic, sanitary and electrical installations, along with a toilet, a washbasin and a shower).

- Part of the studied bathroom pods cannot be distinguished from a traditional bathroom after their assembling and part lay visible their modular aesthetics. **Target** 5: to conceive a bathroom pod with high standards of aesthetics and which transmits a sense of lightness and modernity).

- A limited number of the studied bathroom pods referred specifically to sustainability.
Target 6: to conceive a bathroom pod that reflects sustainability concern in its manufacture and use.

To fulfill targets 1 to 6, a new bathroom pod concept (Figures 6 and 7) is being developed in the framework of the project *MoBaK – Modular Bathroom Kit*, by the companies OLI, Sistemas Sanitários S.A. and Italbox, the Water Protect Lda and the University of Aveiro, with Inovadomus and Lislei as partners.

Figure 6 - New concept of bathroom pod adapted to rehabilitation: front view.

Figure 7 - New concept of bathroom pod adapted to rehabilitation: back view.

Acknowledgments

The study was performed in the framework of the project "*MoBaK – Modular Bathroom Kit/Oliveira & Irmão S.A.*", nº 17719, 33/SI/2015 – *I&DT Empresarial (Copromoção)*, funded by *Fundo Europeu de Desenvolvimento Regional (FEDER)* through *Programa Operacional Competitividade e Internacionalização - COMPETE 2020*.
Thanks are due to University of Aveiro, FCT/MEC for the financial support to the research Unit (FCT/UID/ECI/04450/2013).

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5 Presentation of Authors

Inês Meireles is Assistant Professor with tenure at the Department of Civil Engineering, University of Aveiro (UA). Is responsible for courses on Hydraulics in the MSc. Degree in Civil Engineering at UA and is an integrated member of the RISCO Research Unit, developing research on the areas of Sustainability in Construction and of Risks in the Built Environment.

Ana Velosa is Associate Professor at the Department of Civil Engineering, University of Aveiro (UA). Is responsible for courses on Construction in the MSc. Degree in Civil Engineering and in the Degree in Built Heritage Conservation at UA and is an integrated member of the RISCO Research Unit, developing research mainly on the area of Built Heritage Conservation and Restoration.

PP04 - Map of green roofs of Košice city. A case study

Z. Poorova (1), Z. Vranayova (2)

1. zuzana.poorova@tuke.sk
2. zuzana.vranayova@tuke.sk
2. 3. Technical University of Košice, Faculty of Civil Engineering, Slovakia

Abstract

The paper deals with a possibility of changing traditional roofs in Košice city into green roofs, following temperature and humidity measurements. The research is picturing an ongoing dissertation work focusing on green roofs and their water retention qualities. The aim of this paper, part of the research is to prove that there is a possibility to change one city, or maybe more, following steps this research is picturing.

Keywords

ArcGIS, green roofs, maximum temperature, minimum humidity.

1 Introduction

The ideal way to measure any city´s heat island would be to examine regional weather patterns with and without the city in the place. Measuring heat island´s effects on regional climate is useful, but it cannot tell how effective mitigation measures would be at reducing a heat island´s effect. This is where modeling becomes necessary. Models are used to predict how well mitigation measures can reduce urban temperatures, energy use, air pollution and retain water [1].

The simplest and the most common way to analyze a heat island is to compare existing weather data from two or more fixed locations. Fixed station data are used in three different ways:

- comparing data from a single pair of urban and rural weather stations ;
- studying data from multiple stations to find regional, two-dimensional impacts;
- investigating a large set of historical data to evaluate heat island trends over time as region was developing.

More rigorous analysis of a heat island includes data from numerous fixed stations in and around the city. If enough stations are available, two-dimensional contour map of the city´s temperatures can be generated [1].

2 Selection of period for measurements

According to 5 year analysis, World Meteorological Organization (WMO) stated that the period between 2011 and 2015 was the warmest period of a 5 years long period in the history of observations. During this period there have been many cases of extreme weather, particularly heat waves. Situation of the global climate in 2015 was historic for many reasons. The level of greenhouse gases in the atmosphere has reached new highs in the northern hemisphere during spring 2015. For the first time it exceeded 3 month average of global concentrations of CO_2. 2015 was the warmest year in the history records in terms of the surface temperature of the oceans since the beginning of observations [2].

In 2016 there were 2-7 more days of summer than in extremely warm year 2015. On the other hand, we have experienced significantly fewer tropical days than in the previous year 2015, approximately 15 to 30 days less [3,4].

Summer of 2016 was in all the main features quite different than the summer of 2015. While the year 2015 was extremely warm at the same time it was also very dry. Summer 2016 was much wetter than summer 2015. This resulted in a high number of days and nights, when a people feel stuffy. It also resulted in intense thunderstorms. An essential feature of summer 2016 was also part of the transition significant cold front, which also initiated a significant convective systems that brought abundant rainfall. That is why in 2016 we did not observe similar long periods of high daily maximum air temperatures exceeding 35 °C as in summer 2015 (Fig.1). Characteristic features of the summer 2016 were extremely high temperatures and high frequency of intense storms and torrential rainfalls that are associated with them [3,4].

Following above mentioned information, July 01-31, 2015 data were used to create map of heat island of Košice city and map of green roofs of Košice city.

3 Fixed stations in Košice

The mitigation effect of the green roof on urban heat island therefore retaining water in the original area of rainfall is accessible using meteorological measurements. The measurements were collected using automatic weather stations that are installed on roofs of the buildings in Košice.

This research, completing Košice heat island map and map of green roofs of Košice uses only weather stations listed in Tab.1. The study takes into an account only parameters given by these stations. For further research of this topic, more parameters will be needed to complete it.

2 Data

Figure 1 - Extreme temperatures in July 2015

Table 1 Maximum temperature and minimum humidity trends in 07/2015

address	max. temperature [°C]	min. humidity [%]
Berlínska 3	**41.1**	**22**
Branisková 25	**36.6**	**25**
Brnenská 41	39.6	21
Bukovecká 43	42.7	20
Bukovecká 68	38.4	22
Cesta pod Hradovou 6	**31.4**	**29**
Čingovská 15	**32.4**	**41**
Čingovská 72	36	25
Magnezitárska 2	**37.8**	**22**
Fatranská 39	37.9	24
Hrabová 8	**43.4**	**19**
Kmeťova 51	35.4	26
Komenského 56	33.8	28
Obrody 63	38.4	22
Park angelium 58	35.1	26
Park mládeže 4	34.2	27
Severné Nábrežie 30	45.1	18
Sokolovská 23	**47.6**	**17**
Starozagorská 5	46.5	18
Šuhajova 49	34.3	27
Šuhajova 70	40.5	21
Turgenevova 66	37	24
Zinková 9	**37.8**	**22**
Zupkova 7	**43**	**19**

2.1 Maximum temperature

The studies on urban heat islands in other cities in world are focusing on air temperatures rather than focusing on surface temperatures as a first factor. There are several types of heat islands depending on the climate and topography [5].
This study of heat island in Košice is focusing also on air temperatures, following study of efficiency of green roofs to mitigate urban heat island effect in Rio de Janeiro [5]. Online data from period July 01-31, 2015 **(bold text)** were supplemented with calculated data (regular text) caused by gaps in measurement, using data from period July 01-31, 2016, mathematic calculation and taking into account the location of weather station.
The study uses maximum temperatures, because it takes the worst case scenario into account. Spatial distribution of temperature trends in July 2015 in Košice is pictured in Fig.2 and Fig.3. The distribution of temperature trends used only data (max. temperature [°C]) listed in Tab.1. Tab.2 represents the distribution of temperature of each weather station.

Table 2 Range of maximum temperature trends in 07/2015

address	30-	32-	34-	36-	38-	40-	42-	44-	46-
Berlínska 3					■	■			
Branisková 25				■	■	■			
Brnenská 41				■	■	■	■		
Bukovecká 43			■	■	■				
Bukovecká 68			■	■	■				
Cesta pod Hradovou 6		■	■	■	■	■			
Čingovská 15	■		■	■	■				
Čingovská 72			■	■	■				
Magnezitárska 2		■	■	■	■	■			
Fatranská 39				■	■	■			
Hrabová 8					■	■	■		
Kmeťova 51				■	■	■			
Komenského 56		■	■	■	■	■			
Obrody 63				■	■	■	■		
Park angelium 58				■	■	■			
Park mládeže 4		■	■	■	■	■			
Severné Nábrežie 30					■	■			
Sokolovská 23				■	■	■	■		
Starozagorská 5							■	■	■
Šuhajova 49				■	■	■	■		
Šuhajova 70				■	■	■	■		
Turgenevova 66				■	■	■			
Zinková 9			■	■	■				
Zupkova 7						■	■		

The urban microclimate is influenced by urban form and surfaces. City is characterized by impervious surface with high concentration of anthropogenic activities leading to significant increases in the air temperature and the surface temperature. The urban heat island effect occurs in cities all around the world and it is a result of different thermal properties of surfaces in urban areas. In Košice during summer 2015, up to 15.2°C temperature differences (minimum 32.4°C, maximum 47.6°C) occurred comparing one housing estate to another housing estate. The biggest extremes are observed in Nad Jazerom and Krásna housing estates. The differences are due to presence of heat station, lake and park near weather stations used for this research.

2.2 Minimum humidity

Spatial distribution of humidity trends in July 2015 in Košice is pictured in Fig.4. The distribution of humidity trends used only data (min. humidity [%]) listed in Tab.1. The study uses minimum humidity because it takes the worst case scenario into account. The first radius of minimum humidity of each weather station represents 250 meters, minimal distance between weather stations used for this research. The second radius represents 500 meters. Tab.3 represents the distribution of humidity of each weather station.

Table 3 Range of minimum humidity trends in 07/2015

address	41	29	28	27	26	25	24	23	22	21	20	19	18	17
Berlínska 3									■					
Branisková 25						■								
Brnenská 41										■				
Bukovecká 43											■			
Bukovecká 68									■					
Cesta pod Hradovou 6		■												
Čingovská 15	■													
Čingovská 72						■								
Magnezitárska 2									■					
Fatranská 39							■							
Hrabová 8												■		
Kmeťova 51					■									
Komenského 56			■											
Obrody 63									■					
Park angelium 58					■									
Park mládeže 4				■										
Severné Nábrežie 30													■	
Sokolovská 23														■
Starozagorská 5													■	
Šuhajova 49				■										
Šuhajova 70										■				
Turgenevova 66							■							
Zinková 9									■					
Zupkova 7												■		

The detail of spatial distribution of humidity trends in July 2015 in Košice focusing on city centre and surrounding housing estates is pictured in Fig.4. The distribution used only data listed in Tab.1. 22 self-governing neighborhoods have more than just one humidity zone. The biggest extremes are observed in Nad Jazerom and Krásna housing estates. The differences are due to presence of heat station, lake and park near weather stations used for this research. Important is that these measurement results are related to the temperature measurements. The weather stations with higher temperatures have lower humidity and the weather stations with lower temperatures have higher humidity. In Košice during summer 2015 up to 24% humidity differences (minimum 17%, maximum 41%) occurred in comparison one housing estate to another housing estate.

3 Maps of maximum temperature and minimum humidity

3.1 Maximum temperature

Modelling and analysing tools of ArcGIS – Geostatistical Analyst – in modelling of spatial distribution of temperature trends were used. Geostatistics is based on the regionalization of random variable in a given area. A set of random variables generated random function. Random function model is based on a study of the spatial variability of the studied phenomenon in different directions – experimental variogram. The result of this study is a mathematical model of variogram defined by changing the spatial variability in different directions of space by anisotropy and autocorrelation. Calculation of empirical semivariogram is written in the form [6]:

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [z(s_i) - z(s_i + h)]^2 \quad (6.1)$$

where: $\gamma(h)$ is estimated semivariation for the distance h; $n(h)$ is the number of pairs of measured points separated by a distance h; $z(si)$ is a measured value in point (si).

The first step is the calculation of empirical semivariogram. Followed by the transfer of empirical semivariogram by its theoretical model and determining its parameters. Model found for a given set of data depends on the experimental and theoretical assumptions.

The determining of semivariogram parameters is followed by the actual process of estimating the phenomenon of unknown values based on known data – Kriging [6].

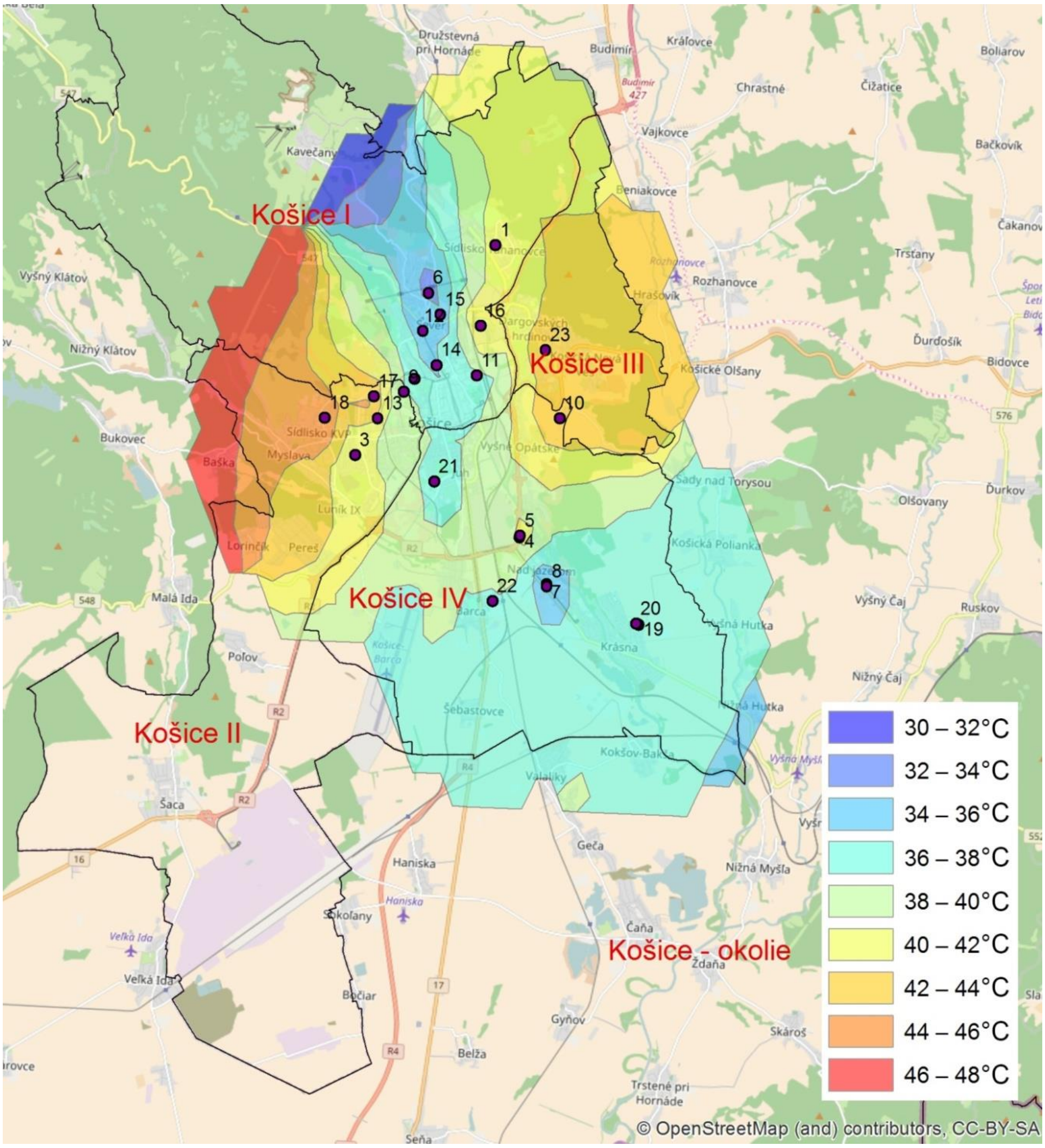

Figure 2 - Spatial distribution of temperature trends in July 2015 in Košice

The detail of spatial distribution of temperature trends in July 2015 in Košice focusing on city centre and surrounding housing estates is pictured in Fig.3.

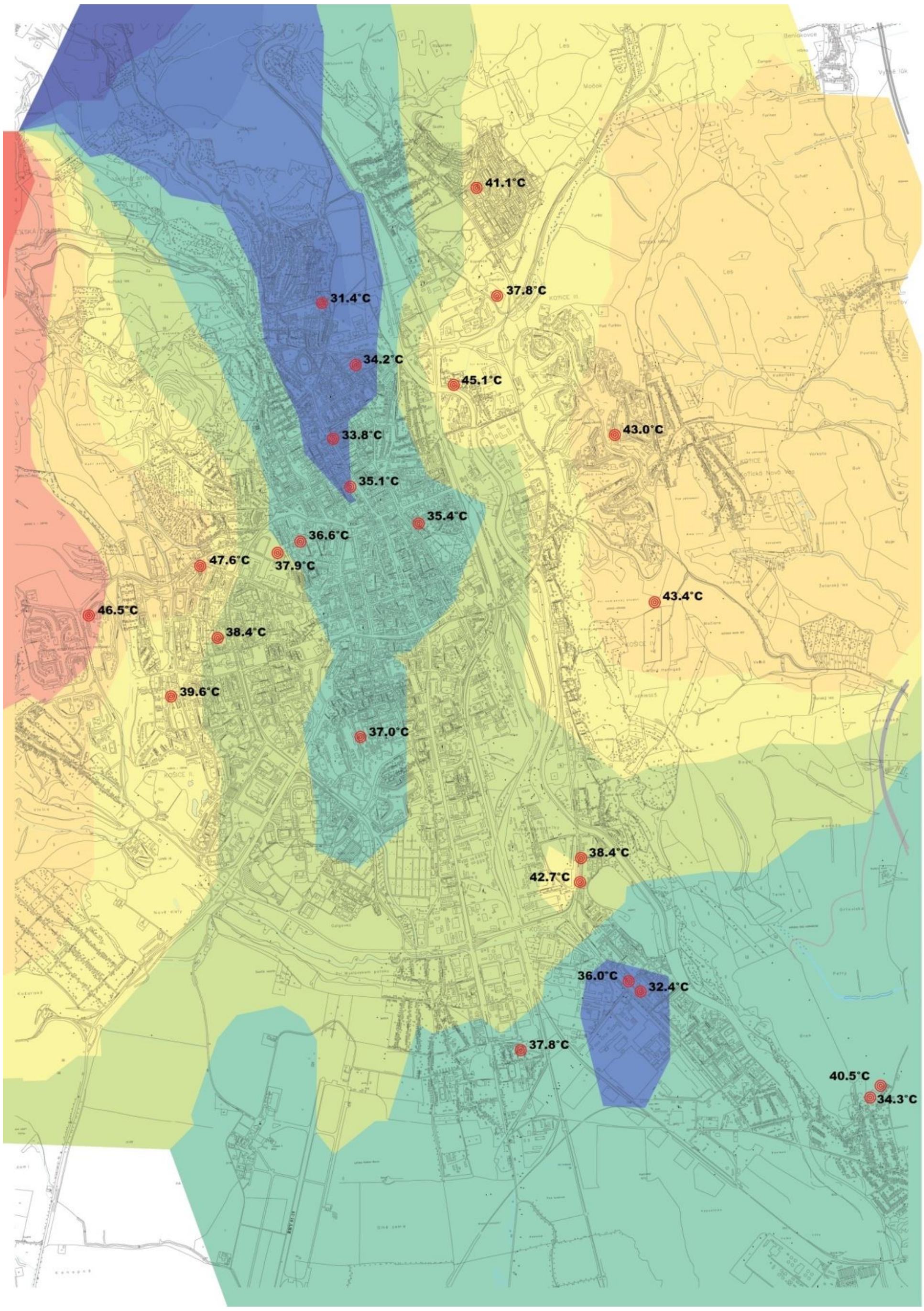

Figure 3 - Spatial distribution of temperature trends in July 2015 in Košice – detail

3.2 Minimum humidity

The detail of spatial distribution of humidity trends in July 2015 in Košice focusing on city centre and surrounding housing estates is pictured in Fig.4.

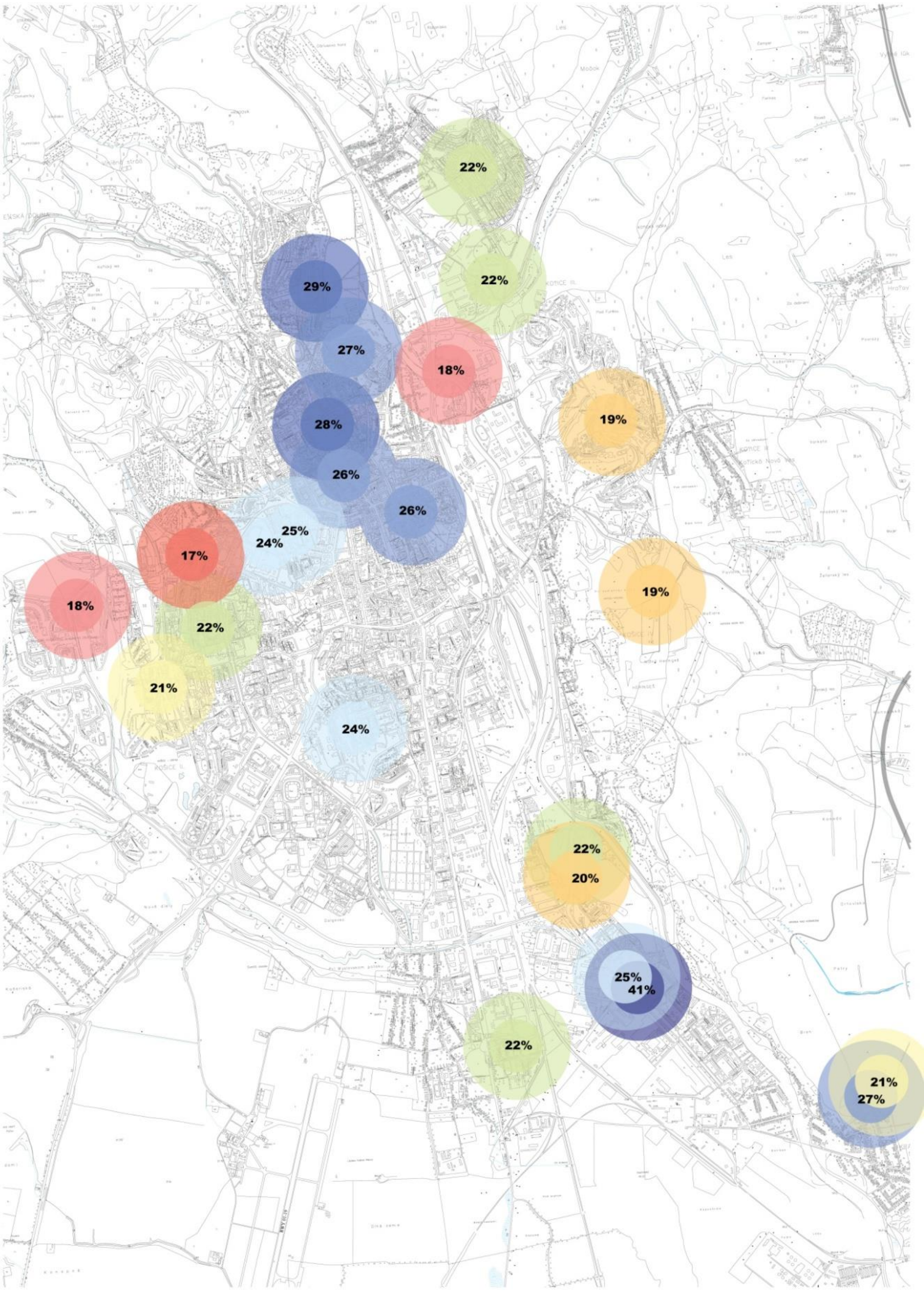

Figure 4 - Spatial distribution of humidity trends in July 2015 in Košice – detail

4 Green roofs beating low humidity

Košice was chosen as a study area to demonstrate the possibility to mitigate low humidity and therefore heat island in the city center and housing estates implementing green roofs. The chapter deals with the possibility to use green roof structures to manage stormwater runoff delay, its reduction into the public drainage system and its storage for later reuse.

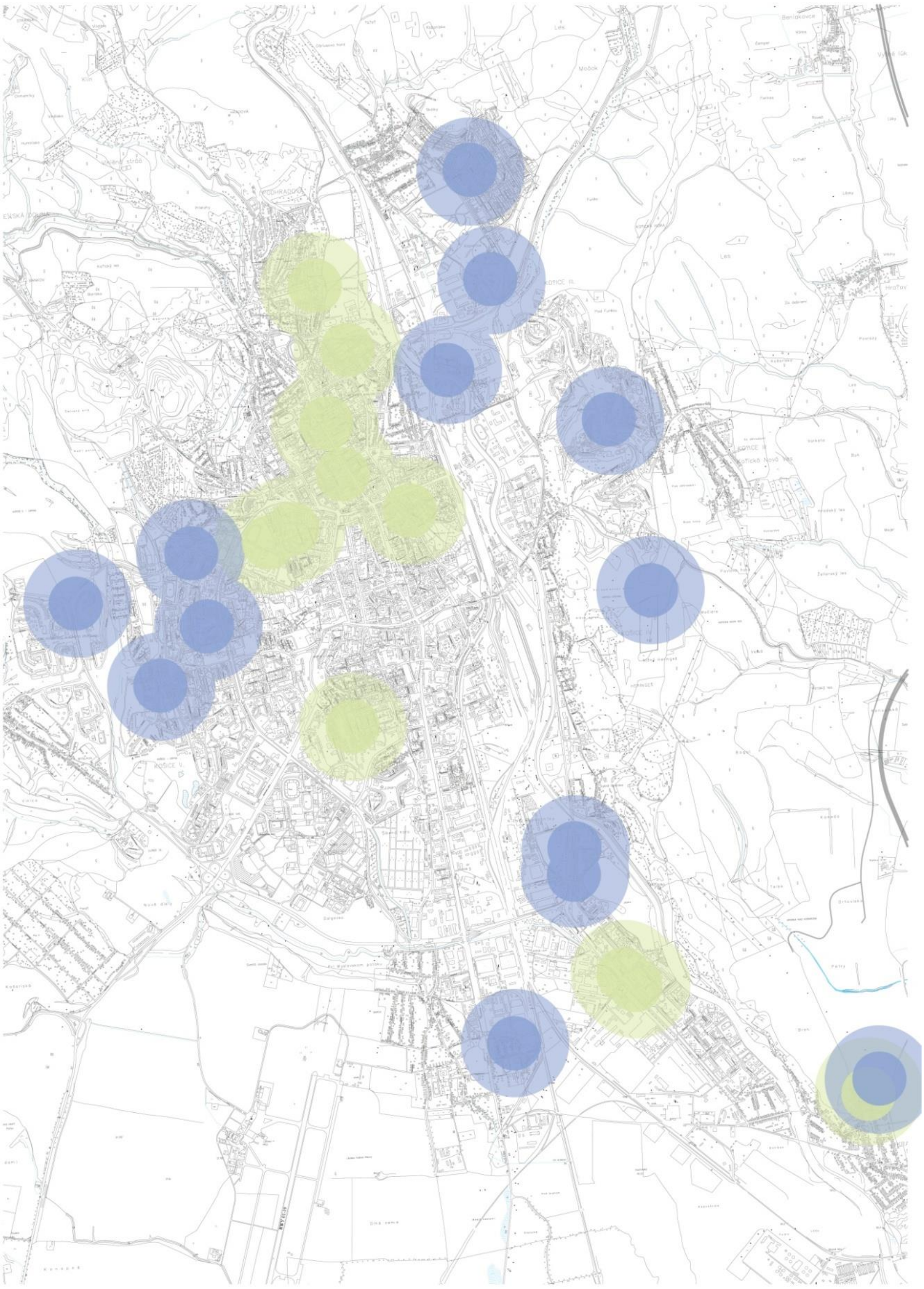

Figure 5 - Allocation of green roofs in Košice following spatial distribution of humidity trends

Green roofs in urban areas are significant due to their capacity of water storage in the layers of the roof. This capacity, retention quality, allows minimizing the effect of extreme rainfall in short period. Retaining water in the layers of the green roof means reducing the flood peak in the urban drainage system and reducing the risk of water distress.

5 Conclusion

The research uses 2 typical types of different green roof construction: with low retention qualities and with high retention qualities.

The area with low humidity (17-22%) needs green roof construction with higher retention qualities (Fig. 5, “blue color”). The city area with higher humidity (24-41%) needs green roof construction with lower retention qualities (Fig. 5, “green color”).

The first radius of suggested green roof construction represents 250 meters. The radius represents minimal distance between weather stations used for this research. The second radius of suggested green roof construction represents 500 meters.

The map of green roofs in Košice (Fig. 5) is modeled using data in Tab. 1. Allocation of two different major types “green color roofs” and “blue color roofs” of green roofs follows these data. More input data is needed to complete more precise and more accurate map of green roofs of Košice city.

Acknowledgments

This work was supported by: VEGA 1/0202/15 Sustainable and Safe Water Management in Buildings of the 3rd. Millennium and Slovak Cultural and Education Grant Agency (contract No. 073TUKE-4/2015).

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5 Presentations of Authors

Zuzana Poorova is a PhD student at the Faculty of Civil Engineering, Technical University in Kosice, Institute of Architectural Engineering. She is specialized in green roofs and their retention qualities.

Zuzana Vranayova is professor at the Faculty of Civil Engineering, Technical University in Kosice, the director at Institute of Architectural Engineering and the academic senate chaiman. She is conducting various researches on her major field of study of water supply and drainage system in buildings at Department of Building Services.

PP06 - Studies on Seal break prevention in Siphonic drainage system with 20m piping

K. Akutsu (1), K. Sakaue (2), T. Inada (3),T. Mitsunaga(4)

1. ce63001@meiji.ac.jp
2. sakaue@isc.meiji.ac.jp
3. to-inada@suga-kogyo.co.jp
4. mitunaga-t@yamashitasekkei.co.jp

(1), (2) Dept. of Architecture, School of Science and Technology, Meiji University, Japan

(3) SUGA Co, Ltd, Japan

(4) Yamashita Sekkei Inc., Japan

Abstract

The siphonic drainage system drives Siphonage which is generated by filled flow in the piping. It is possible to install with small diameter and no slope piping, and become flexible in piping design. For this drainage systems, the trap part is an important role as a device for prevention of odors backflow, but sufficient consideration has not been given to prevent from seal break of traps.

In previous studies, it clarified the flow characteristics and the influence of seal loss using a real scale experimental models that the horizontal pipe length is 20 m, and a S trap and an air admittance valve are installed in the inflow part. As one of the results, when the air admittance valve was installed, it was confirmed a few cases that the seal loss increased as supply flow rates increased.

Therefore, in this study, we focused on flow characteristics and the seal loss of S trap when installing an air admittance valve or a self-sealing trap, which doesn't need seal water, in the inflow part. And we examined about the appropriate method for seal break prevention in siphonic drainage system.

Keywords

Siphonic drainage system; Seal break; Air admittance valve; Self-sealing trap

1 Introduction

Siphonic drainage system operates using siphonage generated by filled flow in the piping as a driving force. It is expected to grow in popularity as it can be installed with small diameter pipes and no slope, which greatly increases flexibility in piping design. While water seal trap has been playing an important role in preventing drainage gas from entering indoors, not much consideration has been given to the retention of seal water in trap.

The previous studies have examined the effects of seal water retained in trap on flow characteristics and seal loss in a simulated factory drainage system where U-PVC pipes with horizontal length of 20 m, and S trap and air admittance valves were attached at the inflow part. As a result, it was found that seal loss had become larger as supply flow rate increased when air admittance valves were used.

In this study we conducted experiments to examine the validity of backflow prevention apparatuses of odor in the siphonic drainage system. We attached S traps and air admittance valves at the inflow part, and observed the effects of flow characteristics and S trap on seal loss when the positions of the valves were varied, and self-sealing traps were attached.

2 Drainage Experiment Using S trap

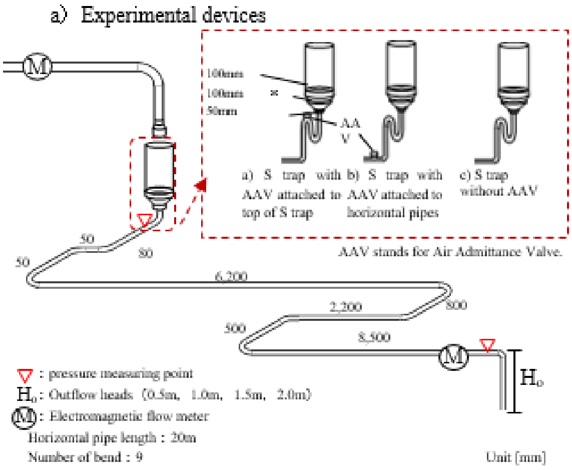
Experiments were conducted to examine the effects of the attachment and Apositions of air admittance valves in preventing seal break in water seal trap.

2.1 Outline of Experiment

2.1.1 Experimental Apparatus

The outline of the experimental apparatus is shown in Figure 1. Two sizes of U-PVC pipes (φ20mm,φ 25mm) with horizontal length of 20 m and outflow heads of 0.5 ~ 2.0 m were used. Pressure was measured near inflow and outflow sections. Supply flow rate and flow velocity were measured with an electromagnetic flow meter located near outflow elbow.

a) Experimental devices



b) Constructional

Type	S trap
Diameter	φ20mm φ25mm
Depth of seal water	60mm
Ratio of leg's cross sectional area	1.0

Type	Air admittance valve
Material	ABS
Vent flow rate	$3.86\times10^{-3}m^3/s$
Resistance ciefficient※	8.41

※The condition of -500pa

Figure 1. Experimental apparatus

2.1.2 Flow phase

Experimental conditions were shown in Table 1. Two sizes of pipe (φ20mm, φ25mm), three configurations of inflow part, four outflow heads (0.5m ~ 2.0mm) and six supply flow rates (10, 12, 18, 24, 30 and 36 L/min.) were used. Measurements were made twice for the total of 144 patterns for 2 minutes each (sampling frequency: 50 Hz).

Table 1. Experimental conditions (with S traps)

Diameter [mm]	Pattern of inflow part		Outflow head [m]	Supply flow rate [L/min]
20・25	S trap with AAV	AAV attached to top of S trap	0.5・1.0・1.5・2.0	10・12・18・24・30・36
		AAV attached to horizontal pipes		
	S trap without AAV			

※Common condition　Material：U-PVC,　Horizontal pipe length：20m

2.2 Results and Discussion

2.2.1 Flow Phase

The images of flow phases are shown in Figure 2, and flow phases with air admittance valves attached in Table 2. Pressure in drain and discharge flow velocity with φ25mm pipe, outflow head of 1.5 m and supply flow rate of 24 L/min. are shown in figure 3 as an example of experimental results.

As there were no significant differences in flow phase for different experimental conditions, it is assumed that the attachment and positions of air admittance valves had little effects on flow phases.

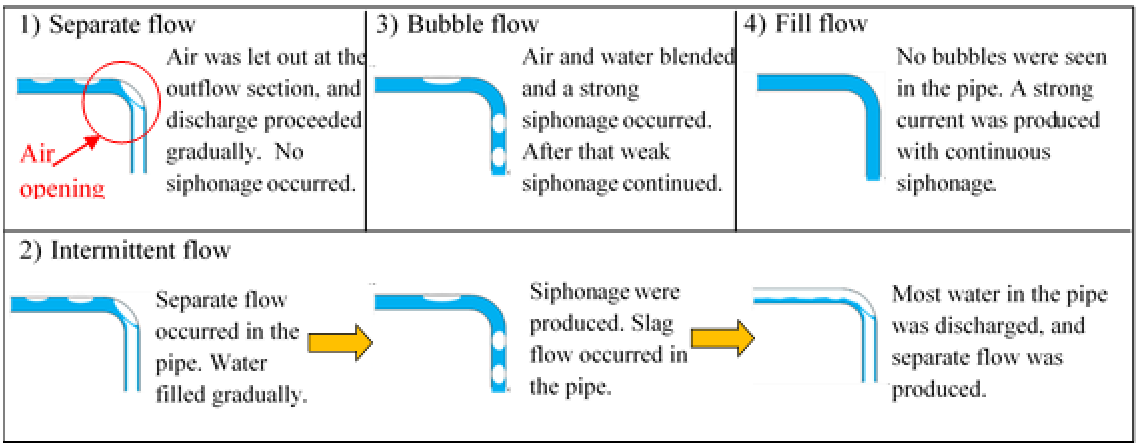


Figure 2. Illustrations of flow phase

Table 2. Flow phases

Diameter	φ20mm								φ25mm							
Inflow part	S trap with AAV attached to top of S trap				S trap with AAV attached to horizontal pipes				S trap with AAV attached to top of S trap				S trap with AAV attached to horizontal pipes			
Outflow head [m] / Flow rate [L/min]	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0
10	Bubble flow	Intermittent flow	Intermittent flow	Intermittent flow	Bubble flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow	Separate flow	Separate flow	Intermittent flow	Intermittent flow	Separate flow	Separate flow
12	Bubble flow	Bubble flow	Intermittent flow	Intermittent flow	Bubble flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow
18	Fill flow	Bubble flow	Bubble flow	Bubble flow	Fill flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Intermittent flow	Bubble flow	Bubble flow	Intermittent flow	Intermittent flow
24		Fill flow	Fill flow	Bubble flow		Fill flow	Fill flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow
30									Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow
36									Fill flow	Fill flow	Fill flow	Fill flow	Fill flow	Fill flow	Fill flow	Fill flow

※ Shaded areas indicate "Drainage impossible".

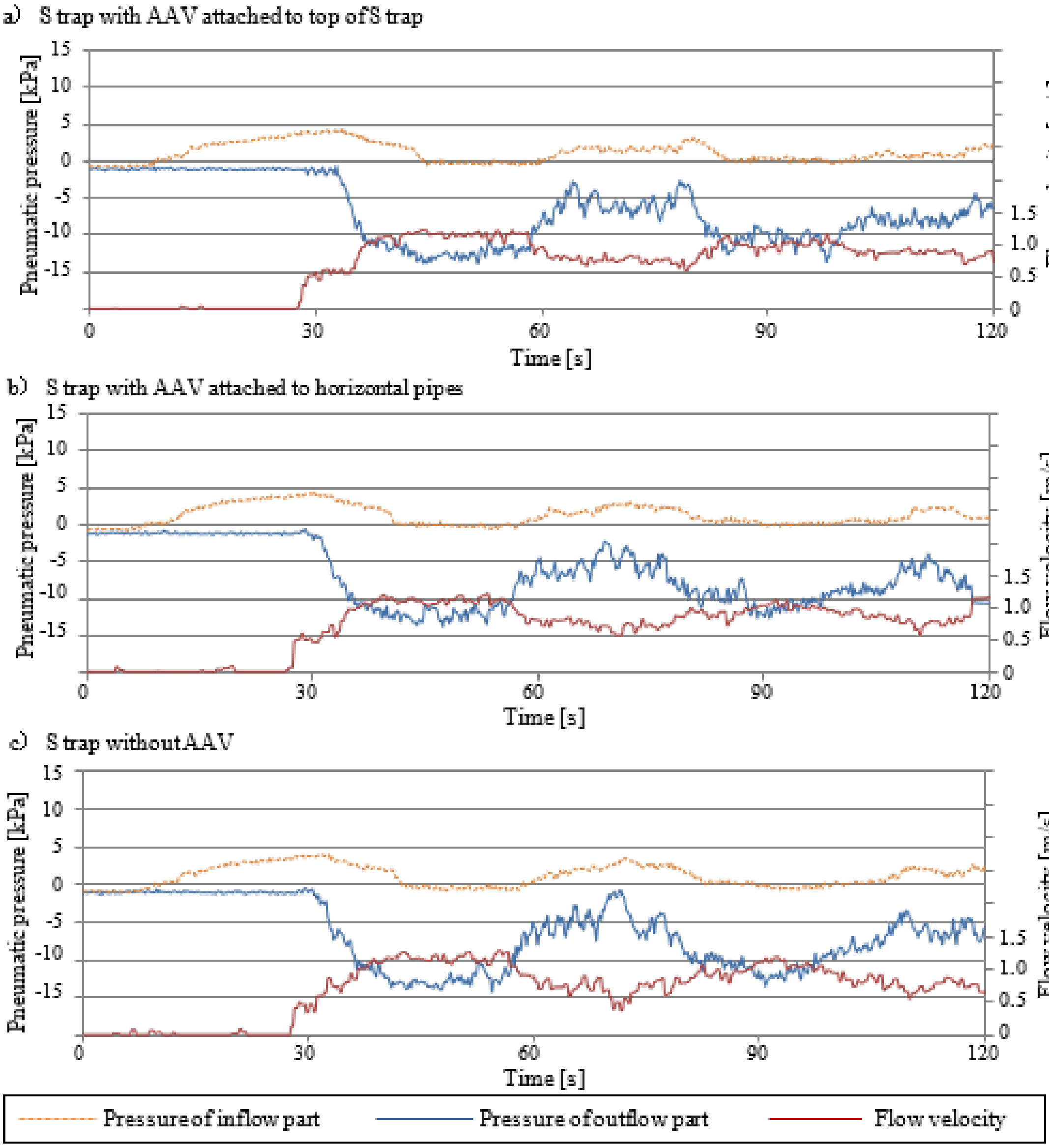


Figure 3. Fluctuations of pressures in drain and discharge flow velocity (the condition of inflow part with S traps, φ25 mm pipes, outflow heads of 1.5 m, supply flow rate 24L/min.)

2.2.2 Maximum Siphonic Negative Pressure and Maximum Flow Velocity

The relationship between supply flow rate and maximum siphonic negative pressure in φ25mm pipe is shown in Figure 4 and that between supply flow rate and maximum flow velocity in Figure 5.

Maximum siphonic negative pressure varied little in response to the differences in pipe diameter, attachment or positions of air admittance valves, but was affected by the heights of outflow heads. Neither did maximum flow velocity show significant differences due to attachment or positions of air admittance valves.

From these results, it can be safely assumed that the positions of air admittance valves had little effects on either maximum siphonic negative pressure or maximum flow velocity.

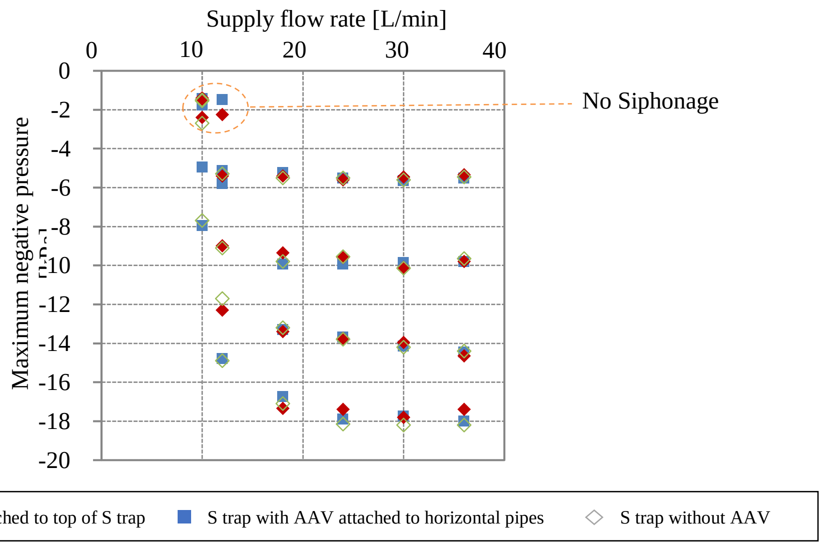


Figure 4. Maximum siphonic negative pressure (φ25 mm pipes)

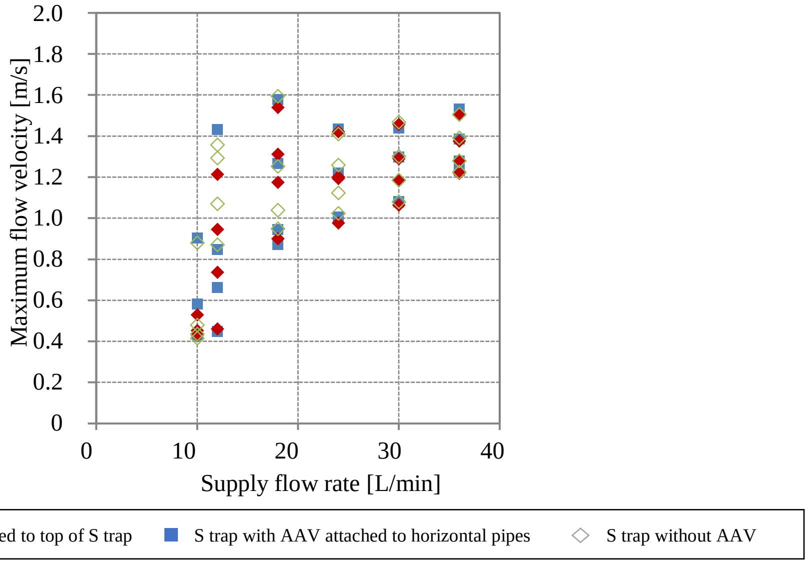


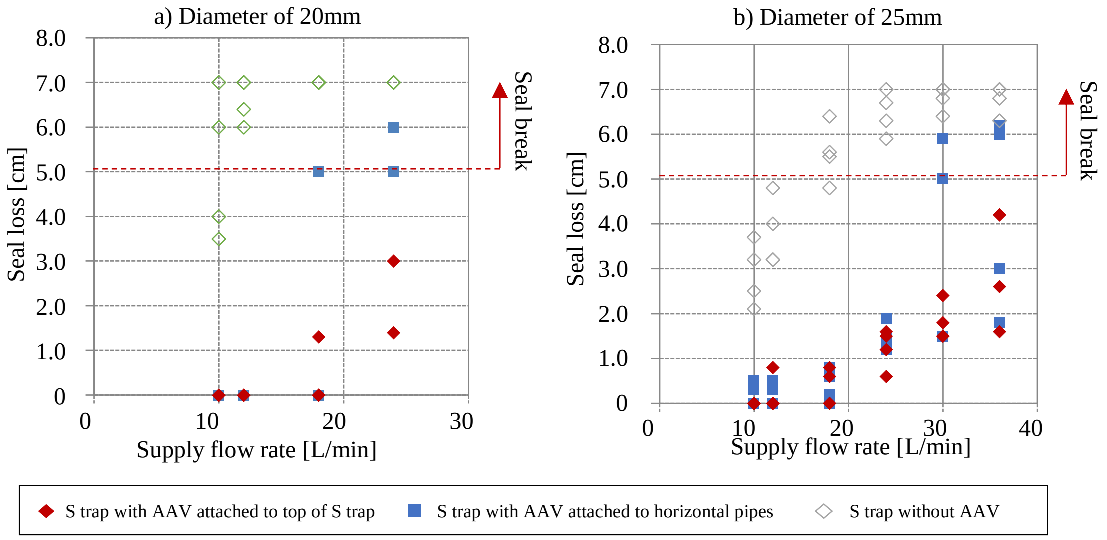
Figure 5. Maximum flow velocity (φ25 mm pipes)

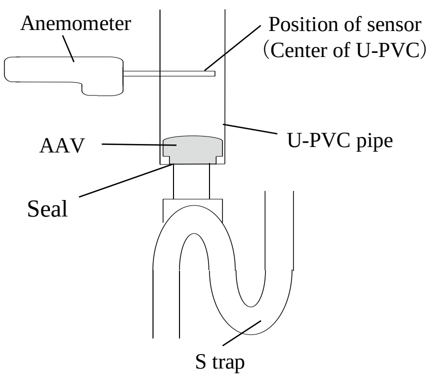
2.2.3 Seal Loss

The relationships between seal loss and supply flow rate in all experimental conditions are shown in Figure 6. The measuring method of air flow velocity in air admittance valves is shown in Figure7, and fluctuations in air flow velocity measured at air admittance valves with φ20mm pipe, outflow head of 2.0 m and supply flow rate of 24 L/min. is shown in Figure 8. Seal loss greatly reduced when air admittance valves were attached as opposed to when S traps only were used, but seal break occurred with large supply flow rates when air admittance valves were attached to horizontal pipes. On the other hand, seal break did not occur when air admittance valves were attached to the top of traps with maximum seal loss of 3.0 cm in φ20mm and 4.2 cm in φ25mm.

As shown in Figure 7, air velocity was measured after the inflow part was covered with U-PVC pipe and the sensor of an anemometer was attached at the center of U-PVC pipe. Air flow tended to start about 3 seconds later when air admittance valves were attached to horizontal pipes than when they were attached to the top of S traps. This may explain why seal loss was larger when horizontal pipes were attached.

Therefore, the top of S trap seemed to be an appropriate position to install an air admittance valve.





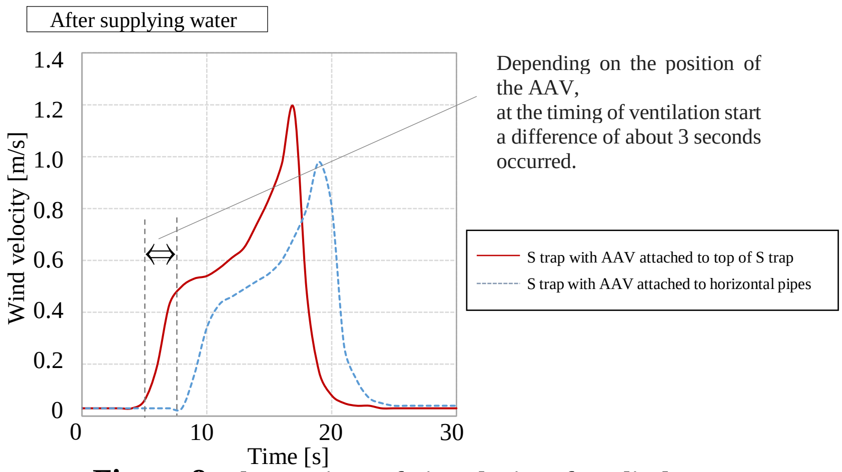


Figure 7. Imaege of method of measuring air velocity

Figure 8. Fluctuations of air velocity after discharge (with 20 A pipes, outflow heads of 2.0 m, supply flow rate 24 L/min)

3 Discharge Experiment When Self-Sealing Trap was Attached

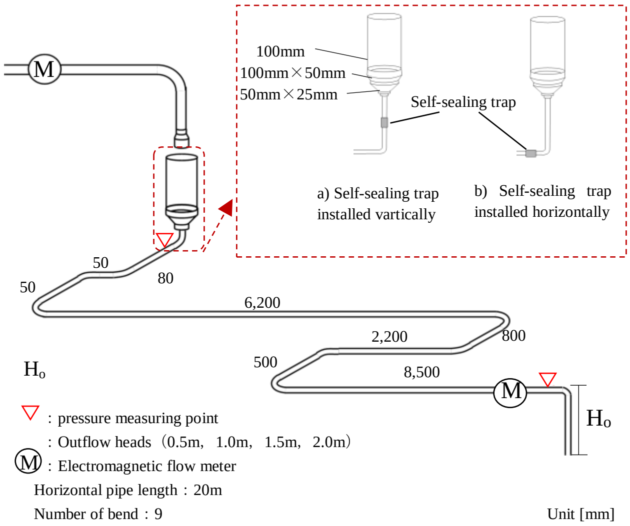
Other than water seal trap, self-sealing trap can be used to prevent odors in drainage pipes from flowing backward. In order to see the validity of self-sealing trap, we attached self-sealing trap to the inflow part and conducted discharge experiments.

3.1 Outline of Experiment

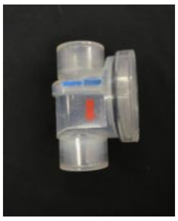
3.1.1 Experimental Apparatus

The outline of the experimental apparatus is shown in Figure 9. U-PVC pipes (φ20mm, φ25mm) were used with horizontal length of 20 m and outflow heads of 500 ~ 2,000 mm. Pressures were measured at two points, near the inflow part and the outflow part. Discharge flow rate and flow velocity were measured with an electromagnetic flow meter attached near the outflow elbow.

a） Experimental devices



b） Constructional



Type	Self-sealing trap
Diameter	φ20mm, φ25mm
Material	Body part：ABS Membrane：Silicon

Figure 9. Experimental apparatus

3.1.2 Experimental Conditions

Experimental conditions were shown in Table 3. Two sizes of pipe (φ20mm, φ25mm), three configurations of inflow part, four outflow heads (0.5m ~ 2.0m) and six supply flow rates (10, 12, 18, 24, 30 and 36 L/min.) were used. Number of measurements were twice for the total of 96 patterns for 2 minutes each (sampling frequency: 50 Hz).

Table 3. Experimental conditions (with self-sealing traps)

Diameter [mm]	Pattern of inflow part		Outflow head [m]	Supply flow rate [L/min]
20・25	Self-sealing trap	Vartical installation	0.5・1.0・1.5・2.0	10・12・18・24・30・36
		Horizontal installation		

※Common condition　Material：U-PVC，Horizontal pipe length：20m

3.2 Results and Discussion

3.2.1 Flow Phase

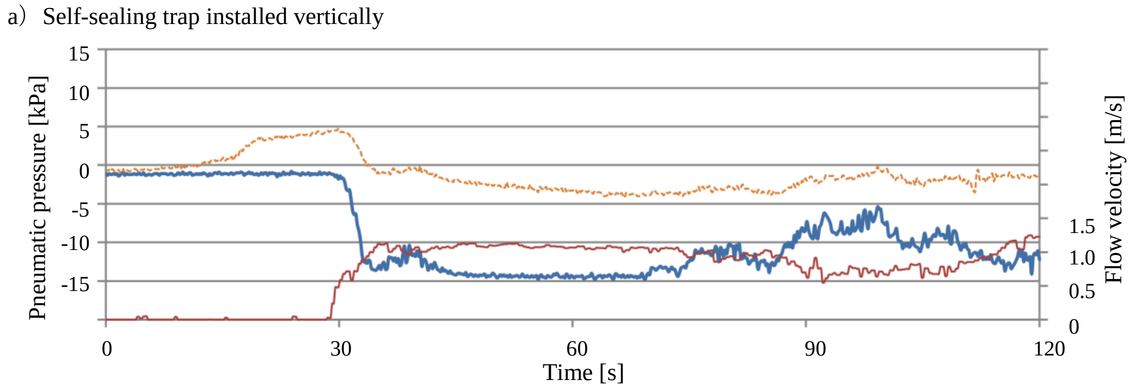
The fluctuations in pressure in drain and discharge flow velocity with φ25mm pipe, outflow head of 1.5 m and supply flow rate of 24 L/min. are shown in figure 10 and flow phases in Table 4 as an example of experimental results.

On the whole, flow phase showed similar patterns as with S trap when supply flow rate was low. However, discharge tended to fail more frequently when supply flow rate was large. This could be attributed to the fact that the opening area of the membrane on a self-sealing trap was smaller than that of S trap, and that the water in the lower portion of the membrane pushed back the membrane creating resistance when water level was higher than the position of a self-sealing trap, and as a result the water level in the inflow part also went up.

Table 4. Flow phase (with self-sealing traps)

Diameter	φ20mm								φ25mm							
Inflow part	Self-seling trap installed horizontally				Self-seling trap installed vartically				Self-seling trap installed horizontally				Self-seling trap installed vartically			
Flow rate [L/min] \ Outflow head [m]	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0
10	Intermittent flow	Intermittent flow	Intermittent flow	Intermittent flow	*Bubble flow*	*Bubble flow*	Intermittent flow	Intermittent flow	Separate flow	Separate Flow	Separate flow	Separate flow	Separate flow	Separate flow	Separate flow	Separate flow
12	*Bubble flow*	*Bubble flow*	*Bubble flow*	*Bubble flow*	*Bubble flow*	*Bubble flow*	*Bubble flow*	*Bubble flow*	Intermittent flow	Intermittent flow	Intermittent flow	Separate Flow	*Bubble flow*	*Bubble flow*	*Bubble flow*	*Bubble flow*
18	Fill flow	Fill flow	*Bubble flow*	*Bubble flow*	Fill flow	Fill flow	*Bubble flow*	*Bubble flow*	*Bubble flow*	*Bubble flow*	Intermittent flow	Intermittent flow	*Bubble flow*	*Bubble flow*	*Bubble flow*	*Bubble flow*
24			Fill flow	Fill flow			Fill flow	Fill flow	*Bubble flow*	*Bubble flow*	*Bubble flow*	*Bubble flow*	Fill flow	*Bubble flow*	*Bubble flow*	*Bubble flow*
30									Fill flow	Fill flow	Fill flow	Fill flow		Fill flow	Fill flow	*Bubble flow*
36																

※Shaded areas indicate "Drainage impossible"



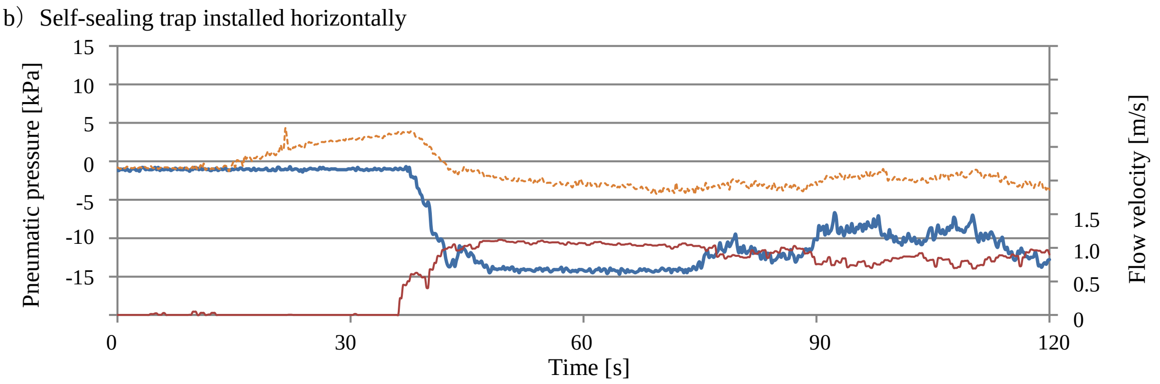


Figure 10. Fluctuations of pressures in drain and discharge flow velocity (the condition of inflow part with self-sealing traps, φ25 mm pipes, outflow heads of 1.5 m, supply flow rate 24 L/min.)

3.2.2 Maximum Siphonic Negative Pressure and Maximum Flow Velocity

The relationship between supply flow rate and maximum siphonic negative pressure in φ25mm pipe is shown in Figure 11 and that between supply flow rate and maximum flow velocity in Figure 12. Maximum siphonic negative pressure and maximum flow velocity showed similar values both with self-sealing trap and with S trap. From this it can be safely concluded that there is little difference in maximum siphonic negative pressure and maximum flow velocity between self-sealing trap and S trap.

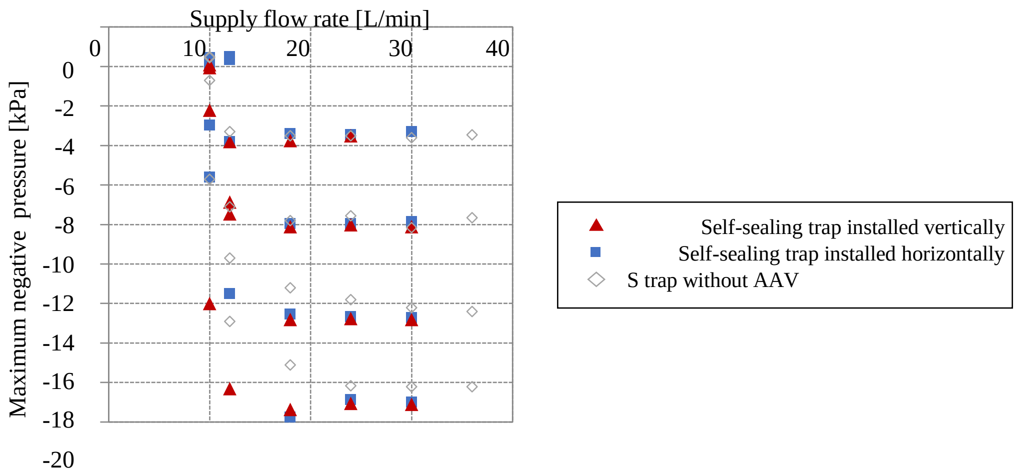


Figure 11. Maximum siphonic negative pressure (with φ25mm self-sealing

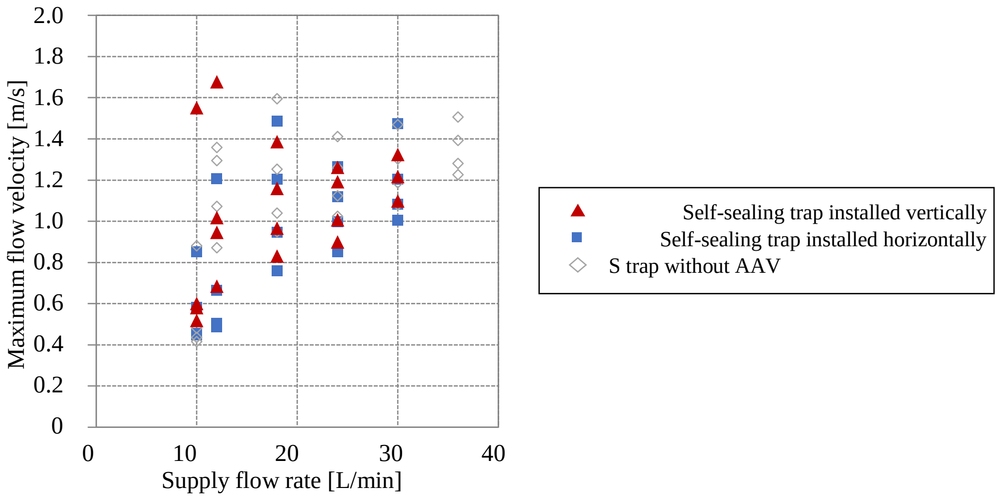


Figure 12. Maximum flow velocity (with φ25mm self-sealing traps)

3.2.3 Noise Caused by Membrane viberation

Noise caused by membrane was heard during and after discharge in all experimental conditions. The noise seems to have been occurred as the membrane was pulled by negative pressure exerted on the inflow part during siphonic drainage. Two kinds of noise were recognized: explosive noise and membrane's vibrations resonating in the pipe. This seems to indicate the necessity of taking measures against noise when using self-sealing trap in the siphonic drainage system.

4 Conclusion

The findings in this study can be summarized as follows:
1) The effects of self-siphonage on seal loss differed according to the positions of air admittance valves. Valves operated quickly, and their protection of seal water was the most effective when they are attached to the top of traps (the inflow side of seal water).
2) Discharge failure tended to occur when self-sealing traps were attached to the inflow part with a large supply flow rate. Noise caused by membranes was also heard.
Further studies are required to examine the nature of the noise occurred with self-sealing traps.

5 References

1. Mitsunaga,T.,Sakaue,K(2016),Studies on Flow Characteristics in Siphonic Drainage Systems Part 14 Seal Loss and Flow Characteristics in Long piping model installed Air-admittance valve, Technical papers of annual meeting, the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan

6 Presentation of Authors

Kenta Akutsu a master of the student at the Sakaue laboratory, Department Of Architecture, School of Science and Technology at Meiji University in Japan.

Kyosuke Sakaue (Dr. Eng.) is a professor at Department of Architecture, School of Science & Technology, and head of New Plumbing System Institute, Meiji University.
His fields of specialization include water environment, building services and plumbing system.

Tomoo Inada (M. Eng.) works for SUGA Co, Ltd.,
He specializes in plumbing and sanitation.

Takehiko Mitunaga (Ph. D) is an engineer at Yamashita Sekkei Inc.
He belongs to Mechanical Systems Design Development.
He finished the doctoral course for worker in Architecture
at Meiji University in Japan.

PP07 - Alternative solutions for domestic hot water recirculation

Th. Mateescu*; R. Luciu*; A. Baran*(1); I. Cazacu*
1. i.aandreea@yahoo.com
(*)Proffessors and researchers from the Building Services Engineering Department from the "Gheorghe Asachi" Technical University of Iasi, Romania

Abstract

In the distribution network of domestic hot water, the temperature drops significantly even if the consumption is low or missing.
Failure to ensure promptly the temperature at the consumption points causes waste of resources – water and energy – being also one of the main reasons why people tend to disconnect themselves from the central heating and domestic hot water supply system.
The modernisation of the existing systems from the collective housing such as block of flats, is in need for technical solutions capable to compensate the heat loss from the domestic hot water network, when it is not used.
The classical solution is to double the entire transportation and distribution network, starting from the source all the way to the consumption point.
In most of the cases, applying these ideas in the existing situation is extremly difficult and, most important, the costs are very high for the investor.
In this paper we have approached innovative solutions, capable to avoid the difficulties that might be encountered, by resolving them both local and at the source.
There are presented constructive and functional diagrams and computational models for dimmensioning the system.

Keywords

domestic hot water, recirculation of hot water, compensation of heat loss, energy saving

1 The need for recirculating installations

Considering the contemporany standards for civilisation, equipping buildings with water supply installation represents an important need both sanitary and for the confort of the users.
Technology's evolution and energy matters raise outstanding problems to meet mandatory requirments for optimal customer service, namely the promptness, continuity and stability of product delivery within rational limits of insurance and energy and economic efficiency.
Assuring the domestic hot water need depends on 3 parameters – temperature, instant flow and available quantities – and the acceptable values depend, also, on these requirments in the social context – way of living and education – on the level and state of equipment of the building.
Considering this, a very important part in the water supply system is the recirculation of domestic hot water installation, having the main role of providing promptly the needed temperature at the consumption point. The lack of this type of installation causes disconfort and, most important, it is not energy efficient.
In Romania the situation is found in urban assemblies built before 1990, that are provided with domestic hot water and heat fed into a centralized system, through thermal power stations dimensioned in order to serve 300/400-1000/1200 flats located in buildings, starting with 4 and up to 12 levels.
Long distance transportation and the unevenness of hot water consuption, with significat interruptions during the night, causes water to cool and delays it at the consumption point, but most importantly in the morining when the demand is high, it takes too much time and energy to provide the desired temperature for users. This can be translated into disconfort and waste of resources.

2 Functional and constructive solutions

Because it is impossible to correct the entire system, there have been analyzed and proposed technical solutions to eliminate the deficiences that may be encountered in the recirculation network, such as localy domestic hot water supply system.
Speaking only about the installations that are just inside the buildings, the thermal capacity and the investment are reduced by facilitating the access for the interested users. The intervention involves realising a local system for heating water and recirculate it between the source and user.

To ensure continuity in operation, the source must be of a bi-energy type, using as primary agent the heating agent (during the winter) and electric energy (during the summer) and have the needed stock to cover the simultaneous flows after the interruption that happen during the night.

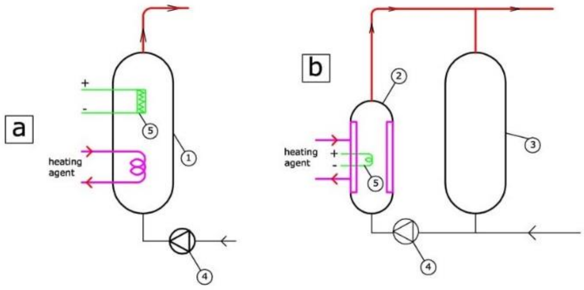


Figure 1 – a) during the winter, b) during the summer

For water recirculation it is foreseen the doubling of the circulation pipes - columns and distribution - throughout the installation (Figure 2) or only in the lower distribution (Figure 3)

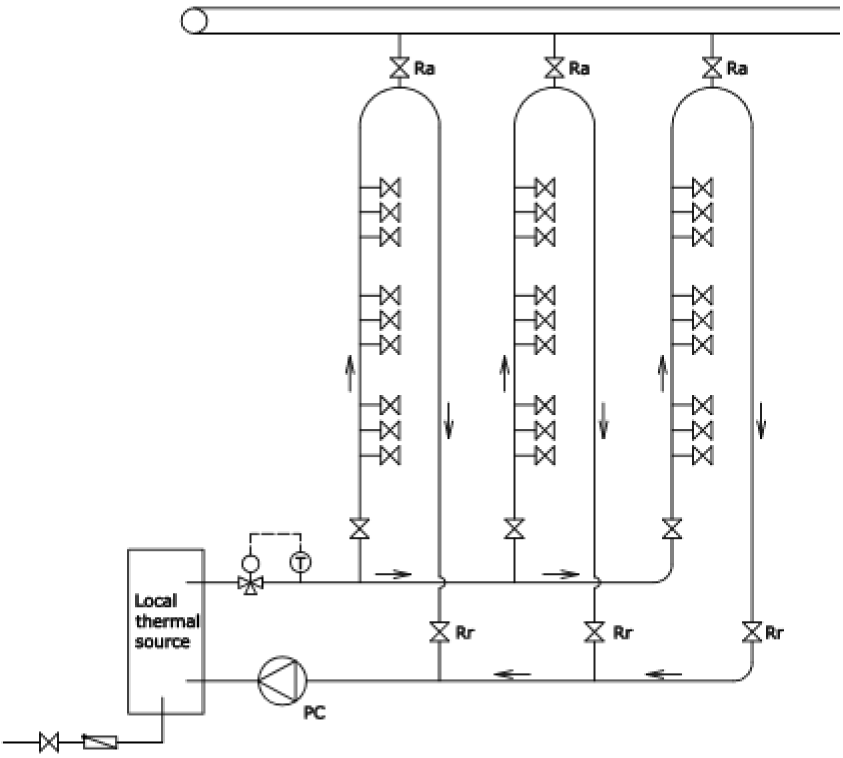


Figure 2 – Horizontal distribution

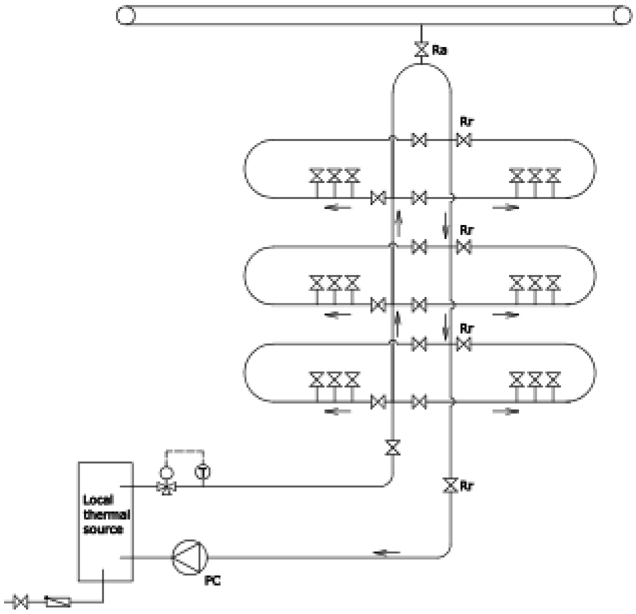


Figure 3 – Distribution on the column

The second variant represents an innovative, investment-friendly solution in which the water recirculation is carried out by means of the inner feeding columns at the top and connected to the base, alternatively, to the horizontal distribution and recirculation pipes. The supply of the sanitary fittings connected to the interconnected columns is, in this case, ascending, respectively descending

The total removal of the recirculation system can be accomplished by compensating the heat losses in the domestic hot water distribution ducts with electric heating cables attached to the pipes and distribution columns.

Compensating the effect of low-temperature water quantities taken from the outside network at the first use is provided with a local accumulating source – Figure 4.

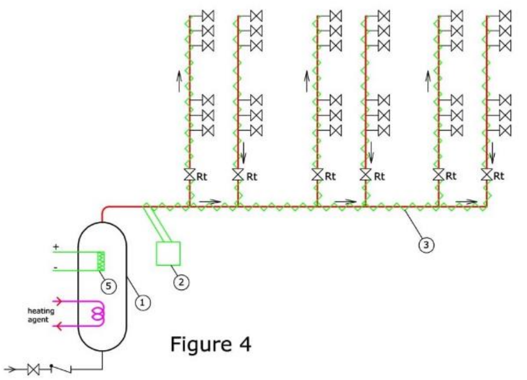


Figure 4 - The scheme of the heat loss compensation with electrical heated cables

The specific power for the heating cables, the thermal power and the capacity of the local source storage are determined similarly to the recirculation installations

The calculation of the installation consists in choosing the recirculation pump, sizing the heat exchanger and determining the storage volume.

3 Dimensioning the installation

The setting of the functional parameters and the sizing of the installations are made according to the dynamic / stationary heat losses corresponding to the geometry and the thermophysical characteristics of the materials and working agents.

3.1 Determining heat loss

The determination of the heat losses in the distribution network of the recycling flow is made from the differential equation of thermal balance and heat transfer:

$$dQ = D_{total} * c * dt = k\varpi d(1-\eta)(t_a-t_e)dL \quad (1)$$

resulting the amount of heat that is ceded:
$Q_{circ}=D_{total}*c*(t_{ainitial}-t_{afinal})$

or

$$Q_{circ}=k\varpi d(1-\eta)(t_a-t_e)L \quad (2)$$

Separating the variables in equation 1 and integrating the length of a section (L1) between the water temperature values in the extreme sections:

$$\int_{tainitial}^{tafinal} \frac{dt}{ta-te} = \frac{[k\pi d(1-\eta)]}{c * Dtotal} \int_{v}^{Li} dL$$

it is possible to determine the water temperature value in the final section of the section:

$$t_{afinal}=t_e+(t_{ainitial}-te)e^{[k\varpi d(1-\eta)]/c*Dtotal} \quad (4)$$

where:
t_e=ambient temperature
η = 0.3-0.6 – thermal insulation yield
k = global transfer coefficient

$$D_{total} = D_{distributed} + D_{recirculated} \quad (5)$$

3.2 Distributed flow

Is determined by the number of columns (i) and number (N) of receptors of type (j) running simultaneously from each column having the specific flow (q_{apa}) and the coefficient of simultaneity according to:

$D_{distributed} = \sum_{i=1}^{n} \sum_{j=1}^{m} (N * s * q) ij$ (6)

Where the coefficient of simultaneity is:

$s = \frac{1}{\sqrt{N-1}}$ (7)

3.3 Recirculating flow

Is calculated the amount of heat delivered by the water from the column / installation to the outside environment (Q_{recirc}) and the permissible reduction of the temperature at the receptors

$\Delta t_{admis} = t_{distr} - t_{min.adm} \cong 50/55 - 40 = 10/15°C$ (8)

$D_{recirc} = Q_{recirc}/c * \Delta t_{admis}$ (9)

The cured heat is determined by the specific heat dissipation (Q_0) and pipe length

$Q_{recirc} = (t_a - t_e)\Sigma(Q_0 * L)I$ (10)

where the specific failure (Q_0) is calculated for each pipe according to diameter (d), the overall transfer coefficient (K) and the thermal insulation efficiency (η) using:

$Q_0 = k\varpi d(1-\eta)$ (11)

where:
t_a = water temperature in the pipe
t_e = ambient temperature
η = thermal insulation efficiency, representing the ratio between reducing heat loss through pipe insulation (Q_{izol}) and losses in non-insulated pipes (Q_t)

$\eta = 1-(Q_{izol}/Q_t)$ (12)

In " Assessing the energy efficiency of hot water transport and distribution systems" by Mateescu Th & Hudisteanu R. (MatrixRom, Romania, 2006) there are presented diagrams for determining the specific failure for different types of pipes, diameters and thermal insulation solutions.

Depending on the scheme adopted for water recirculation, flows through the pipes are adopted with the values resulting from the equation 5 for double-duty columns, respectively with:

$D_{total} = D_{recirc}$ (5’)

for the pipes through which only the recycling flows are circulated.

3.4 Recirculation pump flow (D_P)

The flow rate of the recirculation pump is taken equal to the total flow corresponding to the first section downstream of the thermal source resulting from the summing up of the total flow rates for all distribution (N_D)and recirculation pipes (N_R):

$D_P = \sum_{i=1}^{Nd+Nr} Dtotal * i$ (13)

3.5 The recirculation pump discharge height

The distribution and recirculation piping assembly operates in non-consuming periods as an equivalent binary type network (figure 5)

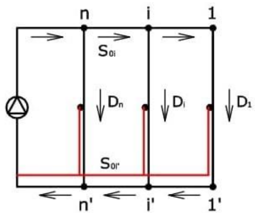


Figure 5 – Binary network

Knowing the geometric characteristics (length and diameters) and the hydraulic ones (equivalent unitary resistance) we are able to calculate the linear load losses corresponding to the recirculation flows:

$h_{ri} = (S_{0ec}*L*D_{recirc})I$ (14)

The pumping height compensates the total load losses on the longest binary circuit:

$H_P = 1.25\Sigma h_{ri}$ (15)

To cover the local load losses, in relationship (15) the coefficient for increasing the linear losses by 25%.

Equivalent unitary resistance

A bar (ii’) of the binary network is formed by catenating the distribution (i0) and recirculation column (0i’), having the same length (L) and the unitary hydraulic resistances (s_{0i}) and (s_{0i}’) with $s_0=8\lambda/g\pi^2d^5$.

The unit equivalent resistance of the bar ($s_{0iechiv}$) that’s equal with 2L results from the equivalent of the corresponding load losses $D_{total\ i}$ and $D_{circ\ i.}$

$h_{ri0} + h_{ri0}' = h_{riiech}$

or

$$S_{0i}L_i(D_{idistr} + D_{icirc})^2 + S_{0i}'L_i'D_{icirc}^2 = 2L_{isoiech}D_{icirc}^2 \quad (16)$$

where:

$$S_{0iech} = S_{0i}[(D_{idistr}/D_{icirc})+1]^2 + S_{0i}' \quad (17)$$

Considering the random character of the consumption and, of course, of the column distribution flows, the network is rebalanced hydraulically in relation to their size

3.6 The power of the thermal source

The thermal power of the local source must compensate for heat loss related to the indoor installation: distribution system and storage system

$$P_{sursa} = Q_{retea} + Q_{stocator} \quad (18)$$

where:

$$Q_{retea} = (t_a\text{-}t_m)\Sigma(Q_{S0}*L)I \quad (19)$$

$$Q_{stocator} = (t_a\text{-}t_m)*A_{lateral}/(0.1+\delta_m/\lambda_m+\delta_{iz}/\lambda_{iz}) \quad (20)$$

$A_{lateral}$, δ_m, λ_m, δ_{iz}, λ_{iz} - The geometric and thermophysical characteristics of the reservoir shell

3.7 Store storage volume

The accumulation volume of the storage facility is determined by the volume of the hot water supply network, so that the water reserve in the stockpile compensates for the volume of input needed for the first use after the resumption of consumption.

In relation to the total volume of the power supply

$$V_{retea} = 0.785\Sigma L_i d_i^2 \quad (21)$$

the storage volume is determined using:

$$V_{stoc} = p*V_{retea} \quad (22)$$

with:
p=i, networks with a reduced length
p=1/number of connected blocks, exterior networks

4 Functional regimes

According to the solution adopted for the installation and operation of the installation, the following situations may occur:

4.1 Bi-energy boiler generator and variable speed recirculation pump

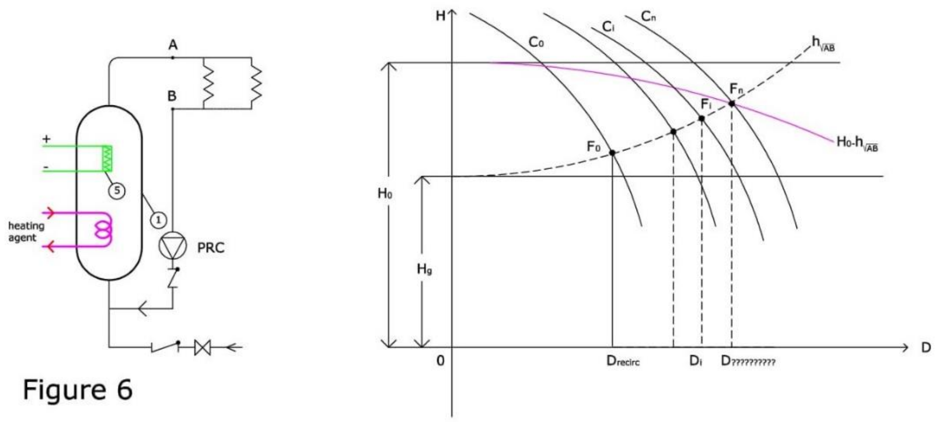


Figure 6 - Bi-energy boiler generator and variable speed recirculation pump

In the absence of consumption, the pump operates at the point 0 corresponding to the flow rate of the recirculation; When increasing the flow rate by changing the speed, the operating point moves on the network characteristic to the point n (when the pump is switched off, the system is fed to the external supply network pressure in n)

4.2 Bi-energy generator, reservoir and constant-speed circulating pump

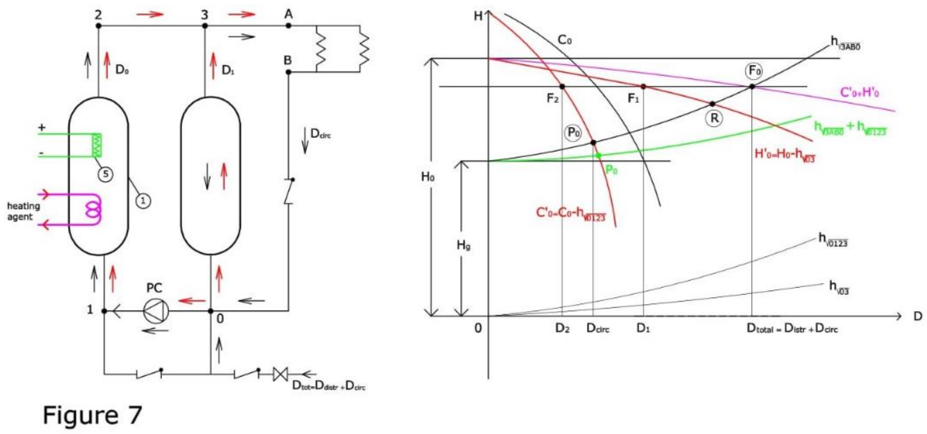


Figure 7 - Bi-energy generator, reservoir and constant-speed circulating pump

The PC circulation pump works continuously. In non-consuming periods, recirculation of the water volumes in the distribution network and in the battery without external input is made through the generator.

In periods of consumption with lower flows than the nominal volume of the pump, consumers are supplied directly through the generator with the reduction of the recirculated volumes, and at higher flows the deficit is compensated from the reservoir.

The F0 operating point results at the intersection of the system's characteristic with the cumulative characteristics of the pump (c'_0) hot water service-line (H'_0).

When switching off the circulation pump, the consumption is directly assured at the supply line pressure (H0) by pumping the pump - the operating point is set in R

4.3 Bi-energy generator, reservoir, circulation pump and constant-speed recirculation pump

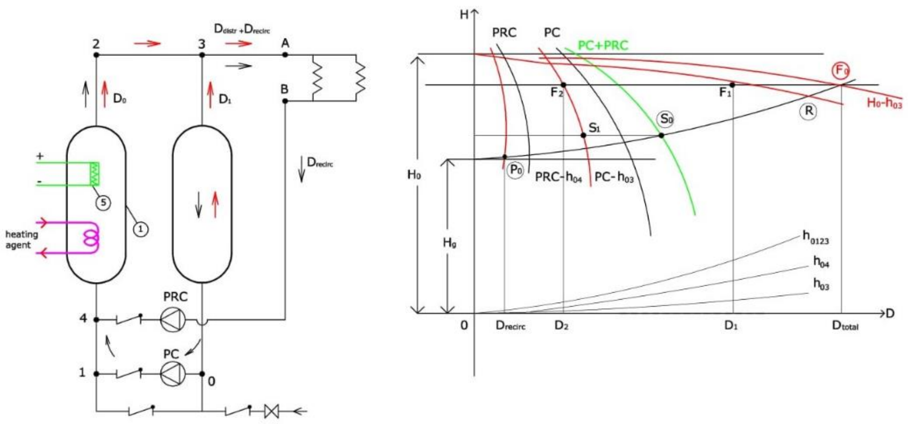


Figure 8

Figure 8 - Bi-energy generator, reservoir, circulation pump and constant-speed recirculation pump

To reduce the energy consumption for pumping, the recirculation pump (PRC) works only during the non-consuming period of time to drive the volume of water in the distribution network in order to compensate for heat loss.
Maintaining the temperature of the water in the reservoir is under the action of the circulating pump (PC) that can work synergistically or in parallel with the recirculation pump (PRC).
The power supply of the receivers can be made directly from the outside network by passing or in parallel with the circulation pump, according to the phases presented above.

5 Conclusions

- In hot water distribution networks, the temperature drops significantly when consumption is low or zero
- Supplying flows, resuming consumption below the minimum comfort temperature leads to waste of resources (water and energy)
- In order to keep the temperature within acceptable allowable limits, it is necessary to recirculate a flow that compensates for the heat loss in the installation

- The classic solution requires the doubling of transmission and distribution pipelines throughout the section, from the centralized source to the points of consumption
- The difficulty of intervening in the existing underground network and the related costs are the main impediments to promoting the solution
- As an alternative solution, it is proposed to carry out recirculation installations with local-centralized thermal sources, located at the level of dwelling blocks
- To reduce the investment effort it is envisaged to eliminate the recirculation columns and take over their function by interconnecting the distribution columns
- Compensation of heat loss from the domestic hot water distribution system can be done with electric heating cables
- Technical solutions can be differentiated in relation to local situations and financial availability
- The efficiency of solutions is conditioned by the correct dimensioning of all system components

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Please select one style for referencing, preferably sequential numbering or Harvard. Examples are shown below for: a Code/Standard; a thesis; a journal article and a symposium publication.

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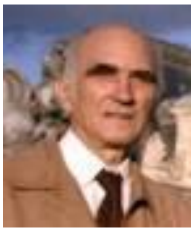
7 Presentation of Authors

1. MATEESCU Theodor
Associated professor at "Gheorghe Asachi" Technical University of Iasi,Department of Building Services Engineering, specialized in Plumbing Installations, Water Management, HVAC, PhD supervisor in the field of Civil Engineering, member in various committees such as ASHRAE, The association of building services engineers in Romania (Moldova Branch).



2. LUCIU Razvan
Asistant professor at "Gheorghe Asachi" Technical University of Iasi,Department of Building Services Engineering, specialized in sanitary and HVAC installations.

3. BARAN Andreea
PhD Student at “Gheorghe Asachi” Technical University of Iasi,Department of Building Services Engineering, performed a Master from March until June 2016 at Polytech Marseille, France in an Erasmus program on the field of heat transfer using nanofluids.

4. CAZACU Ionela
PhD in Civil Engineering at “Gheorghe Asachi” Technical University of Iasi,Department of Building Services Engineering, in heating transfer field, currently working as an Executive Director at the Association of Building Services Engineers, Moldova Branch.

PP08 - Photogrammetry as a quick assessment tool of urban rainwater harvesting and green area retention potential

Blanka Grajfoner (1), Matjaz Nekrep Perc (2)
1. blanka.grajfoner@um.si
2. matjaz.nekrep@um.si
(1) Faculty of Civil Engineering, Transportation Engineering and Architecture, University of Maribor, Slovenia
(2) Faculty of Civil Engineering, Transportation Engineering and Architecture, University of Maribor, Slovenia

Abstract

The objective of this work is to use photogrammetry to evaluate rainwater harvesting and green area retention potential in urban area. Several sources of remote sensing data has been described and a field test with semi-professional drone was performed by means of computer evaluation of rainwater harvesting and green area retention potential. We identify and evaluate some of the most important design parameters for rainwater harvesting systems as roof area and slope and available green areas. The results have shown that even with semi-professional drones in price range about 1000$ can be successfully used for mapping areas of interest. The results of six-minute flight over twelve hectares of city centre where comparable with professional results with well-equipped research plane remote sensing. Image segmentation from orthomosaic together with elevation model has been used to detect roofs and green areas.

Keywords

Remote sensing, rainwater harvesting, retention potential, photogrammetry, DSM, NDVI, UAV

1 Introduction

The use of remote sensing in mapping and data acquisition in applications like urban studies, hydrological modelling and floodplain, vegetation covering etc. is well known. There is satellite sensing starting with Landsat (1972), plane sensing from simple orthographic photos of some area to the multi-sensor and laser scanning (Melesse et al. 2007). In past years the use of Unmanned Aerial Vehicles (UAV) based on remote sensing has generated low cost monitoring, since the data can be acquired quickly and easily with a low cost UAV (Calvario et al. n.d.). This paper reports the experience

related to quick assessment of urban rainwater harvesting and green area retention potential with consumer drone. The data were processed with traditional photogrammetric data flow and data extraction techniques were applied to extract data regarding roofs and green areas. The fusion of photogrammetry, computer vision, image segmentation and point cloud data use leads to interesting results.
We asked ourselves, if we can obtain data needed for assessment of urban rainwater harvesting and green area retention potential with consumer drone, and process data in reasonable time.

2 Remote sensing

2.1 Remote sensing overview

Satellite imagery and aerial photography play an important role in environmental and urban area monitoring, however there is a limitation; free sources of satellite imaginary do not provide images with enough spatial resolution as those given by planes or by UAVs as we can see in Figure 1.

Figure 1– Public satellite image of our area of interest (GoogleMaps 2017)

We can order aerial photography scan from commercial provider, but with high costs. We got results of high quality as we can see on Figure 2 and Figure 3 where city of Izola has been orthographic photographed in resolution of 5 cm with high details and in scale an exact position.

Figure 2 – Orthophoto of Izola (Mensuras d.o.o. 2017)

Figure 3 – Orthophoto zoom – high details resolution 5 cm (Mensuras d.o.o. 2017)

Another usable and free source of geospatial data in Slovenia is our public environmental agency ARSO, where we can obtain free aerial photography and DEM database of whole country in high resolution and maximum height error of 15 cm (Domen Mongus, Mihaela Triglav Čekada 2013). Plane is flying about 1200-1400 m above sea level with several sensors (LIDAR...) and cameras with results precision 0.03/0.03/0.025 m, 5 points per sqm and final result is processed digital terrain model DTM 1m/1m (Figure 4).

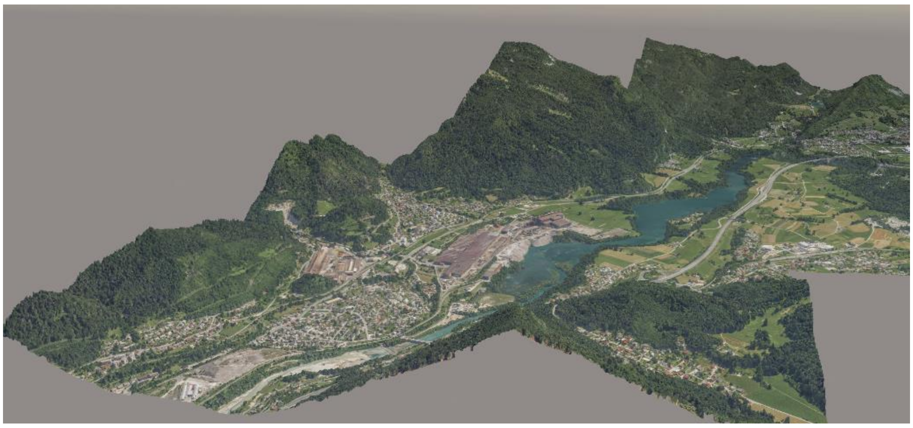


Figure 4 - 3D model based on public data DEM+orthophoto

2.2 Some remote sensing terms used in our work

Digital Surface Model - DSM is 3D model generated from Airborne Laser Scanning ALS through Light Detection and Ranging LiDAR, which delivers a massive point cloud filled of varying elevation values. These elevation values can come from the top of buildings, tree canopy, powerlines and other types of features. A DSM captures the natural and built features on the Earth's surface when digital elevation model DEM exclude vegetation and buildings (Geodetski institut slovenije 2014).

Figure 5 – DSM of Maribor done by aerial photogrammetry (Mensuras d.o.o. 2017)

Photogrammetry is the science of making measurements from photographs. The input to photogrammetry is photographs, and the output is typically a map, a drawing, a measurement, or a 3D model of some real-world object or scene. In **Aerial**

Photogrammetry, the camera is mounted in an aircraft and is usually pointed vertically towards the ground. Multiple overlapping photos of the ground are taken as the aircraft flies along a flight path. The results can be stunning as we can see on Figure 5. Traditionally the aerial photogrammetry has been done with manned aircrafts but many projects now are done with drones and other UAV (Alan Walford 2017).

Normalised difference vegetation index (NDVI) is another term used in our paper. The normalised difference vegetation index (NDVI) is a simple graphical indicator that can be used to analyse remote sensing measurements, typically, but not necessarily, from a space platform, and assess whether the target being observed contains live green vegetation or not. Example of NDVI analyse of our area of interest is on Figure 6.

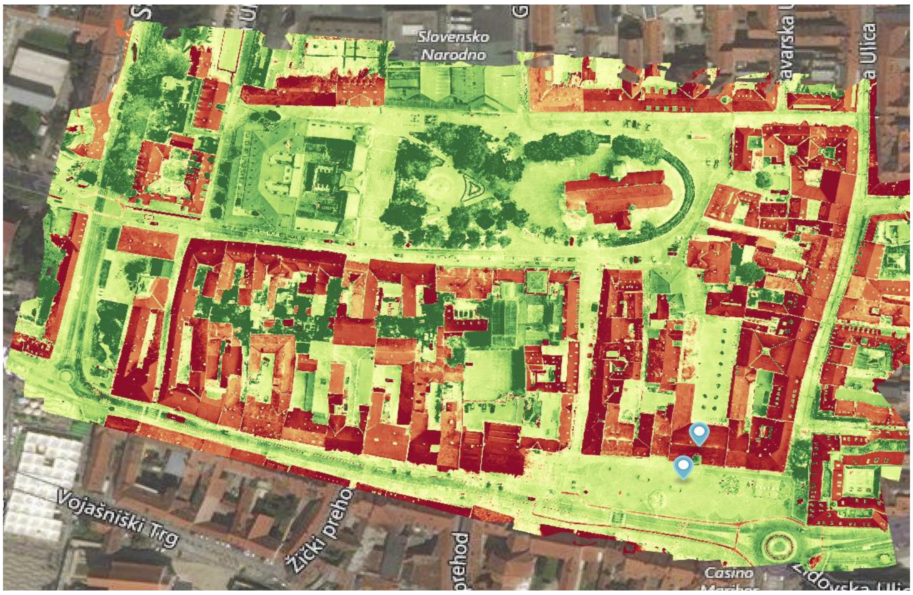


Figure 6 – NDVI of area of interest

3 Assessment tool of urban rainwater harvesting and green area retention potential

Growing water scarcity and global climate change call for more efficient alternatives of water conservation; rainwater harvesting (RWH) is the most promising alternative among others. However, the assessment of RWH potential and the selection of suitable sites for RWH structures are very time consuming especially on larger scales (Jha et al. 2014). This work addresses this challenge by presenting an example of quick and low cost tool for evaluating RWH potential and identifying zones for different RWH structures and green areas with retention potential using drones, photogrammetry and image segmentation.

We have selected area in the centre of the city Maribor, Slovenia, for which we have obtained also geospatial data from professional areal scan done by plane for comparison and test. We can see precise DSM model on Figures 7 and 8.

Figure 7 – Detailed DSM of Maribor centre – orthographic view (Mensuras d.o.o. 2017)

Figure 8 – Detailed DSM of Maribor centre – 3D view (Mensuras d.o.o. 2017)

We have started with flight plan (Figure 9). Our area of interest has been 12 hectares of Maribor city centre. It is a highly urbanised old town centre with some green areas.

Figure 9 – Flight plan

Flight takes 6 minutes to cover whole area of 12 hectares with planned precision 3.9 cm per pixel.

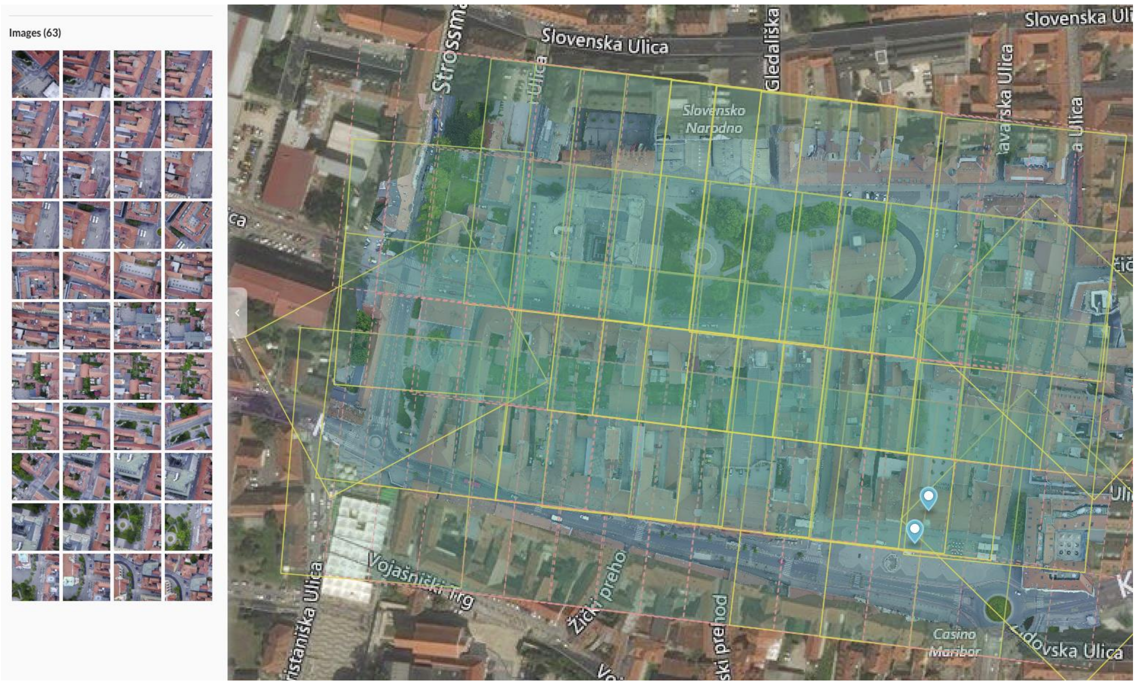


Figure 10 – Map of taken photos

63 photos have been taken from the height of 90 meters in high resolution and with overlapping of 60% (Figure 10). Photogrammetric processing has been done in the cloud by provider DroneDeploy. The result is high resolution orthomosaic photo and 3D DSM model with tolerances in centimetres (Figure 11). Such a results can be useful in variety of applications of mapping and detection purposes (Champion et al. 2010).

Figure 11 – Orthomosaic with resolution 5 cm

Besides orthomosaic cloud of point gives us elevation model (Figure 12) of area needed for RWH potential assessment (Campisano & Lupia 2017).

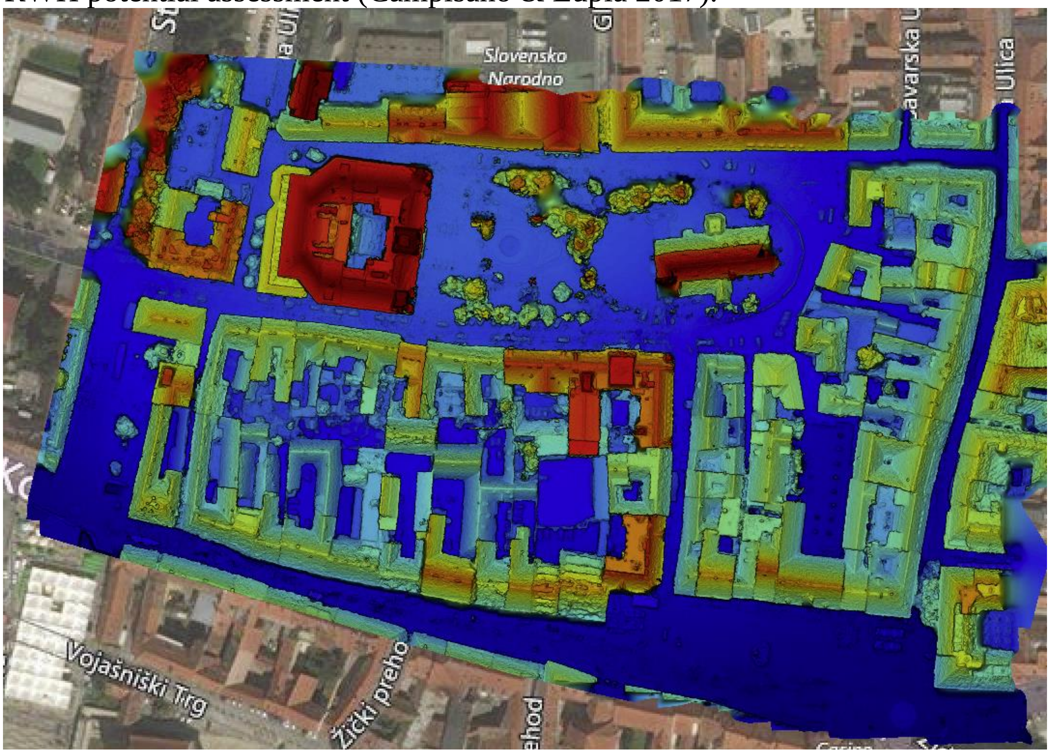


Figure 12 – Heights map

The results where comparable and almost identical to those from DSM made by plane (Figure 13).

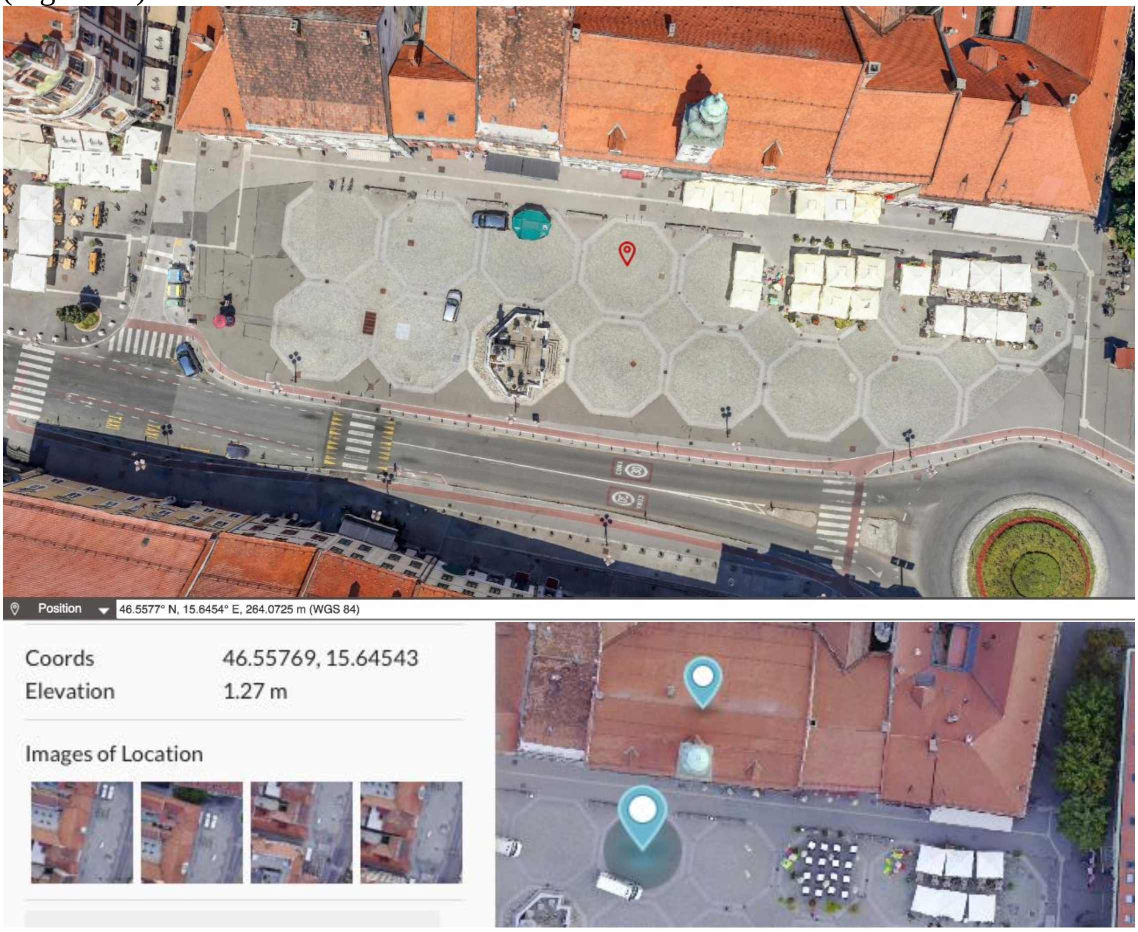


Figure 13 – Coordinates and heights as result of professional plane scanning (upper) and our drone scan (lower)

4 Results

After image segmentation and combination of computer vision and heights information the result is measureable map of detected roof areas (Figure 14) and detected green areas (Figure 15).

Figure 14– Roof areas of 3.9 hectares

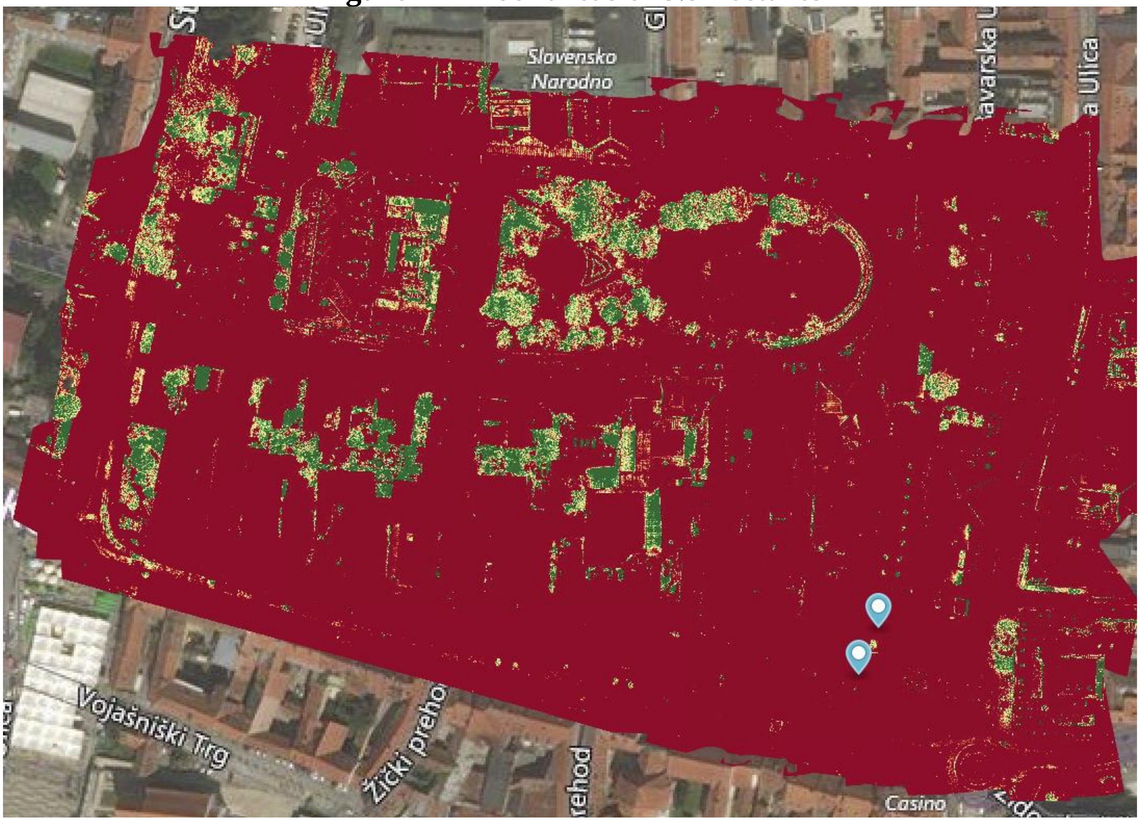


Figure 15– Green areas of 0.8 hectares

Without expensive equipment and in a very short time (6 minutes of flight and three hours of post processing) we have got quit informative results. Most surprisingly our results and height model where comparable with professional one.
Detection algorithms needs some improvements but results can be used as quick assessment.
While the practice of rainwater harvesting (RWH) can be traced back millennia, the degree of its modern implementation varies greatly across the world, often with systems that do not maximize potential benefits and potentials (Campisano et al. 2017).
More and more need for use of rainwater has been taken into account. Quick assessment tools as ours can be help for decision makers to "see" local RWH potential.

Acknowledgments

The paper is side product from the student project BLAKE which was financed by the European Union (European Social Fund) and the Republic of Slovenia (Javni štipendijski, razvojni, invalidski in preživninski sklad and the Ministry of Education, Science and Sport).

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6 Presentation of Authors

Blanka Grajfoner is an Assistant and PhD student at the Faculty of Civil Engineering, Transportation Engineering and Architecture, University of Maribor, Slovenia

Matjaz Nekrep Perc is a Researcher and Lecturer at the Faculty of Civil Engineering, Transportation Engineering and Architecture, University of Maribor, Slovenia

PP10 - A study about the evaluation of the under-slab-floor drainage performance of a multiple water-saving toilet system comprising eight toilet units

Toshiya Kawaguchi (1), Masayuki Otsuka (2)
1. Toshiya.Kawaguchi@kumesekkei.co.jp
2. dmotsuka@kanto-gakuin.ac.jp
1. M. Eng, Kume Sekkei Co., Ltd., Japan
2. Prof. Dr. Eng., Department of Architecture and Environmental Design,
College of Architecture and Environmental Design, Kanto Gakuin University, Japan

Abstract

This study relates to basic research with the aim of acquiring knowledge about the fixture discharge characteristics and carrying performance of multiple water-saving toilet systems, which are typically installed in commercial office buildings, and applying the knowledge to future technological development and its widespread use. At the 41st International Symposium of CIB W062 (Beijing, China in 2015) and the 42nd International Symposium of CIB W062 (Košice, Slovakia in 2016), the authors reported the results of studies that verified the performance of multiple water-saving toilet systems, especially in the case of using five water-saving toilet units, which are typically installed in medium- to high-rise buildings with a recently popular plumbing-friendly horizontal fixture drain branch that is fixed onto a slab floor surface to be connected to the toilet units. During the verification, it was also examined how the carrying performance was affected in said multiple water-saving toilet system by different fitting shapes and pipe pitches of the horizontal fixture drain branch.

This report presents the results of the study carried out on a multiple water-saving toilet system in the case of using eight water-saving toilet units, instead of five, which were connected to the horizontal fixture drain branch installed under the slab floor, as in many existing office buildings, and examined how the configuration affected the fixture discharge characteristics and carrying performance of said multiple water-saving toilet system. Furthermore, as part of the study, it was also examined how the drainage and ventilation performance was affected by different fitting shapes and the presence or absence of a loop vent pipe and a vent pipe.

Keywords

Carrying Performance, Water-Saving toilets, Horizontal fixture drain branch

1 The background and objectives of the study

In recent years, as part of global warming countermeasures, the technological advancement of water-saving sanitary fixtures has been significant in contributing to securing water resources. In particular, much focus has been on water-saving toilets. As well as for residential use, the use of water-saving toilets in offices, as a multiple unit system, has been promoted, but it raises concerns in terms of carrying performance deterioration.

At the 42nd International Symposium of CIB W062 (Košice, Slovakia in 2016), the previous report[1)] presented findings on the fixture discharge characteristics and carrying performance of a multiple water-saving toilet system comprising five 6.0L toilet units when the toilet units are plumbed on the slab floor.

With a focus on the case where a multiple water-saving toilet system comprising eight water-saving toilet units, and the horizontal fixture drain branch, to which said toilet units are connected, is installed underneath the slab floor, this report examines the fixture discharge characteristics of the system and how the fixture discharge characteristics affect the carrying performance, as well as examining the system's performance with or without a loop vent pipe.

The study has three objectives as follows:

(1) Acquiring fixture discharge characteristic values

(2) Identifying single-flush and combined-flush characteristics

(3) Understanding the influence of using a loop vent pipe

(4) Discussion on the amount of water for fixed-time-period flushing and flushing intervals

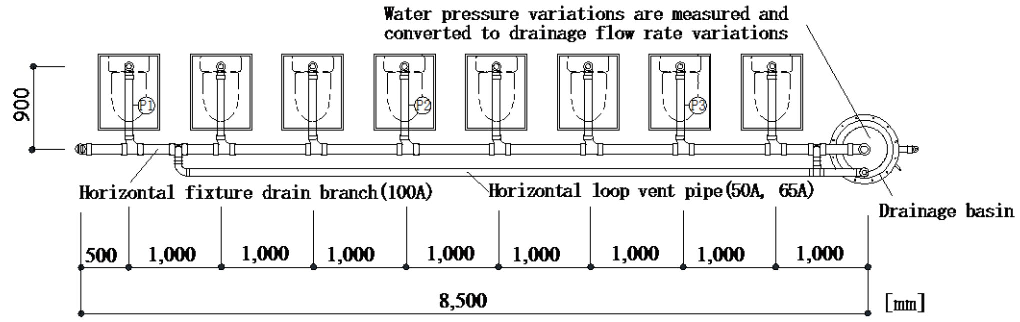
2 Experiment overview

2.1 Experimental horizontal fixture drain branch system

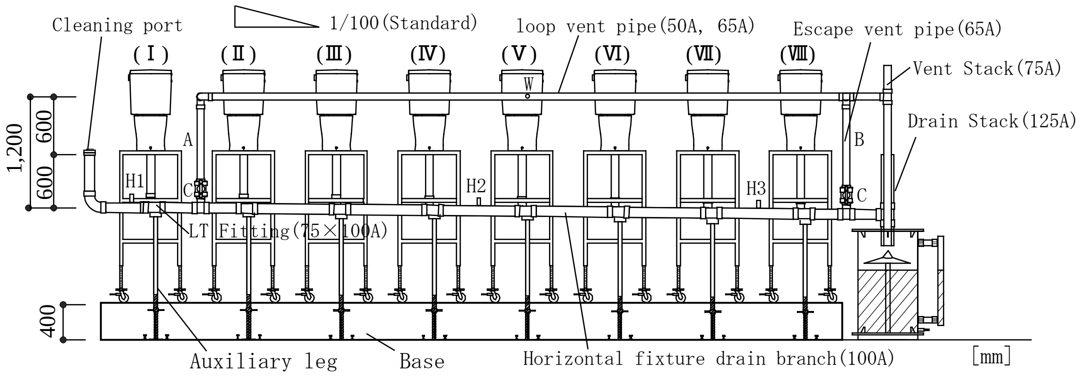
As shown in **Fig. 1**, the study involves an experimental horizontal fixture drain branch system comprising an 8.5m pipe and JIS-A 5207-approved type II water-saving toilet units with 6.0L flush water. The system simulates a series of toilet booths installed in an office building, i.e., eight experimental toilet units are sequentially connected to a horizontal fixture drain branch that is fixed under the slab floor. Moreover, the system comprises a drainpipe, which connects each experimental toilet unit and the horizontal fixture drain branch together, in two configurations, as shown in **Fig. 2** and **Photo 1**; one with an LT fitting to provide a 90° flow angle in the joint part (hereinafter referred to as 'LT fitting' and the other with a 45° Y fitting and a 45° elbow to provide a 45° flow angle (hereinafter referred to as '45° Y fitting).

The experimental toilet units are installed at 1m intervals. Toilet unit (I) is positioned at the most upstream side of the experimental horizontal fixture drain branch, and toilet units (II) to (VIII) are then positioned downstream of the horizontal fixture drain branch in a descending manner. A transparent rigid PVC pipe is used as the experimental horizontal fixture drain branch, and the nominal diameter thereof is 100A (inside diameter 103mm) and JIS-DT fittings (100A×125A) are attached to the ends thereof.

A loop vent pipe is provided between the most upstream toilet unit (I) and toilet unit (II) which is immediately after toilet unit (I), and an escape vent pipe is erected on the downstream side of the most downstream toilet unit (VIII). The loop vent pipe and the escape vent pipe are both provided with a valve, which is normally closed but is opened or closed, as appropriate, depending on the type of experiment.



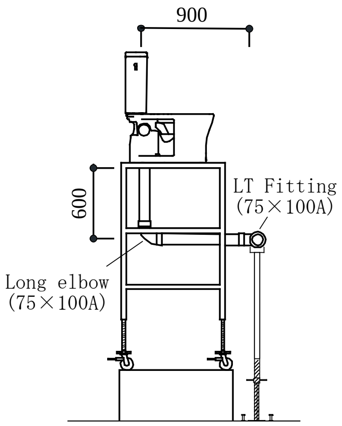
(1) Plane view



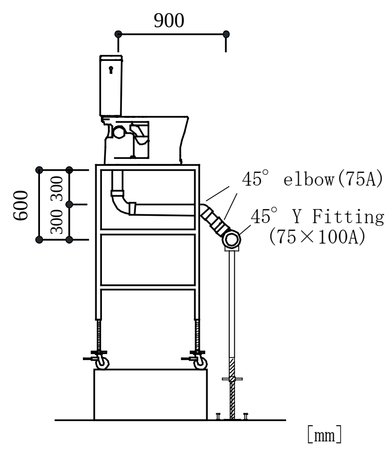
＊(Ⅰ)～(Ⅷ) indicate the respective toilet units.

(2) Elevation view

Fig. 1 Experimental horizontal fixture drain branch system



(1) LT fitting



(2) 45°Y fitting

Fig. 2 Fittings used for connecting the horizontal fixture drain branch

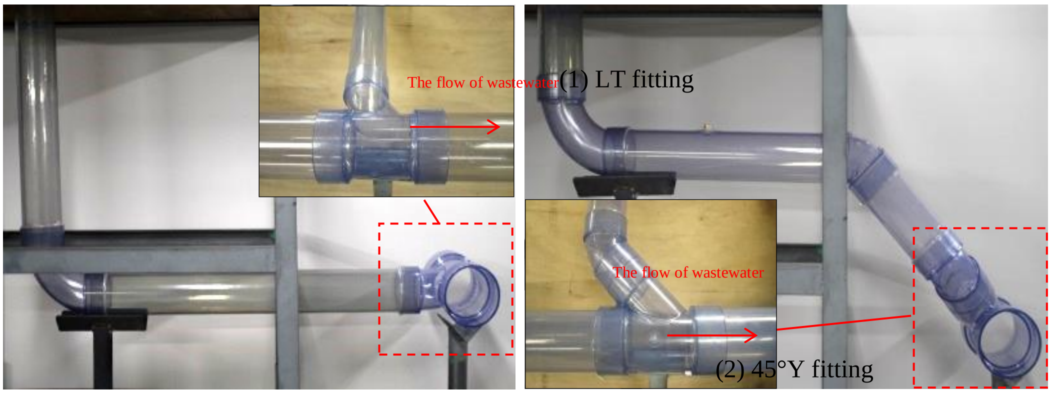


Photo 1 Shapes of the fittings

2.2 Fixture discharge characteristics experiment

The fittings connecting the experimental toilet units and the experimental horizontal fixture drain branch together are all LT and 45° Y fittings, and fixture discharge characteristics are measured in accordance with SHASE-S220[2)] when the experimental toilet units are flushed individually using clean water only. **Fig. 3** shows an example of the variation of discharge flow rate and the variation of discharge volume when a toilet unit is flushed. In **Fig. 3**, the maximum fixture discharge flow rate, q'max [L/s], refers to the maximum value of discharge flow rate. Moreover, the draining time, td[s], refers to the period between the time when 20% of the total discharged water has been drained and the time when 80% of the same has been drained, and the average fixture discharge flow rate, qd'[L/s], refers to the average discharge flow rate, which is calculated from the draining time by using formula (1).

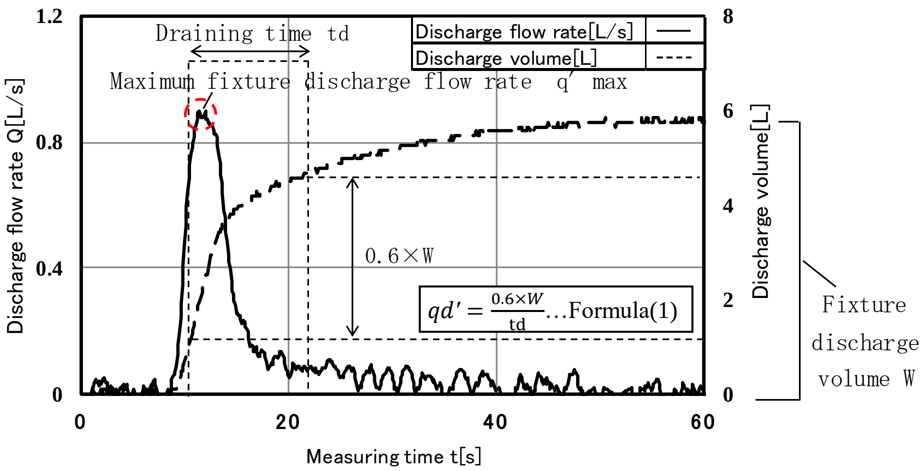


Fig. 3 Fixture discharge volume/flow rate curve (example)

2.3 Single-flush / combined-flush carrying performance experiment

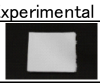
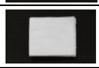
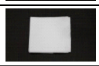
The carrying performance experiment includes a single-flush experiment and a combined-flush experiment, in which three types of experimental waste substitutes, shown in **Table 1**, are flushed down the experimental toilet units. Using the waste substitutes, toilet units (I)-(VIII) are flushed, individually, in the single-flush experiment, and some or all of the toilet units are flushed in the combined-flush experiments. Each carrying distance is then measured from the core of the most upstream fixture drainpipe (see **Fig. 1**) to the tail of each waste substitute where it stopped.
As for the flushing timing in the combined-flush experiment, the toilet units are flushed in sequence, starting with the most upstream toilet unit (I), and then toilet units (II) to (VIII), respectively, at 1-second intervals, so that the flows of discharged water from the toilet units collide with each other as they pass the joining points. Moreover, in the combined-flush experiment, variations in the in-pipe pressure and variations in the trap seal loss are compared in the case of using both the loop vent pipe and the escape vent pipe and in the case of using the loop vent pipe only.

2.4 Fixed-time-period flushing experiment

From the results obtained in the single-flush experiment, the flushing pattern where the carrying distance is the shortest is identified, in which the most upstream toilet unit (I) is flushed with clean water only one hour after the experimental waste substitute stagnated in the horizontal fixture drain branch, and the further carrying distance of the waste substitute by fixed-time-period flushing is measured.

As for the items to measure and the measuring methods, ultrasonic water level sensors are disposed at points H1-H5 (see **Fig. 1**) to measure the water level in the pipe, H[mm], at the time of flushing, and pressure sensors P1-P3 are also disposed near the fixture drainpipes to measure the air pressure in order to check for induced siphonage. In addition, a hot-wire anemometer (W) is used for measuring the velocity in the loop vent pipe.

Table 1 Experimental waste substitutes

Type	Experimental waste substitute	Description
D	 	1-ply toilet paper, laid flat, 1m x 6 pieces
D'	 	2-ply toilet paper, laid flat, 1m x 6 pieces
BL*	 	1-ply toilet paper, laid flat, 0.9m x 4 pieces

＊In accordance with Better Living BLE WC:2013

Table 2 Flushing patterns

(1) Single flush

Flushing pattern		Toilet (I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
Single flush	No.1	○							
	No.2		○						
	No.3			○					
	No.4				○				
	No.5					○			
	No.6						○		
	No.7							○	
	No.8								○

(2) Combined flush

Flushing pattern		Toilet (I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
Combined flush	No.9	○	○	○	○				
	No.10	○	○	○	○	○	○		
	No.11	○	○	○			○	○	○
	No.12	○	○	○	○	○	○	○	○

*○: Toilet(s) used for testing

3 Results and discussions

3.1 Fixture discharge characteristics experiment

In **Fig. 4**, the discharge flow rate curves of toilet units (I), (IV) and (VIII) are compared to one another according to the type of fitting used. The toilet units are typically located upstream, midstream and downstream along the horizontal fixture drain branch, respectively. **Fig. 4** also includes qd' (average fixture discharge flow rates) of the eight toilet units according to the type of fitting used. It is evident that regardless of the location, the flow rate curves of the three toilet units change in a similar manner. However, the maximum discharge flow rates are greater when using the 45° Y fitting than when using the LT fitting; by approximately 0.36L/s in the case of toilet unit (VIII), 0.56L/s in the case of toilet unit (IV), and approximately 0.25L/s in the case of toilet unit (I), i.e., by approximately 28.8-57% on the whole. **Fig. 5** compares the water levels that were measured at H2 and H3 when flushing toilet unit (V) with clean water and when using the LT fitting or the 45° Y fitting. At H2, which is upstream from toilet unit (V), the water level was measured to be approximately 25mm at maximum when using the LT fitting, and approximately 8mm at maximum when using the 45° Y fitting. As shown in **Photo 2**, the 45° Y fitting creates less backflow than the LT fitting. Meanwhile, at H3, which is downstream from toilet unit (V), the LT fitting creates less resistance than the 45° Y fitting, and therefore, the water level was measured to be lower with the LT fitting than with the 45° Y fitting. In other words, the water is drained from the toilet unit at a higher water level when using the 45° Y fitting than when using the LT fitting.

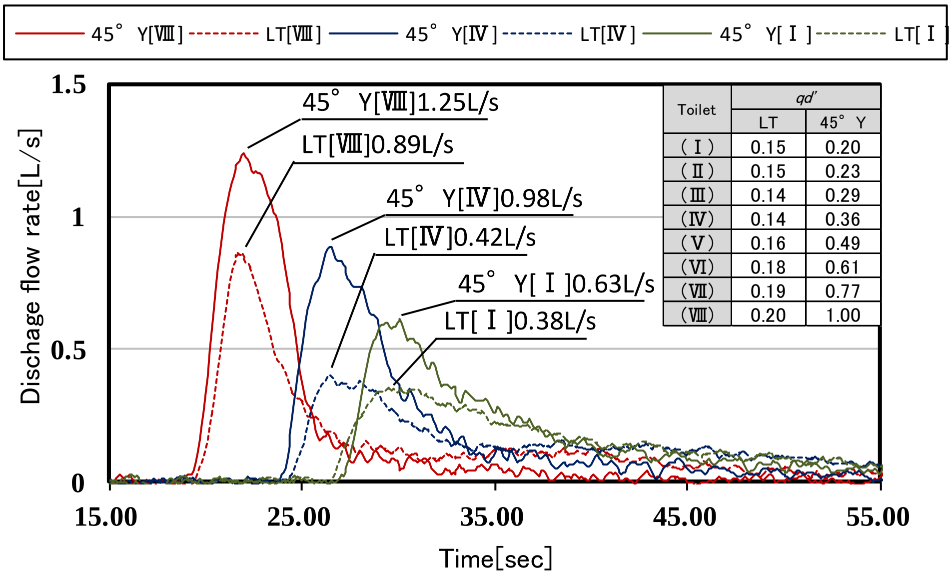
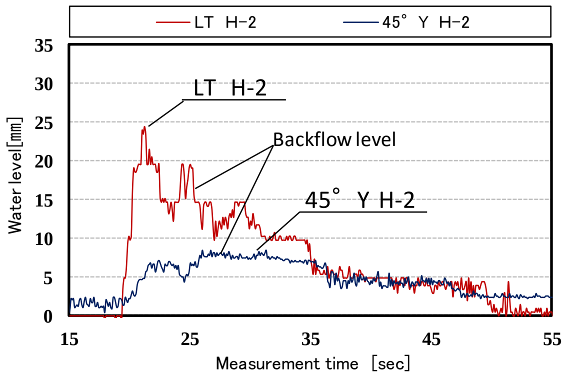
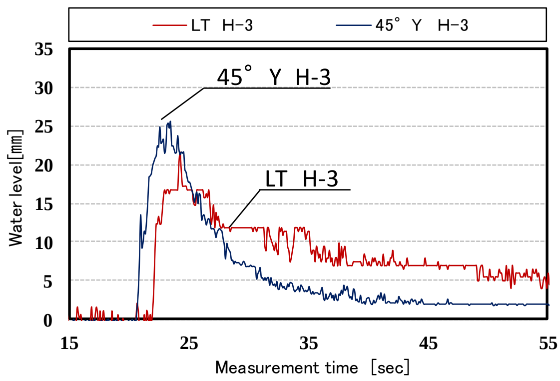


Fig. 4 Discharge flow rate curves compared by the shape of fitting



(1) Water level sensor H2



(2) Water level sensor H3

Fig. 5 Water level variations when flushing toilet (Ⅴ)

Meanwhile, **Fig. 5** shows the flow velocity of drainage measured at H2 and H3 when flushing toilet unit (IV) and when using the LT fitting or the 45° Y fitting. With the LT fitting, the flow velocity was measured to be 0.77L/s, and with the 45° Y fitting, the flow velocity was measured to be 0.84L/s. Therefore, it is clear that drained water flows faster when the 45° Y fitting is used. According to these experiment results, compared to the LT fitting, in the 45° Y fitting, drained water flows at a higher water level and at a higher velocity, and this is thought to be why significant differences were made to the maximum discharge flow rates, as shown in **Fig. 6**.

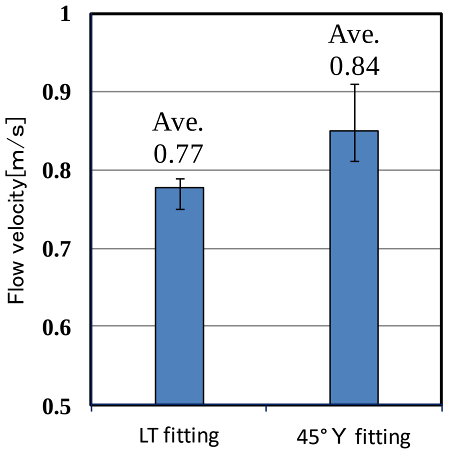
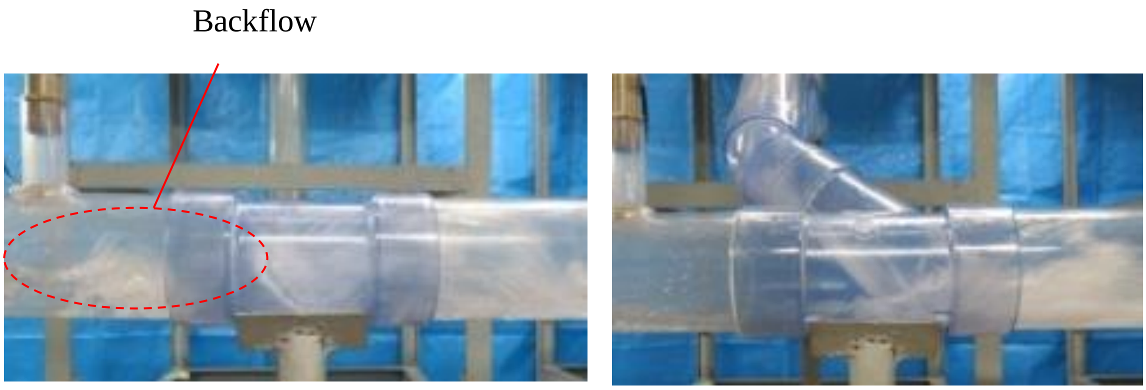


Fig. 6 Flow velocities compared by the shape of fitting



(1) LT fitting **(2) 45° Y fitting**

Photo 2 Clean water drained through the joint part

3.2 Carrying performance experiment

3.2.1 Single-flush experiment

Fig 7 compares the results of the single-flush carrying performance experiment, using the LT fitting or the 45° Y fitting. When using the LT fitting, all of the three types of experimental waste substitutes most likely stagnated in the horizontal fixture drain branch in nearly all of the flushing patterns. It was observed, although not too often, that due to the flow angle being 90 degrees in the almost horizontal state in the LT fitting, drained waste substitutes collided against the wall of the LT fitting and were further pressed against the wall by subsequently drained water to cause stagnation in the joint part (see **Photo 3**). When using the 45° Y fitting, unlike with the LT fitting, waste substitutes D and BL, apart from D', were completely drained through to the drainage stack. This is because the 45° Y fitting provides a 45°flow angle, thus, keeping the drainage resistance small and facilitating a smooth flow. Unlike with the LT fitting, no waste stagnation was caused in the joint part with the 45° Y fitting. As for waste substitute D', it was drained completely through to the drainage stack in patterns 5 to 8, while in patterns 1 to 4, although D' stagnated, the distance it was carried in each pattern was longer when using the 45° Y fitting than when using the LT fitting, with a maximum difference of approximately 4.5m.

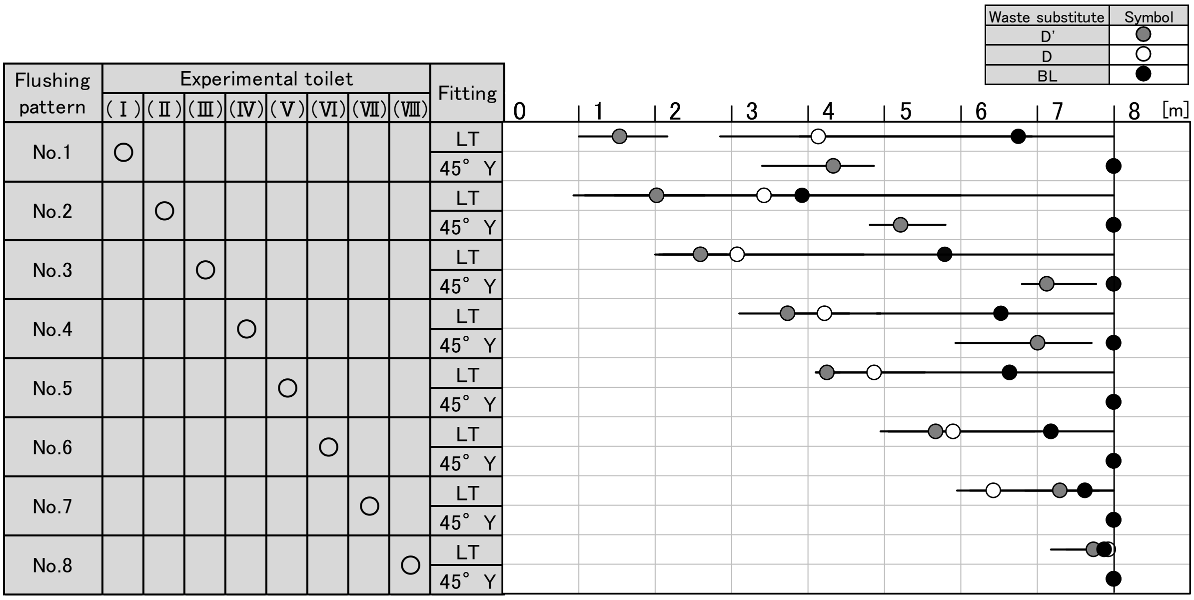


Fig. 7 Single-flush testing results

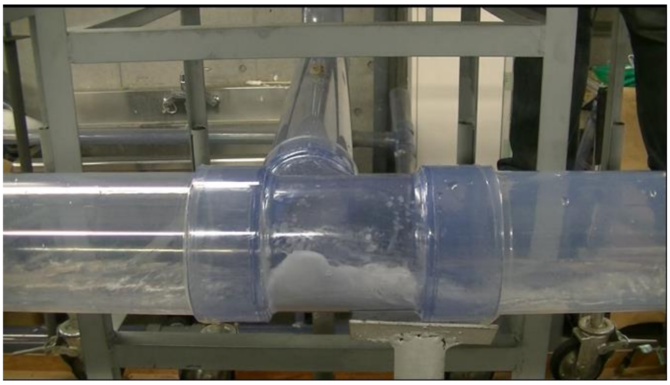


Photo 3 Stagnation in the LT fitting part

Moreover, the average fixture discharge flow rate qd' of waste substitute D', which was obtained from the results of the fixture discharge characteristics experiment using the LT fitting or the 45° Y fitting and serves as a carrying performance index, was used for calculating *qd'* of the carrying distances in **Fig. 7** (carrying limit value qd'_{cp}). The changes in qd'_{cp} are shown in **Fig. 8**. When looking at the changes in qd' by the type of fitting, *qd'* is lower with the LT fitting than with the 45° Y fitting and is almost constant. This is thought to be because the drainage resistance is greater with the LT fitting than with the 45° Y fitting, thus, creating adverse impact such as backflow. Furthermore, the LT fitting is prone to blockage, and therefore, qd'_{cp} obtained with the 45° Y fitting is applied. It is clear from Fig. 8 that qd'_{cp} is 0.43L/s, and it is considered necessary to set the pipe length so as to ensure that *qd'* is at least 0.43L/s.

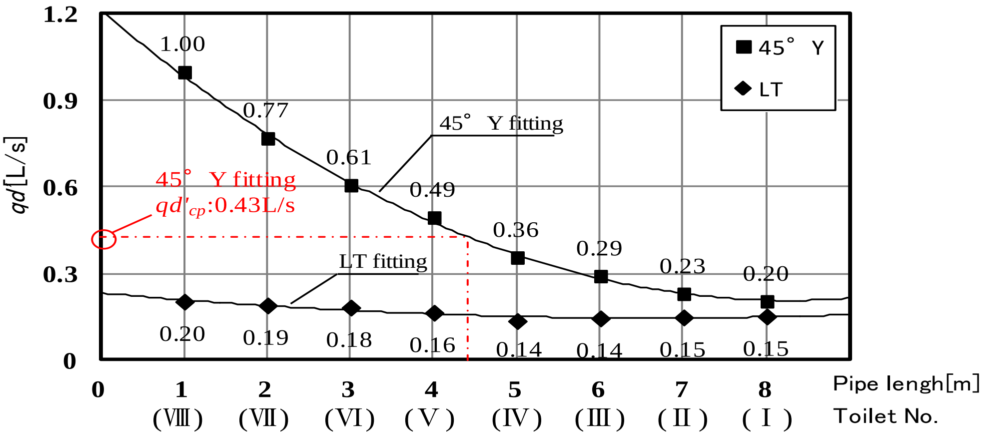


Fig. 8 qd' in relation to the pipe length

3.2.2 Combined-flush experiment

Fig. 9 shows the typical results of the combined-flush carrying performance experiment in the cases of patterns 10 and 11, using the LT fitting or the 45° Y fitting. Whichever fitting was used, waste substitute BL was completely drained through to the drainage stack. Moreover, with the 45° Y fitting, all of the waste substitutes were completely drained in both patterns, while with the LT fitting, waste substitutes D' and D stagnated in the horizontal fixture drain branch. To be more specific, only D from the most upstream toilet unit (I) stagnated in the pipe, and D', with the largest load, from toilet units (I) to (I I I) also stagnated in the pipe.

Flushing pattern	Experimental toilet								Waste substitute	Fitting
	(Ⅰ)	(Ⅱ)	(Ⅲ)	(Ⅳ)	(Ⅴ)	(Ⅵ)	(Ⅶ)	(Ⅷ)		
No.10	○	○	○	○	○	○			D	LT
										45° Y
									D'	LT
										45° Y
									BL	LT
										45° Y
No.11	○	○	○			○	○	○	D	LT
										45° Y
									D'	LT
										45° Y
									BL	LT
										45° Y

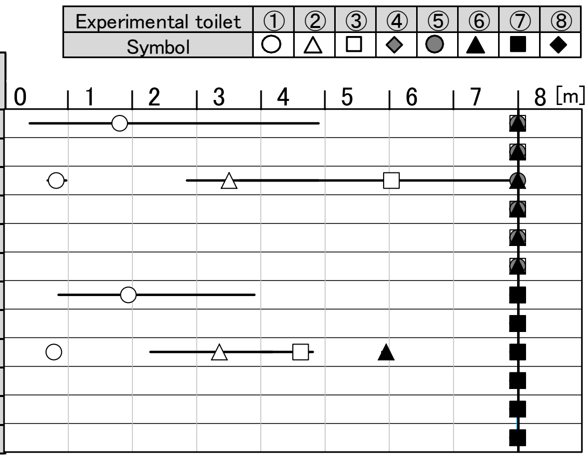
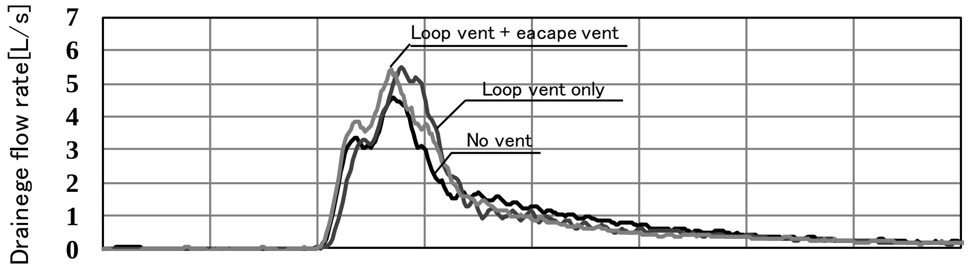
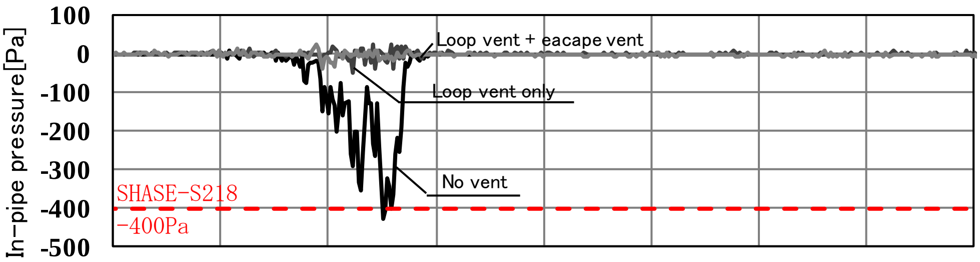


Fig. 9 Combined-flush experiment results

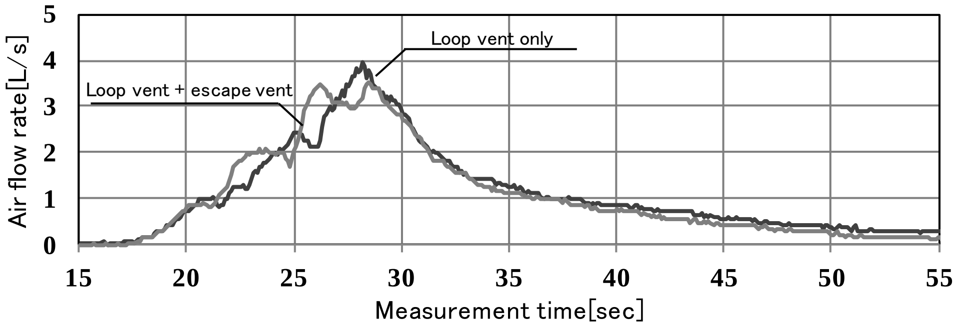
Fig. 10 shows, as an example, that the drainage flow rates, in-pipe pressure and air flow rates, which were measured in pattern 11 (where three upstream toilet units and three downstream toilet units were flushed in a coordinated manner) using the 45° Y fitting, are compared between with and without ventilation. According to **Fig. 10**, there is no significant difference in the drainage flow rate values regardless of with or without ventilation, but the in-pipe pressure falls below -400Pa, the reference value specified by SHASE-S 218, without ventilation. However, in the case of using vent pipes, the in-pipe pressure becomes reduced within the SHASE reference range. Moreover, in the case where the loop vent pipe and the escape vent pipe are both opened and in the case where only the loop vent pipe is opened, there is no significant difference in the in-pipe pressure values or the drainage flow rate values. Furthermore, even in the case of using the loop vent pipe solely, adequate ventilation is still ensured and the in-pipe pressure remains unchanged, and this makes the effect of the escape vent pipe rather insignificant. Meanwhile, the in-pipe pressure and the trap seal loss were measured during combined flushing, using the LT fitting or the 45° Y fitting and with or without ventilation, and the measured values are compared in **Fig. 11** and **12**. Incidentally, the in-pipe pressure and the trap seal loss were measured at non-draining points, among the pressure sensor points P1-P3 in **Fig. 1**, where the toilets that were not used for combined flushing are located. According to the diagrams, the in-pipe pressure exceeded the reference value of -400Pa only in pattern 11 using the 45° Y fitting and without ventilation, and there is no significant difference in the in-pipe pressure or the trap seal loss, with or without ventilation, when using the LT fitting.



(1) Drainage flow rate variations



(2) In-pipe pressure variations



(3) Air flow rate variations

Fig. 10 Variations in flushing pattern No. 11 with or without vents

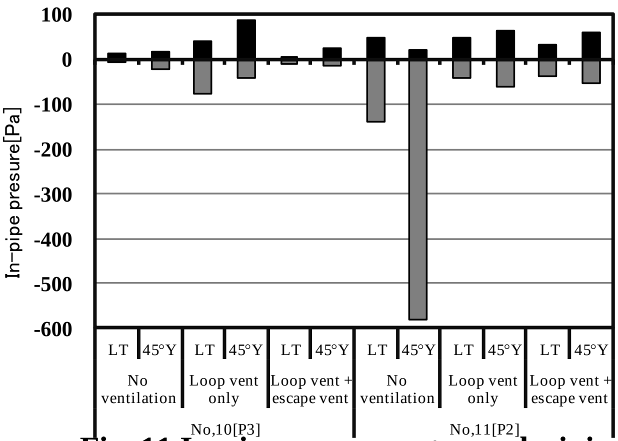


Fig. 11 In-pipe pressure at non-draining points

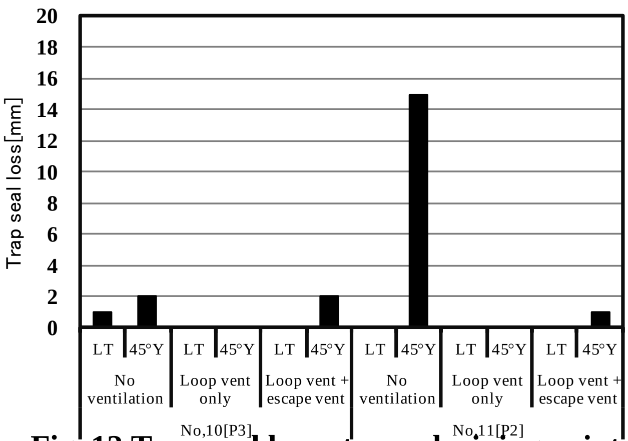
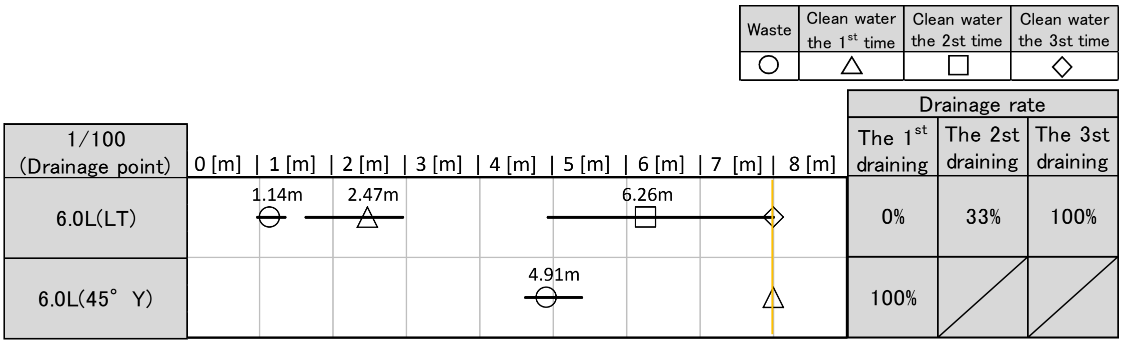


Fig. 12 Trap seal loss at non-draining points

3.3 Fixed-time-period flushing experiment

Fig. 13 shows the results of the fixed-time-period experiment in which clean water was repeatedly drained one hour after water stagnation occurred in the horizontal fixture drain branch. When the LT fitting was used, the first water stagnation occurred at the average distance of 1.14m, and the wastewater was completely drained through to the drainage stack after draining clean water three times. When using the 45° Y fitting, the first water stagnation occurred at the average distance of 4.91m, and the wastewater was completely drained through to the drainage stack after draining clean water once. Therefore, adequate carrying performance is obtained by flushing three times with the LT fitting used and once with the 45° Y fitting used.



Draining rate: (No. of times of carrying waste to the drainage stack / No. of attempts) × 100

Fig. 13 Carrying performance by repeated flushing after a fixed period of time

4 Conclusion

In the study, experiments were carried out to discuss the discharge characteristics and carrying performance of a multiple water-saving toilet system comprising eight toilet units and under-slab-floor piping, and the following knowledge was acquired as a result.

(1) In the multiple water-saving toilet system comprising eight toilet units and under-slab-floor piping, the carrying performance is better when using the 45° Y fitting

than when using the LT fitting, but when there is no ventilation, the in-pipe pressure exceeds the reference value of -400Pa specified by SHASE-S218. Moreover, the in-pipe pressure can be reduced within the SHASE reference range by making use of a loop vent pipe and an escape vent pipe. Furthermore, a very similar pressure reducing effect can also be achieved by using the loop vent pipe solely, and therefore, the effect of using the escape vent pipe is thought to be rather insignificant.

(2) It has been confirmed in the fixed-time-period experiment that water stagnation in the horizontal fixture drain branch is cleared and the wastewater is completely drained through to the drainage stack after draining clean water three times (18L), using the LT fitting, and only once (6L), using the 45° Y fitting. These findings could serve as basic data for designing a toilet unit with a regular flushing program installed therein.

5 References

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2) SHASE-S220 'Testing Method of Discharge Characteristics for Plumbing Fixtures', The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE)
3) Toshiya Kawaguchi, Masayuki Otsuka, Shintaro Gomi: A study about the evaluation of under-slab-floor drainage performance of an eight multiple water-saving toilet units, transactions of the Society of Heating, Air-Conditioning Sanitary Engineers of Japan, Tohoku Division, 2016.3, 2017.3

6 Presentations of Authors

Toshiya Kawaguchi is a master of engineering of KUMESEKKEI. He is a member of AIJ and SHASE. His current study interests are to acquire knowledge that is conducive to devising a piping section and a flushing method to improve the carrying performance of a toilet system comprising serially arranged water-saving toilets.

Masayuki Otsuka is the Professor at Department of Architecture and Environmental Design, Kanto Gakuin University. He is a member of AIJ (Architecture Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan).His current research interests are the hybrid drainage system that uses both force feed type and gravity type drainage methods compatible with commercial building conversion.

PP11 - Rainwater harvesting systems in buildings with green roofs: a study on runoff coefficients

C. Pimentel-Rodrigues (1), A. Silva-Afonso (2), Márcia Lima (3)

1. anqip@anqip.pt
2. silva.afonso@clix.pt
3. marcia.lima@anqip.pt

(1) Technical Director, Portuguese Association for Quality in Building Installations, Portugal.

(2) Chairman of the Board, Portuguese Association for Quality in Building Installations, Portugal.

(3) Grant holder, Portuguese Association for Quality in Building Installations, Portugal.

Abstract

Introduction and aims: The hydric stress is increasing on a global scale (especially in a Mediterranean zone), and it is imperative to search measures to reduce these consequences. The use of rainwater in buildings can be a good solution to increase their water efficiency, but also to reduce flood peaks on public storm water drainage systems. On the other hand, the use of green roofs (GR) in buildings can also bring advantages, since it reduces the flow of surface water and rises the number of green infrastructures as well as all its associated benefits. Thus, it is possible to state that the GR technology combined with rainwater harvesting is particularly promising, becoming important to develop studies that help the design of this systems, specifically about the runoff coefficient. **Method**: Experimental studies carried out for an extensive green roof pilot system (in Porto city, Portugal) have led to low values of runoff coefficient and have allowed the development of an expression to predict a 'monthly runoff coefficient' of the GR. In this paper, a current research is presented aiming to generalize and validate this expression in different locations and for GR of different characteristics. **Results and conclusion**: The theoretical results, obtained by the application of the expression in different zones in Portugal, show wide variations in runoff coefficient, with a minimum of the 0.04 and maximum of the 0.14 (annual averages). The experimental tests to validate these results are in progress. **Contributions**: This study is a contribution to improving the design of rainwater harvesting systems in buildings with green roofs, through the determination of the runoff coefficient in different conditions.

Keywords

Rainwater harvesting, green roofs (GR), runoff coefficients.

1 Introduction

The risk of hydric stress will increase significantly across the entire planet, especially in the Mediterranean basin, and some countries, might experience very serious problems in a large part of their territory in the short to medium term. In other hand, the impacts of climate change on urban environments are starting to be felt and the intensity and frequency of heavy rainfall events are expected to increase in the next decades (Chalmers, 2014**).**

The use of GR on top of buildings may counteract some of these effects since it reduces the flow of stormwater and increases the number of green infrastructures contributing to the mitigation of climate change. The construction of GRs combined with rainwater harvesting systems (RHS) appears as a fundamental measure to reduce peak flows in the drainage of stormwater (Kasmin *et al.*, 2010; Stovin, 2010). Improving stormwater management systems for rainwater harvesting in buildings is particularly appropriate to address the many impacts of climate change because, besides reducing the flood peaks in urban areas, it promotes additional water storage in buildings (Silva-Afonso and Pimentel-Rodrigues, 2014). It is possible to state that the GR technology combined with rainwater harvesting systems is particularly promising, becoming important to develop studies that help the design of this systems, specifically about the runoff coefficient.

Current GR systems still make use of various synthetic components, and the natural elements, which offer so much welfare, are used only on the surface of the system in the form of vegetation and, occasionally, substrate. This ecosystem can be extended through the core layers of the system, like vegetation support layer, water filter layer and drainage course with the appropriate natural material creating a healthy GR. Expanded cork agglomerate (ICB), produced from cork waste (Portugal is the world’s largest cork producer) is suitable for building insulation and can be a good compromise between thermal insulation, environmental impact and natural integration.

Now, a project focused on the conception and study of innovative GR made with cork agglomerate (ICB) are being developed. This project concerns the conception and behavior of GR made of healthy engineered expanded cork systems, a totally natural and environmentally friendly product, as the inner layer of the system. It plans to use one or more layers of expanded cork as a lightweight water retention layer, a drainage layer, and simultaneously as insulation. This system should provide the required thermal insulation and durability, protect against the filling of drainage layer and guarantee that the pH of the substrate stays between 6.0 and 8.0. The system is also expected to be light enough to extend its applicability to retrofitting existing buildings with structural limitations.

Experimental studies carried out for an extensive GR pilot system (in Porto city, Portugal) have led to low values of runoff coefficient and have allowed the development of an expression to predict a ‘monthly runoff coefficient’ of the GR (Monteiro *et al.*, 2016). Thus, the main objective of this work is to generalize and validate, in different locations, the expression previous deduced for the GR pilot system for the innovative GR (with ICB) in development.

2 Determination of run-off coefficients in green roofs

2.1 Run-off coefficient

When designing a rainwater harvesting system combined with a GR structure, it should take into account several factors such as the roof runoff coefficient (ETA 701-2012), that should be assessed for each particular climate and type of GR.

In general, the runoff coefficient is a dimensionless parameter that depends on the characteristics of the roof surface. It is calculated based on the total runoff volume and the total amount of precipitation in a certain time period (ANQIP, 2015). In the case of GR, even if the roof water runoff coefficient can be considered valid within similar climatic zones, it is dependent on the type of coverage used in the systems, on the type of plants used and on the characteristics of the substrate, and there is still a large potential for research in this area.

It should be noted that, in Mediterranean regions, the design of the RHS cisterns is usually based on monthly balance sheets, which implies the determination of "monthly runoff coefficients", as is explained further on.

2.2 Description of the green roof pilot system in Mediterranean climate

The pilot green roof system initially developed for the study of the runoff coefficient in green roofs was located on the top of a building at *Escola Superior de Biotecnologia – Universidade Católica Portuguesa*, Porto (Figure 1). This Portuguese city has a Mediterranean climate, although with Atlantic influences. The extensive pilot system followed the typical extensive GR structure – with geotextile membranes, a water holding capacity layer using expanded clay, and the growing substrate with 10 cm height, composed of a mixture of expanded clay and organic matter (Monteiro et al. 2016).

The GR pilot system was established with three different aromatic plant species: *Satureja montana*, *Thymus caespititius* and *Thymus pseudolanuginosus*. The study was in operation for a period of 12 months (March 2013-February 2014), through different rainfall conditions (Monteiro *et al.*, 2016). For the calculation of runoff coefficients, the water that drained from the system was manually collected every 24 hours and the volume was measured using a graduated flask. Rainfall-runoff volume was measured for several natural rainfall events during a year, in order to develop a model to evaluate monthly runoff coefficients of the system (Monteiro *et al.*, 2016). Although atmospheric temperature might influence evapotranspiration and the amount of rainwater retained by the GR system, the goal was only to quantify the amount of rainwater that runoffs the system and relate it directly with rainfall and temperatures in prior periods and not establish relationships with evapotranspiration and retention on the roof. Atmospheric data were provided from a meteorological station from FEUP (*Faculdade de Engenharia da Universidade do Porto*), located one-kilometre distance from the pilot GR (Monteiro *et al.*, 2016).

Figure 1 – Location of the green roof pilot system: Porto, Portugal.

Constant runoff coefficient values through the year for green roofs systems (or even values for each season), which are proposed in some publications, are revealed manifestly inadequate in Mediterranean climates where there may be extended drought periods in the hot season in opposition to cold and rainy winters (Uhl and Schiedt 2008). In the Mediterranean climate (like Portugal) it is highly recommended that the design of rainwater harvesting systems, in particular the design of the storage tank, should be made based on monthly average runoff coefficients (Silva-Afonso and Pimentel-Rodrigues 2014). The main goal of the work developed by Monteiro *et al.* (2016), was to obtain a practical mathematical expression that allows, with acceptable approximation, to determine average values of the monthly runoff coefficient for a particular GR. Measurements made in the experimental GR system allowed for the development of the following expression for monthly runoff coefficient prediction (Monteiro et al. 2016):

$$C_M = \frac{k_1(P_M - R_M)}{(k_2 T_M - T_{M-1})^{k_3}} \quad (=) \quad C_M = \frac{0.016(P_M - R_M)}{(2T_M - T_{M-1})^{1.2}} \qquad (1)$$

where:
C_M = Runoff coefficient of the month *M*;
P_M = Precipitation of the month *M* (mm)
R_M = Watering of the month *M* (mm)
T_M = Mean air temperature of the month *M* (ºC)
T_{M-1} = Mean air temperature of the month *M*-1 (ºC)

The obtained expression, which depends significantly from temperature in previous periods and precipitation, has similarities with the well-known Turc formula (Chow, 1964), widely widespread in hydrological studies to determine flow deficit, that can be considered an indicator of its consistency. Figure 2 shows experimental values obtained vs. the model prediction.

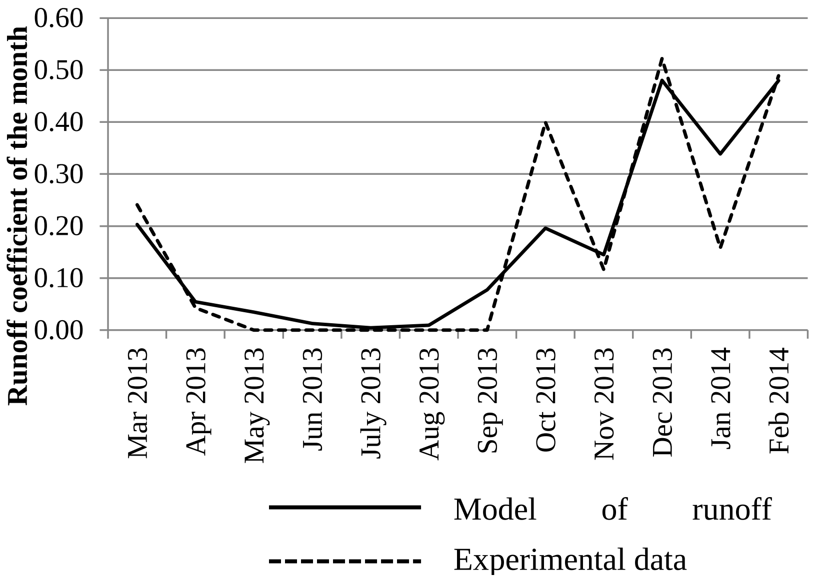

Figure 2 – Monthly runoff coefficient of the pilot GR system.

The developed expression (valid for the extensive GR studied) revealed a correlation coefficient of 0.81 when compared to experimental values, which can be considered a good approximation, since this type of determination is affected by several other parameters that could not be controlled (e.g. wind). The obtained value for runoff coefficient is quite reliable as we can consider that the error of this value is lower than the parameters variability (Monteiro et al. 2016).

3 Methods

Experimental studies carried out for the extensive green roof pilot system have led to low values of runoff coefficient and have allowed the development of an expression to predict a 'monthly runoff coefficient' of the GR. In this paper, a current research is presented aiming to generalize and validate this expression in different locations and for a GR of different characteristics, specifically for an innovative GR, using cork in the substrate. Experimental tests are in progress, within an investigation project, with the aim to determine the expression's coefficients (k_1, k_2 and k_3) corresponding to a specific innovative GR in development.

In a first phase, theoretical values were determined based on the expression previously determined and on the climatic characteristics of several zones of Portugal, not considering the influence of the specific characteristics of GR. These theoretical results are obtained from the application of expression 1 to the 12 stations of Portugal where it is possible to get temperature and precipitation values. Data is available in http://snirh.apambiente.pt in period 2015/2016. The location of the different stations considered are represented in Figure 3.
In the research phase that is underway, the results will be validated and the coefficients (k_1, k_2 and k_3) will be adjusted to a particular location (Coimbra)

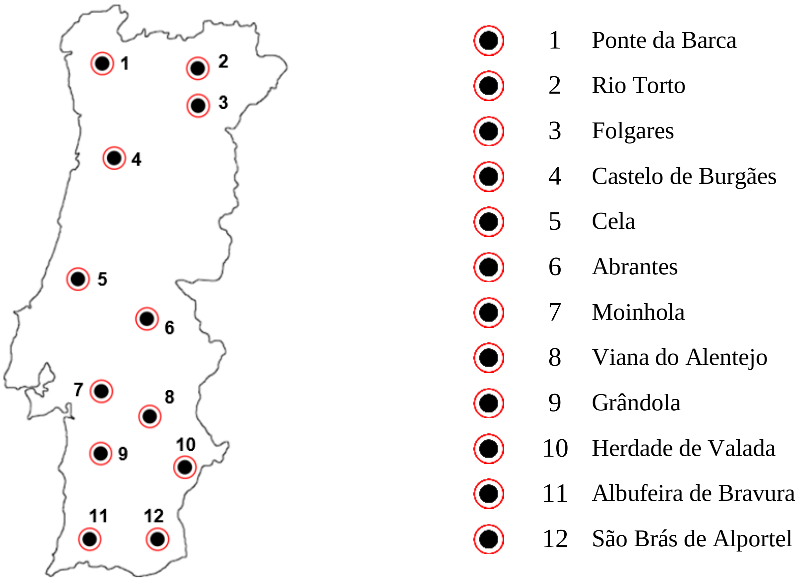

Figure 3 – Stations location available in http://snirh.apambiente.pt.

The methodology considered in present work, for generalize and validate the expression 1for the innovative GR, is summarized in Figure 4.

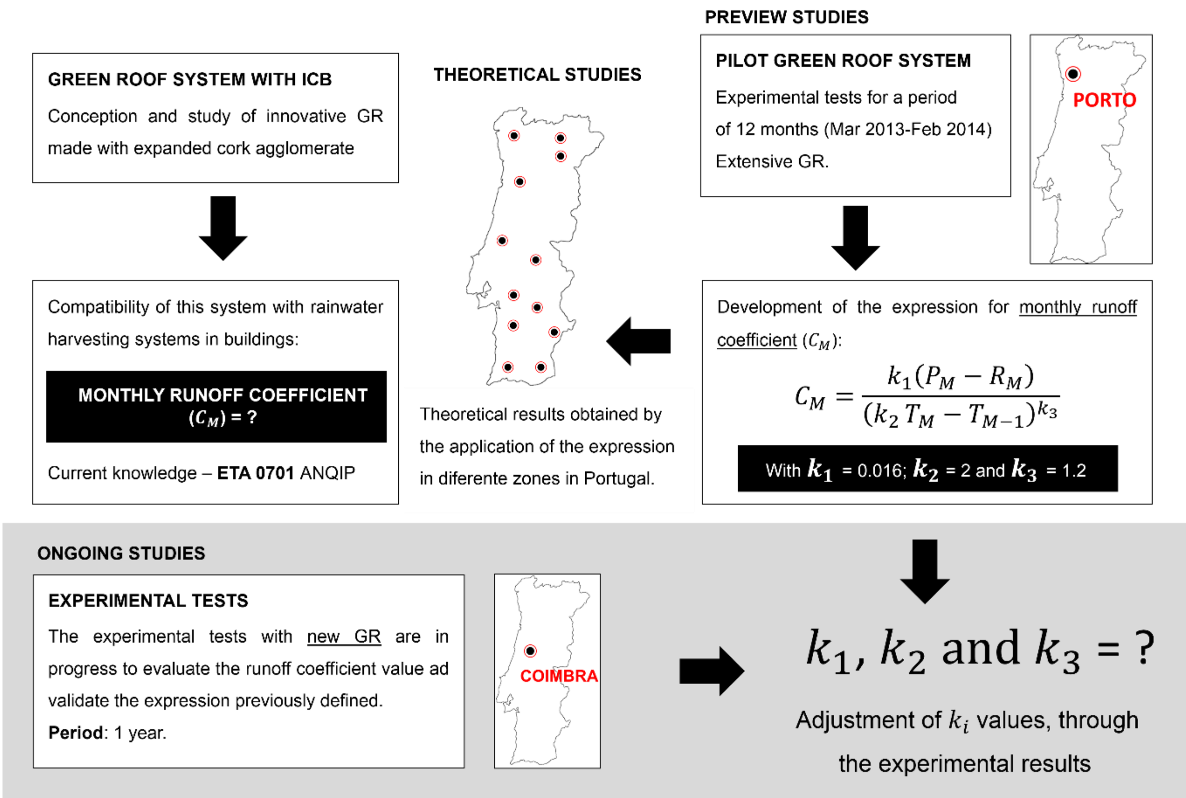

Figure 4 – Methodology considered in present work

4 Results

The theoretical results, obtained by the application of the expression in different zones of Portugal are represented in Figure 5 and in Table 1.

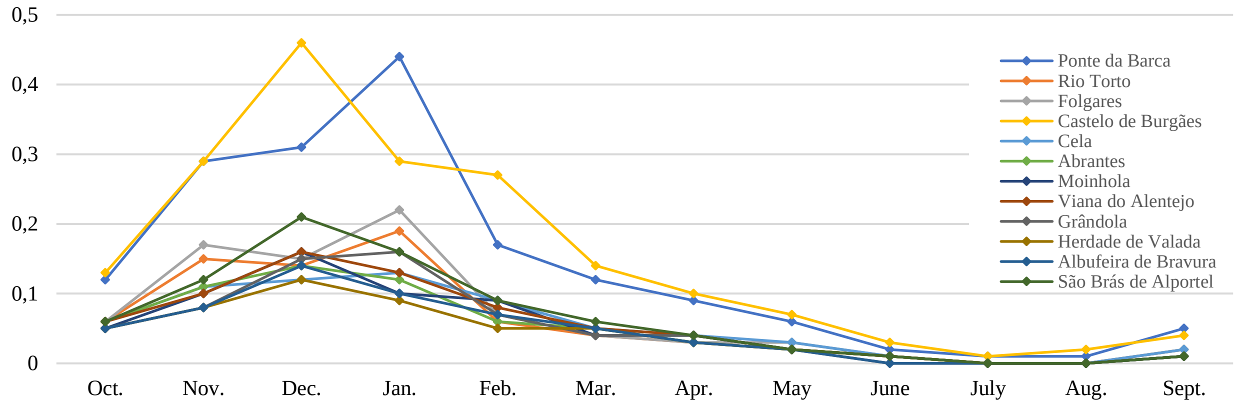

Figure 5 – Monthly runoff coefficient for the different stations (2015-2016).

Table 1: Results of the application of the expression 1 to the different stations of Portugal.

STATION	HYDROLOGICAL YEAR 2015/2016											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Ponte da Barca	0,12	0,29	0,31	0,44	0,17	0,12	0,09	0,06	0,02	0,01	0,01	0,05
Rio Torto	0,06	0,15	0,14	0,19	0,06	0,04	0,03	0,02	0,01	0,00	0,00	0,02
Folgares	0,06	0,17	0,15	0,22	0,07	0,04	0,03	0,03	0,01	0,00	0,00	0,02
Castelo de Burgães	0,13	0,29	0,46	0,29	0,27	0,14	0,10	0,07	0,03	0,01	0,02	0,04
Cela	0,06	0,11	0,12	0,13	0,09	0,05	0,04	0,03	0,01	0,00	0,00	0,02
Abrantes	0,06	0,11	0,14	0,12	0,06	0,05	0,03	0,02	0,01	0,00	0,00	0,01
Moinhola	0,05	0,10	0,16	0,10	0,09	0,04	0,04	0,02	0,01	0,00	0,00	0,01
Viana do Alentejo	0,06	0,10	0,16	0,13	0,08	0,05	0,04	0,02	0,01	0,00	0,00	0,01
Grândola	0,05	0,08	0,15	0,16	0,07	0,04	0,04	0,02	0,00	0,00	0,00	0,01
Herdade de Valada	0,05	0,08	0,12	0,09	0,05	0,05	0,03	0,02	0,01	0,00	0,00	0,01
Albufeira de Bravura	0,05	0,08	0,14	0,10	0,07	0,05	0,03	0,02	0,00	0,00	0,00	0,01
São Brás de Alportel	0,06	0,12	0,21	0,16	0,09	0,06	0,04	0,02	0,01	0,00	0,00	0,01

5 Conclusions

Mediterranean countries are among those with high risk of water stress. It is crucial to develop water efficiency measures, like the rainwater harvesting in buildings (Silva-Afonso and Pimentel-Rodrigues 2011) which requires the proper knowledge of criteria for the design of systems in this climate. The combination of green roofs with rainwater utilization systems seems a promising solution that can contribute greatly to a very appropriate response to the impacts of climate change.

These solutions should be widely generalized, preferably with a mandatory character in some regions. However, the design of these combined solutions has a great dependence on particularities of local or regional climate and research in this field is needed at present. Experimental studies carried out for an extensive GR pilot system (in Porto city, Portugal) have led to low values of runoff coefficient and have allowed the development of an expression to predict a 'monthly runoff coefficient' of the GR (Monteiro *et al.*, 2016). In this context, the main objective of this work was to generalize and validate, in different locations, the expression previous deduced for the GR pilot system for the innovative GR (with ICB) in development.

The theoretical results, obtained by the application of the expression for the determination of runoff coefficients in extensive GR in different zones in Portugal (not considering the specific characteristics of the green roofs - substrate, plants, etc.), show wide variations in runoff coefficient, with a minimum of the 0.04 and maximum of the 0.14 (annual averages). The experimental tests to validate the values k_1, k_2 and k_3 in the innovative GR are in progress.

Finally, it is possible to verify that this study is a contribution to improving the design of rainwater harvesting systems in buildings with GR.

Acknowledgments

The authors are grateful for the financial support provided by the Portuguese Foundation for Science and Technology (FCT) under the Project (POCI-01-0145-FEDER-016852), co-funded by the Operational Program for Competitiveness and Internationalization (POCI) of Portugal 2020 with the support of the European Regional Development Fund (FEDER).

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7 Presentation of Authors

Armando Silva-Afonso is a retired Full Professor at the University of Aveiro (Portugal), Department of Civil Engineering, where he still collaborates as Visiting Professor. His specializations are urban and building hydraulics and water efficiency in buildings, and he is the President of the Board of the ANQIP – Portuguese Association for Quality in Building Installations.

Carla Pimentel Rodrigues holds a PhD from the University of Aveiro (Portugal) in Civil Engineering (water efficiency). She is senior researcher and technical director of the ANQIP – Portuguese Association for Quality in Building Installations.

Márcia Lima graduated from the University of Aveiro (Portugal) in Civil Engineering. She is a PhD Student at University of Aveiro and grant holder at ANQIP – Portuguese Association for Quality in Building Installations.

PP12 - Study on a technology to suppress calcified urine in a horizontal branch drainpipe system where multiple urinals are installed successively
Second report: Field survey of calcified urine in drainpipe installed in various buildings, and experimental verification of remaining trend of urine in drainpipes plumbed under a slab

Y. Araki (1), M. Otsuka (2)

1. yusuke.araki@jp.toto.com
2. dmotsuka@kanto-gakuin.ac.jp
1. TOTO LTD., Products R&D Dept., Research Institute.
2. Prof. Dr. Eng., Department of Architecture and Environmental Design,
College of Architecture and Environmental Design, Kanto Gakuin University.

Abstract

As part of the measures to prevent global warming, water efficiency of urinals as well as water closets have become essential. Moreover, blockage of drainpipes caused by adhesion and deposition of calcified urine after long-term use has become a problem in public and office buildings, where multiple urinals are installed successively. As previously reported, it had been proposed that water with high urine concentration remains in horizontal branch drainpipes after flushing, as a result of urinal backflows. The purpose of this study is to reveal the relationship between the utilization of multiple urinals and the trend of calcified urine adhesion, based on a field survey of drainpipes installed in school facilities, commercial facilities and office buildings. Additionally, in most cases where a urinal drainpipe has been installed, we verified the tendency for urine to remain in the horizontal branch drainpipes plumbed underneath a slab. As a result of this study, we have found a relationship between field survey results and experimental results, and gained a basic knowledge about the adhesion and deposition of calcified urine in the drainpipe of actual public fields.

Keywords

Multiple urinals installed successively, calcified urine, water-efficient-type

1 Introduction

As part of the measures to prevent global warming, the water efficiency of urinals as well as water closets has become essential. Moreover, the blockage of drainpipes caused by the adhesion and deposition of calcified urine after long-term use has become a problem in public and office buildings (Photograph 1), where multiple urinals are installed successively[1)]. As previously reported, it had been proposed that water with a high urine concentration remains in horizontal branch drainpipes after flushing, as a result of urinal backflows[2)]. The purpose of this study was to reveal the relationship between the utilization of multiple urinals and the trend of calcified urine adhesion, based on a field survey of drainpipes installed in school facilities, commercial facilities and office buildings. Additionally, in most cases where a urinal drainpipe has been installed, we verified the tendency for urine to remain in the horizontal branch drainpipes plumbed underneath a slab.

Photograph 1 – Horizontal branch drainpipe of multiple urinals and calcified urine deposited in the drainpipe

2 Field survey of calcified urine in drainpipes installed in various buildings

2.1 Overview of the field survey

First, we conducted a questionnaire-style survey to understand the usage situation, daily cleaning conditions and implementation of piping cleaning. After that, we confirmed the piping route and presence of inspection holes necessary for observation. After this pre-survey, we observed inside the urinal drainpipes using Industrial-Videoscope (iPLEX LX/LT IV8635L1: Olympus).

2.1.1 Pre-survey using questionnaire
Table 1 shows the details of surveyed buildings and questionnaire items. We conducted this survey on School Facility (A, C, D, E, F), Commercial Complex (G) and Office Building (B).

Table 1 – Outline of surveyed facilities

	Category	Floor		Years of use	Numbers of urinals	Numbers of daily usage	Working Hours	Insertion point of Fiberscope	Types of flushing water
A	School	1st		2 years	4	0~100	From morning to night	Rubber-connect	Recycled water
		3rd			5		24 hours		
		5th							Tap water
B	Office	North	22nd	11 years	4	500~1000	From morning to night	Cleaning port	Tap water
			23rd						
			24th			100~500			
		South	22nd			500~1000			
			23rd						
			24th			0~100			
C	School	2nd		12 years	3	0~100	24 hours	Cleaning port	Tap water
		3rd							
D	School	5th		18 years	3	0~100	24 hours	Cleaning port	Tap water
E	School	2nd		8 years	6	100~500	24 hours	Cleaning port	Tap water
		4th							
F	School	2nd		23 years	6	100~500	24 hours	Cleaning port	Tap water
		3rd			9	0~100			
		4th			6				
G	Commercial Complex	West	1st	3 years	6	500~1000	From morning to night	Cleaning port & Trap	Recycled Water
			2nd	3 years		100~500		Cleaning port	
			3rd	3 years	2			Trap	
		South	2nd	over 11 years	5			Cleaning port	
			3rd	over 11 years	3			Trap	

2.1.2 Survey method of calcified urine deposition in drainpipe

We have taken photographs of passing the Industrial-Videoscope fiber scope through the inspection hole or rubber-connect placed on the horizontal branch drainpipe (Photograph 2), and estimated the deposition thickness of the calcified urine from the photograph taken inside of the drainpipe. Validity of the estimated thickness was checked using the thickness value measured at rubber-connect placed on the horizontal branch drainpipe of school facility A.

Photograph 2 – Survey of calcified urine in horizontal branch drainpipe using Industrial-Videoscope

2.2 Results and Discussion

2.2.1 Results of Pre-survey

Table 2 shows the results of the questionnaire-style survey. As a result of this survey, it is evident that the men's toilets are cleaned at least once a day in all facilities, and urinals are mainly cleaned at the drain trap section. Regarding the blockage of drainpipes, we obtained a reply that vomit caused the blockage of drainpipes at urinals of commercial complex G. Also, in office building B and commercial complex G, high pressure washing of the drainpipes was conducted periodically to clean the inside of the drainpipes, but most others did not implement this.

Table 2 – Results of questionnaire-style survey

<table>
<tr><th></th><th>Category</th><th colspan="2">Floor</th><th>Frequency of daily cleaning</th><th>Cleaning part of urinal</th><th>Blocking of drainpipe</th><th>Blocking part</th><th>Last cleaning of drainpipe inside</th><th>Frequency of cleaning for drainpipe</th><th>Cleaning method of drainpipe inside</th></tr>
<tr><td rowspan="3">A</td><td rowspan="3">School</td><td colspan="2">1st</td><td rowspan="3">1</td><td rowspan="3">Inside of trap</td><td rowspan="3">None</td><td rowspan="3">–</td><td rowspan="3">unknown</td><td rowspan="3">unknown</td><td rowspan="3">Brushing</td></tr>
<tr><td colspan="2">3rd</td></tr>
<tr><td colspan="2">5th</td></tr>
<tr><td rowspan="6">B</td><td rowspan="6">Office</td><td rowspan="3">North</td><td>22nd</td><td rowspan="6">2-3</td><td rowspan="6">Inside of trap</td><td rowspan="6">None</td><td rowspan="6">–</td><td rowspan="6">unknown</td><td rowspan="6">unknown</td><td rowspan="6">Brushing</td></tr>
<tr><td>23rd</td></tr>
<tr><td>24th</td></tr>
<tr><td rowspan="3">South</td><td>22nd</td></tr>
<tr><td>23rd</td></tr>
<tr><td>24th</td></tr>
<tr><td rowspan="2">C</td><td rowspan="2">School</td><td colspan="2">2nd</td><td rowspan="2">1</td><td rowspan="2">Inside of trap</td><td rowspan="2">None</td><td rowspan="2">–</td><td rowspan="3">unknown</td><td rowspan="3">unknown</td><td rowspan="3">Brushing</td></tr>
<tr><td colspan="2">3rd</td></tr>
<tr><td>D</td><td>School</td><td colspan="2">5th</td><td>1</td><td>Inside of trap</td><td>None</td><td>–</td></tr>
<tr><td rowspan="2">E</td><td rowspan="2">School</td><td colspan="2">2nd</td><td rowspan="2">1</td><td rowspan="2">Inside of trap</td><td rowspan="2">None</td><td rowspan="2">–</td><td rowspan="2">unknown</td><td rowspan="2">unknown</td><td rowspan="2">Brushing</td></tr>
<tr><td colspan="2">4th</td></tr>
<tr><td rowspan="3">F</td><td rowspan="3">School</td><td colspan="2">2nd</td><td rowspan="3">1</td><td rowspan="3">Inside of trap</td><td rowspan="3">None</td><td rowspan="3">–</td><td rowspan="3">unknown</td><td rowspan="3">unknown</td><td rowspan="3">Brushing</td></tr>
<tr><td colspan="2">3rd</td></tr>
<tr><td colspan="2">4th</td></tr>
<tr><td rowspan="5">G</td><td rowspan="5">Commercial complex</td><td rowspan="3">West</td><td>1st</td><td rowspan="5">1</td><td rowspan="5">Inside of trap</td><td rowspan="3">None</td><td rowspan="3">–</td><td rowspan="5">less than 1 year</td><td rowspan="5">once a year</td><td rowspan="5">High-pressure cleaning</td></tr>
<tr><td>2nd</td></tr>
<tr><td>3rd</td></tr>
<tr><td rowspan="2">South</td><td>2nd</td><td rowspan="2">Blocking by vomits</td><td rowspan="2">Horizontal branch drainpipe</td></tr>
<tr><td>3rd</td></tr>
</table>

2.2.2 Results and Discussion of survey of drainpipe

Figures 1 to 4 shows plumbing of survey buildings, a distinctive photograph of the calcified urine, and an illustration of the deposition and adhesion of calcified urine on the horizontal branch drainpipe.

School Facility A

There was a little calcified urine on the upstream side of the horizontal branch drainpipe, and the deposition thickness of calcified urine was approximately 0~5 mm. On the other hand, the thickness value of the calcified urine was approximately 5~6 mm at the downstream side of the drainpipe, near the entrance of the men’s restroom. In the bend section of the downstream side, the thickness value of the calcified urine was approximately 7~8 mm. In the connection to the vertical drainpipe, the value was approximately 5~6 mm.

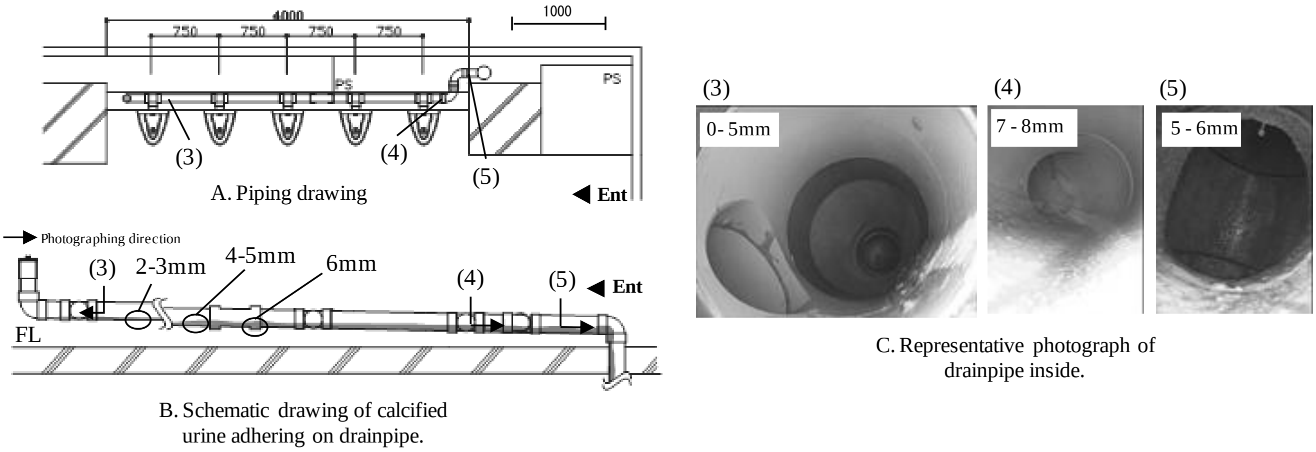


Figure 1 – Piping drawing, schematic drawing of calcified urine and photograph of drainpipe at School Facility A

Office Building B

Because the number of users in the men's restroom in this building was large compared to other surveyed facilities, there was large amount of calcified urine in the downstream side of the horizontal drainpipe. In particular, the drainpipe of the downstream side on the 22nd floor north toilet was almost blocked with a mass of calcified urine containing hairs, and the thickness of the calcified urine was no less than 31 mm. For this reason, the discharge rate of flushing water in the urinal near the pipe blocking was long relative to normal water discharge. Except for the 24th floor north toilet, calcified urine thickly adhered to fittings on the merging section horizontal branch drainpipe and instrument drainpipe (16~30 mm). Furthermore, we found deposition of calcified urine on most, upstream of the horizontal branch drainpipe. As previously reported[2)], it is considered that water with high urine concentration backflows to the upstream side of the horizontal branch drainpipe.

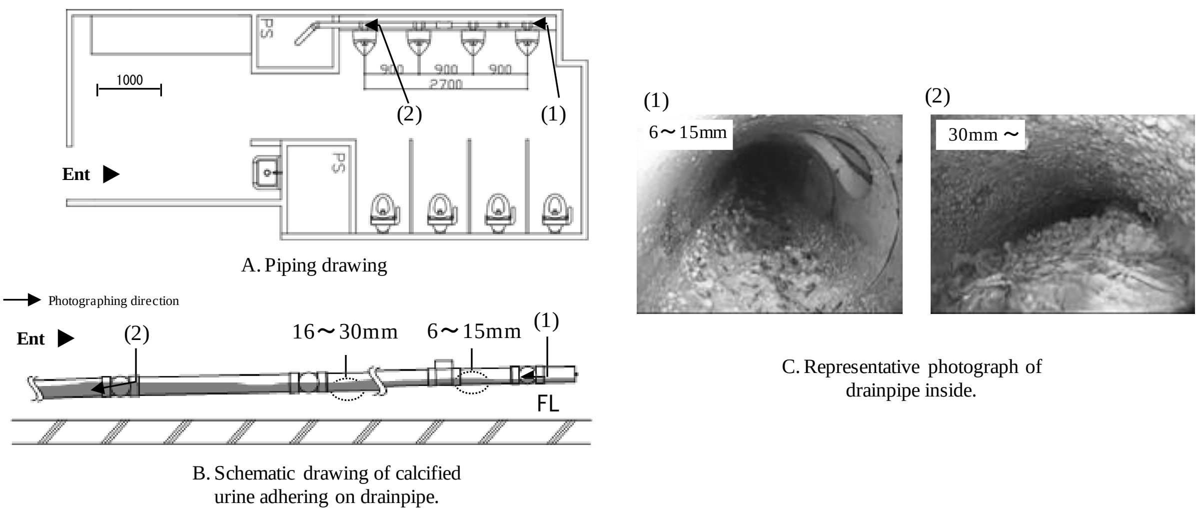


Figure 2 – Piping drawing, schematic drawing of calcified urine and photograph of drainpipe at Office Building B

School Facility E

In the upstream side of the drainpipe, the thickness of the calcified urine was approximately 16mm. However, in the middle and downstream side of the drainpipe, the thickness was approximately 5mm and 10mm respectively. As a result of the backflow of drainage water from the water closet, it is considered that waste from the water closet was stagnated furthest upstream of the horizontal branch drainpipe. The reason that calcified urine adhered to the merging section was because of periodic flushing with water from the water closet, and the amount of calcified urine in the middle of the drainpipe was less than in the upstream side and downstream side.

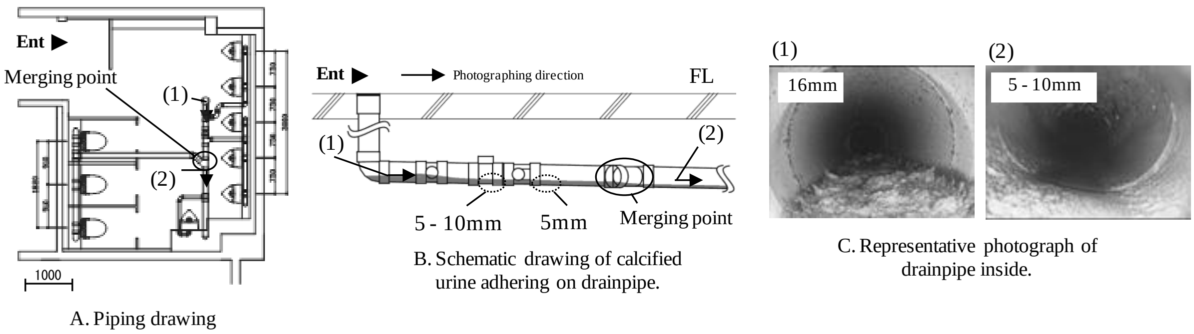


Figure 3 – Piping drawing, schematic drawing of calcified urine and photograph of drainpipe at School Facility E

Commercial Complex G

In spite of annual high-pressure washing of the drainpipes, there was more calcified urine than other facilities. In particular, in the 1st floor men's restroom in the East building, we observed copious adhesion of calcified urine with biofilm on the fittings on the merging section horizontal branch drainpipe and instrument drainpipe, as with the case of Office Building B.

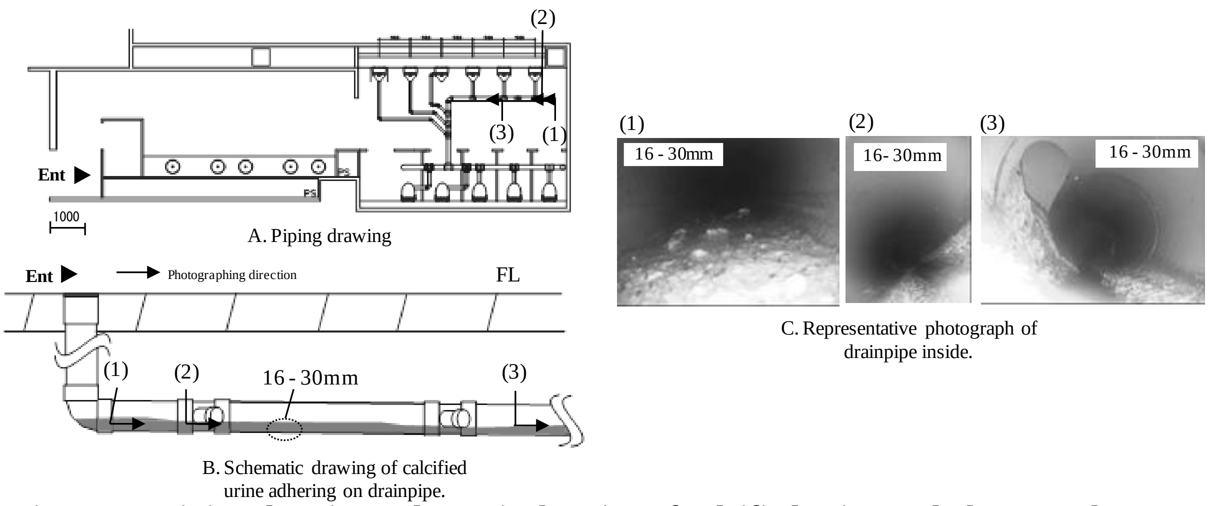


Figure 4 – Piping drawing, schematic drawing of calcified urine and photograph of drainpipe at Commercial Complex G

2.3 Summary of the field survey

We obtained the following conclusion from the field survey of the calcified urine adhering to drainpipes installed in various buildings.

(1) It is difficult to inhibit calcified urine from adhering to horizontal branch drainpipes by only simple daily cleaning of the trap section.

(2) The number of urinal users has a huge effect on the adhesion of calcified urine.

(3) In any restroom there is the tendency for a large amount of calcified urine to adhere to the upstream side and downstream side of the horizontal branch drainpipe of the urinal located closest to the restroom entrance door.

(4) We found the deposition of calcified urine mostly upstream of the horizontal branch drainpipe. As previously reported, it is considered that water with a high urine concentration backflows to the upstream side of the horizontal branch drainpipe.

(5) There is a possibility of inhibition of calcified urine on the drainpipe by periodically flushing the drainpipe rather than flushing per each use.

3 Experimental verification of remaining trend of urine in drainpipe plumbed under a slab

3.1 Overview of the experiments

3.1.1 Horizontal branch drainpipe system used in the experiment
Figure 5 shows the experimental urinal system. As equipment for experiments, urinals that the flushing volume can be switched between 2.0 L, 1.0 L and 0.5 L were implemented. We considered the flushing volume 2.0 L, 1.0 L and 0.5 L as standard-type, water-efficient-type and super-water-efficient-type, respectively. Figure 1 shows the horizontal branch drainpipe system for experiments. As in Figure 5, we numbered the urinals urinal-1, urinal-2 and urinal-3 from upstream to downstream. In addition, we drilled a hole (H1) on the upper surface of horizontal branch drainpipe at the point 200 mm upstream measured from the center of the merging point of the horizontal branch drainpipe and drainpipe for urinal-1. Furthermore, we drilled a hole at intervals of 200 mm from H1 to downstream (H2~H10). As the plumbing under the slab, we built a system using two fittings (JIS-DT-fittings, JIS-LT-fittings) and a two instrument drainpipe (inflow-angle 45 degree, inflow-gradient 1/50).

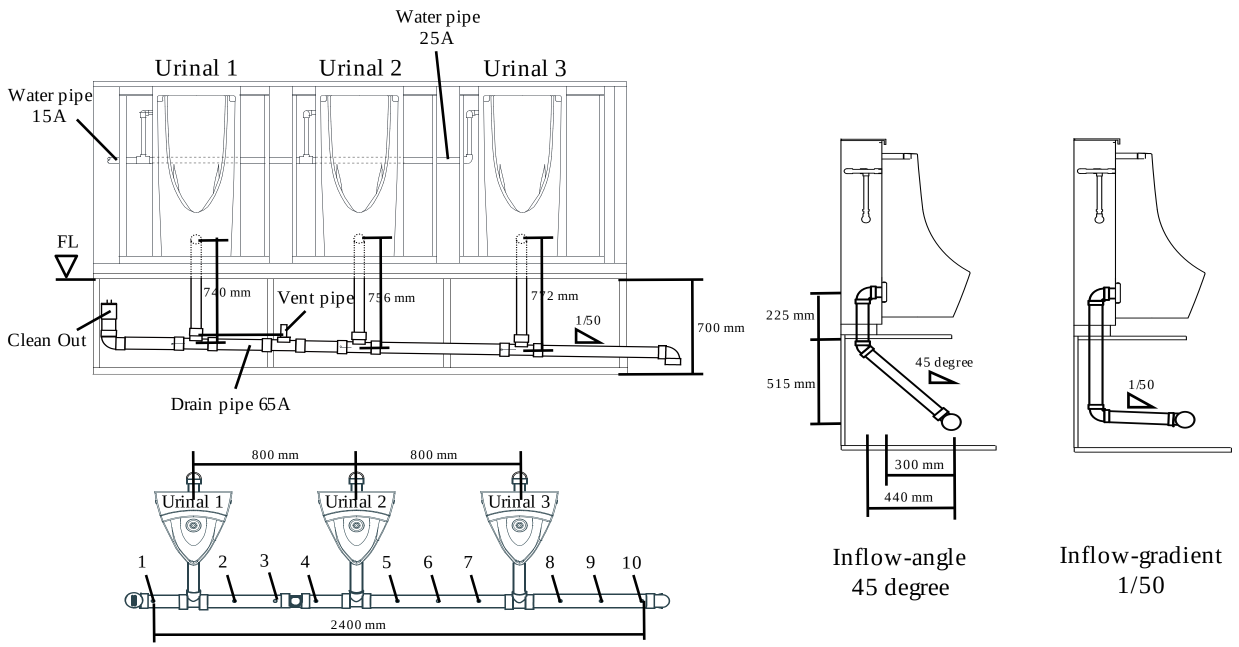


Figure 5 – Horizontal branch drainpipe system used in the experiments

3.1.2 Overview of various experiments

As previously reported2), 1%-concentration salt water was used as a urine substitute. Based on the actual volume and flow rate of urination by an adult male, 300 ml of urine substitute was poured into the urinal at a flow rate of approximately 25 ml/sec. The urinal was then flushed with 1.0L of water. With this operation as 1 cycle, 3 cycles were performed successively. After 3 cycles, measurement items of Clause 3.1.3 described below were measured. Drainage load patterns were single-instrument drainage and multiple-instrument drainage. To confirm single-instrument drainage, normal cleaning was performed in one of the urinals. Additionally, to confirm multiple-instrument drainage with merging of flow, normal cleaning was performed in two or all urinals. Figure 6 shows an example of the drainage timing of normal flushing at each urinal. For multiple-instrument drainage, based on the drainage timing of normal cleaning at urinal-1 located upstream, drainage of urinal-2 and urinal-3 was to merge the drainage coming from upstream with a 1 second time lag at each urinal.

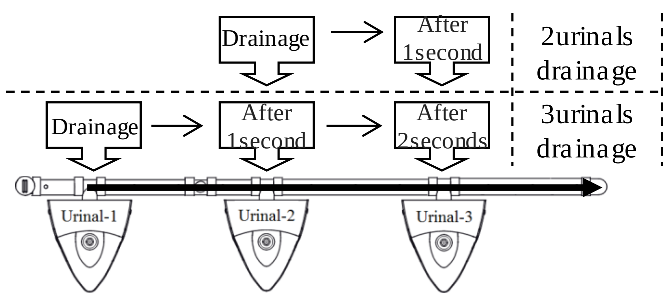


Figure 6 – Example of drainage timing of normal flushing

3.1.3 Evaluation indices and measurement methods

There are three evaluation indices in this study as described below:

a) Backflow distance:

Visually confirm the point at which cleaning water backflows toward the upstream of the horizontal branch drainpipe. The position of the measurement shall be the center of the merging point of the horizontal branch drainpipe behind each urinal.

b) Max value of water level:

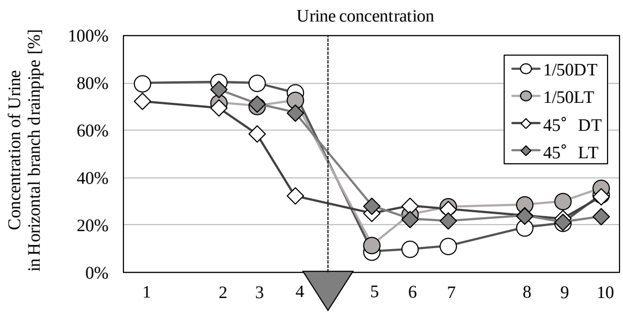
Take a straight scale with calligraphy practice paper placed vertically, put it into the hole for measurement. Measure the height of the calligraphy practice paper that became wet from the cleaning water.

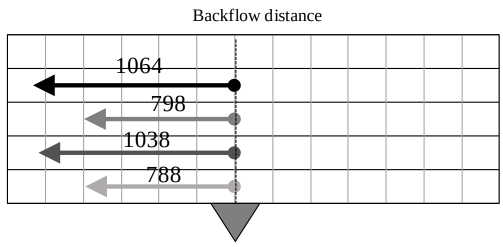
c) Concentration of residual urine substitute:

After cleaning, take the urine substitute remaining in the horizontal branch drainpipe from the hole for measurement, measure electrical conductivity, and calculate the concentration from the ratio of electric conductivity of the charged urine substitute. (1% concentration saline)

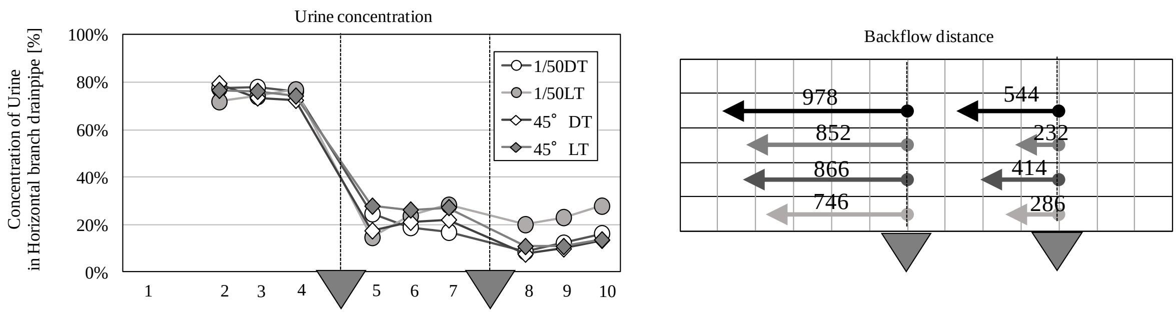
3.2 Results and Discussion

Figure 7 shows the results of the measurement of residual urine substitute and backflow distance in the horizontal branch drainpipe. In the case of the single-instrument drainage pattern, the concentration of the residual urine was 70~90% the furthest upstream of the horizontal branch drainpipe in any fittings and inflow gradient. At the furthest downstream side, whereas the concentration was a low value of 24 % in the case of 45-LT, the concentration in the case of 1/50-LT was a higher value at 36 %. It is presumed that drainage water from the urinals was well diluted with fresh flushing water by the stirring effect of acceleration due to the large gap between the urinal outlet and horizontal branch drainpipe. In addition, we found that urine extensively remained in the upstream side of the drainpipe when using DT-fittings. It seems that the amount of drainage water backflow was larger in the case DT-fittings were used, more than with LT-fittings due to the direction of the drainage. In all cases of multiple-instrument drainage, the dispersion of urine concentration was small compared to cases of single-instrument drainage. Moreover, dispersion of urine concentration was larger in the downstream side of the 1/50-LT system with a value of 17 % of the other case. From these results, we confirmed that DT-fitting is immune to inflow variation.

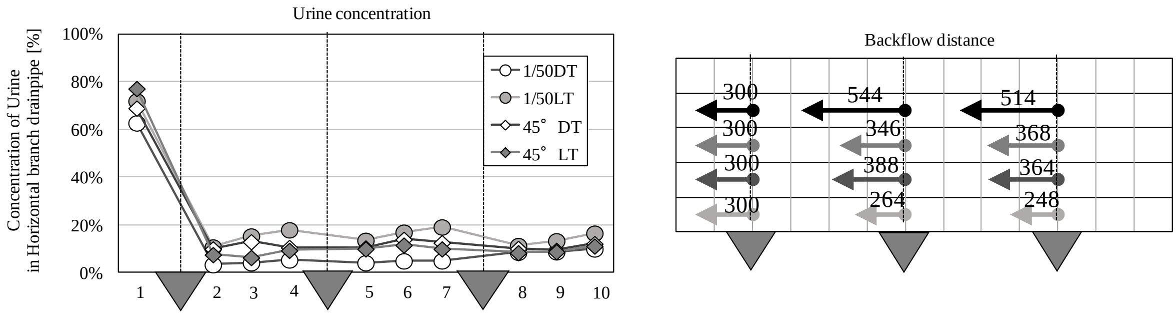




(1) Urinal 2



(2) Urinal 2 + Urinal 3



(3) Urinal 1 + Urinal 2 + Urinal 3

Figure 7 – Residual concentration and backflow distance of urine at each flushing

In comparison of all backflow distances, the value of a 45 degree-DT system was the largest, and the value of 1/50-LT system was the smallest. The variation of backflow distance of these two systems was at most 312 mm. We found that backflow distance was short in the case where LT-fittings were used with a small inflow angle such as a 1/50 gradient.

Figure 8 shows water level in the horizontal branch drainpipe when flushing water. The value of the water level was indicated at high in the case of multiple-instrument drainage, because the amount of drainage water was increased by the merging of drainage water.
We observed the swirling flow at the fittings of the merging of the horizontal branch drainpipe, especially with an inflow-angle of 45 degrees. Because of this swirling flow, the value of water level at the merging point to the horizontal branch drainpipe was very high. However, the swirling flow did not occur in the case of the 1/50 inflow-gradient. This can be considered to mean that calcified urine adhered prevalently to the upper side of the drainpipe in the case of a steep inflow, such as fittings of a 45 degree inflow-angle.

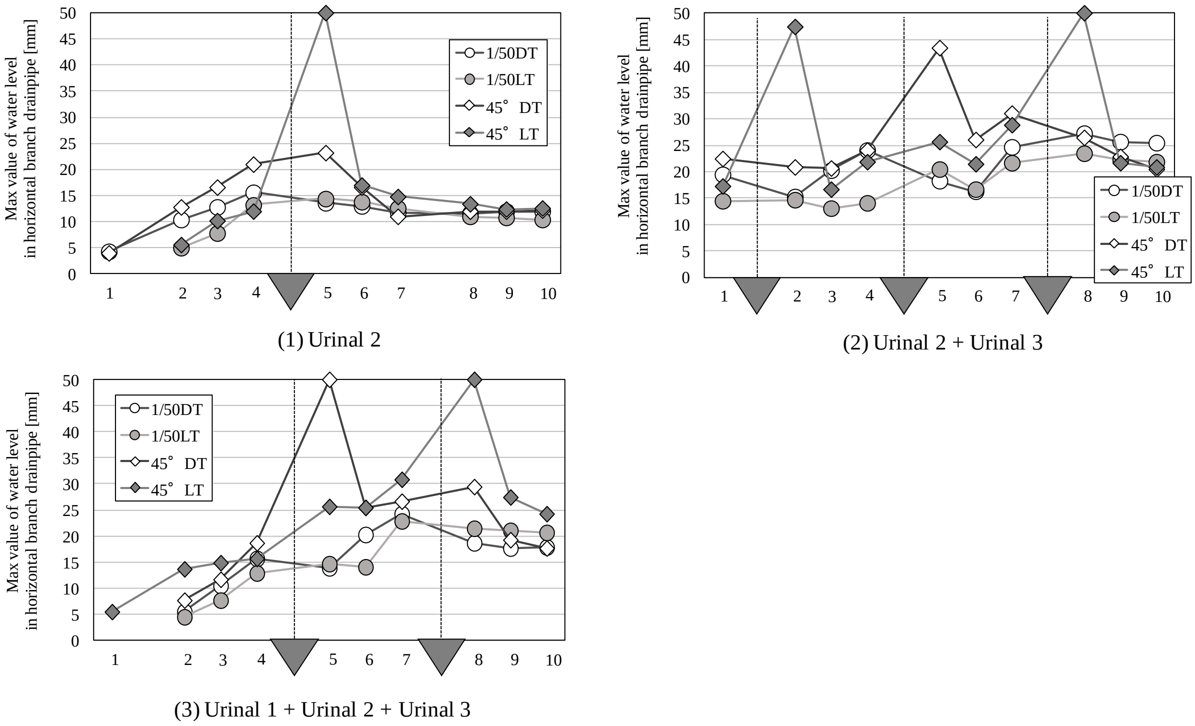


Figure 8 – Max value of water level in horizontal branch drainpipe during each flushing

3.3 Summary of the experiments

We obtained the following conclusion from experiments using four plumbing systems under a slab.

(1) There is not much difference between an inflow-gradient 1/50 system and an inflow-angle 45 degree system on residual urine concentration in a horizontal branch drainpipe. However, in considering the backflow distance, adhesion by the swirling flow of diluted urine and easy planning of the drainpipe system, it is preferable to select small inflow-gradient systems in case of plumbing under a slab.
(2) As a result of residual urine concentration, it is confirmed that calcified urine tended to adhere to the upstream side and the downstream side, rather than to the vicinity of the urinal outlet and horizontal branch drainpipe merging point.

4 Conclusions

As a result of the field survey at various buildings, we found the adhesion of calcified urine occurred on the furthest upstream side of the horizontal branch drainpipe, and periodically flushing such waste water from the water closet effectively suppressed deposition of calcified urine. Consequently, we confirmed that the phenomenon reported in our previous study occurred in actuality. Additionally, the backflow of highly concentrated urine also occurred on the horizontal branch drainpipe plumbed under the slab, and we found that inflow angle to the horizontal branch drainpipe affected the residual concentration and backflow distance of urine.

The piping configuration of the horizontal branch drainpipe has many variations. However, it is possible to suppress calcified urine in the drainpipe by elucidating the basic characteristics of the behavior of urine flow during flushing, and the effect of the pipe joint geometry.

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6 Presentation of Authors

Yusuke Araki is engineer of TOTO LTD, Research Institute. He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His current research interests are the control technology of calcified urine in the drainage system of urinals (in particular, automatic cleaning urinals).

Masayuki Otsuka is a professor at the Dept. of Arch. & Env., Kanto Gakuin University, Doctor Engineer. He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, Academic Director). His current research interests are the hybrid drainage system that uses both force feed type and gravity type drainage methods compatible with commercial building conversion.

PP13 - Dry-wells dimensioning: using analogy between heat flux in solids and water flow in the soil

Armando Traini Ferreira (1), Marina Sangoi de Oliveira Ilha (2)
1. armandotraini@uol.com.br
2. milha@fec.unicamp.br
(1) Federal Institute of Education, Science and Technology of São Paulo, IFSP, São Paulo, Brazil
(2) Department of Architecture and Building Construction, School of Civil Engineering, Architecture and Urban Design, University of Campinas, Campinas, SP, Brazil

Abstract

The dry-well is a strategy for the management of rainwater, constituting an important strategy to infiltrate water and minimize the impacts of soil sealing in the cities. One of the determining variables for the design of dry-well is the total filling time of the system. This paper proposes the incorporation of interface coefficients into equations for the determination of humidity, established through the domain transfer via analogy, for the representation of the three-dimensional phenomenon of water drainage. Considering the simulated design flows in an experimental installation, which varied from 2,68 m^3/h to 11,01 m^3/h, the corresponding filling times were determined and, from the Least Squares Method, with $R^2>0,95$, an equation was proposed for the determination of filling time of dry-wells that can be used in places with physical and hydrological characteristics like those in the study site.

Keywords

Water infiltration; on lot drainage; dry-well; hydraulic modeling, scientific analogy.

1 Introduction

The envelope curve method, proposed by [1], has been used for the determination of the maximum volume of dry-wells, obtained by the maximum difference between curves of the accumulated volumes of input and output of the system, according to Figure 1.

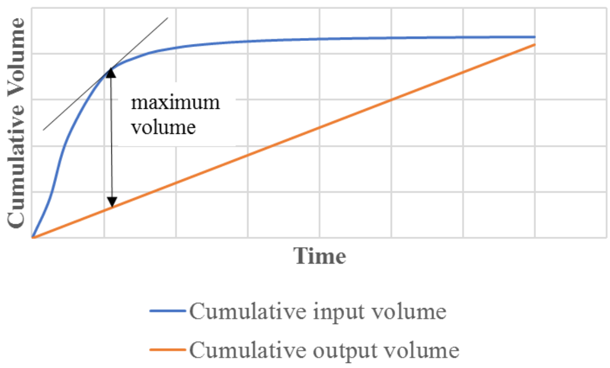


Figure 1: Graphical representation of the envelope curve.
Source: Adapted from [1]

The curve of the input volume in the system is obtained by multiplying the Intensity-Duration-Frequency (IDF) equation by the duration of the rain and the output volume curve is governed by the Darcy Equation.

In this case, we must know the IDF equation, which is not always updated, and the filling time, which is considered, in a simplified way, equal to the duration of the rain. However, while rainwater enters the system, infiltration occurs in the soil layers, and this simplification is inadequate.

In [2] the filling time was determined using the design of the domain transfer via analogy DTA, considering that the flow is analogous to the heat flow of a solid medium and the filling time is analogous to the time to reach a certain temperature in the solid medium, considering the phenomenon of water drainage in the soil in a one-dimensional form. From the proposed equations for the determination of the humidity in the different layers of the dry-well and the soil below it, the heights of water level within the dry-well were determined in function of the time. The filling time presented in that work corresponds, for each flow studied, to the moment when the height of the water level equaled the useful height of the experimental well.

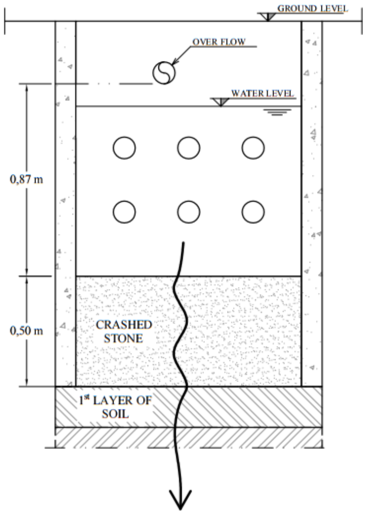
This work presents an evolution of the equations proposed for the determination of humidity, with the incorporation of interface coefficients to represent the three-dimensional phenomenon of the drainage. According to [3], the greater the number of directions in which the drainage of a fluid occurs, the greater the complexity of the analysis of the phenomenon, being used coefficients that represent the experimental data in the proposed modeling.

2 Method

This research considered the same design flow rates used in [2], which were: 2,68 m^3/h and 11,01 m^3/h.

The water level corresponding to these flows were obtained through a model sensor HOBO U20-001- 01, positioned on the upper face of the crushed stone layer at the bottom of the experimental dry-well.

The experimental dry-well (Figure 2) is composed of a cylindrical excavation of 1,50 m depth and 1,10 m internal diameter, with 0,87 m of effective depth, counted from the top face of the crushed stone layer number 2 (0,50m thick) to the bottom generating line of the overflow pipe. The pre-dimensioning of the dry-well, as presented in [4], was made from the rational equation, considering a design rain with a return period of 5 years and duration of 10 minutes, precipitated on an existing cover in the local.



Source: Elaborated from [2]

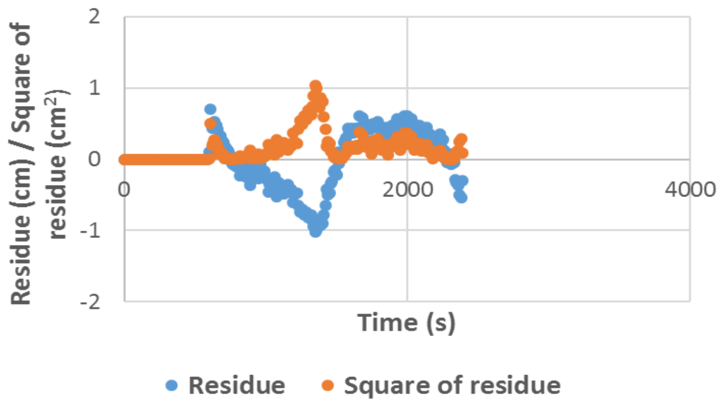
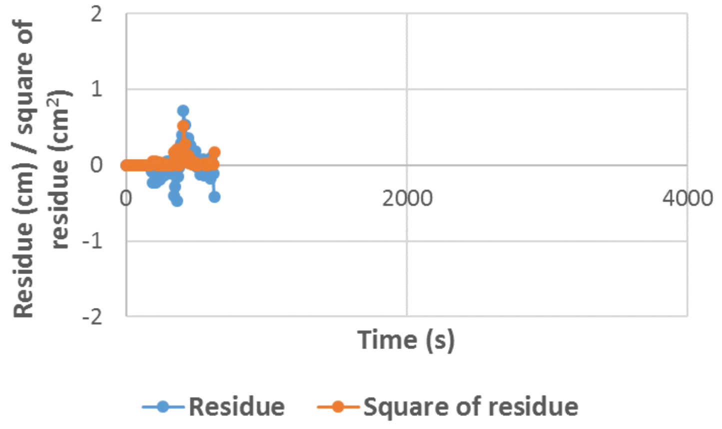
Source: Authors

Figure 2: Experimental dry-well

For each of the selected flows, several values of height of the-water level were recorded during the test in the experimental installation, thus, obtaining a total of 311 values of the height of the water level in function of the time.

Table 1 presents the residues analysis when comparing the values of the height of the experimental water level and those obtained in [2]. The variance of the sum of the residues squared was equal to 0,167 cm for the flow rate of 2,68 m³/h and 0,038 cm for the flow rate of 11,01 m³/h.

Table 1: Analysis of the residues – values of the height of the experimental water level **obtained through the model proposed in [2]**

Design flow (m^3/h)	Residues (cm) e residues squared (cm^2) in function of the time (s)	Sum of the residues (cm)
2,68		1,023
11,01		0,820

Source: Authors

From the analysis of the residues, interface coefficients were proposed, which were determined by equating the observed filling times and those obtained in [2].

The equations of the interface coefficients were obtained by the Least Squares Method with correlation coefficient (R2)> 0,95, to minimize the sum of the residues squared.

The experimental dry-well has 20 holes in the lateral walls, through which infiltration also occurs, thus, it was considered the addition of these areas in the total crushed stone area, by means of a coefficient of form, analogous to the thermal resistance factor proposed by [5] for cylinders of defined length, in a homogeneous medium and with constant conductivity (Equation 1):

$$R=\frac{\ln(4*e_s/d)}{(2\pi e_s)} \quad (1)$$

Thus:

R	=	Resistance factor [dimensionless];
e_s	=	Equivalent thickness of the soil [m];
d	=	Hole diameter [m].

From the humidity equations with the interface coefficients, the corresponding water level heights were determined over the corresponding time, as shown in [2], that is:

If $h_p^{m+1} \leq \eta$, $H^{m+1} = 0$ cm (2)

If $h_p^{m+1} > \eta$, $H^{m+1} = (h_p^{m+1} - \eta)* \Delta Xp$ (3)

Em que:

h_p^{m+1}	=	Humidity of the crushed stone layer in the bottom of the dry-well in the time "m+1" [%];
η	=	Porosity of crushed stone [%];
H^{m+1}	=	Water depth in the time "m+1" [cm];
ΔXp	=	Crushed stone thickness [cm].

Then, the water level heights observed in the experimental installation for the two flows under study and those obtained by the model were compared by means of the t-paired test with a significance level of 5%, according to [7].

From this, the filling times were determined for the two design flow rates under study, which correspond to the time when the water level height equaled the useful height of the dry-well.

By applying the same procedure for other 28 simulated design flows in the experimental installation, which ranged from 2,68 m^3/h to 11,01 m $^3/h$, the corresponding filling times were determined and, from Least Square Method, With $R^2 > 0,95$, an equation was proposed for the determination of the filling time.

3 Results and discussion

Table 2 presents the interface coefficients determined as presented in the method.

Table 2: Interfaces coefficients proposed in the model.

Interaction air-crushed stone ($C_{ar,b}$)	$C_{ar,b}=\frac{0{,}04001*Q_p*10^{\frac{\log\left(\frac{A_2}{5*10^8}\right)}{0{,}565}}}{(\Delta X_b*A_b)}$	**(4)**
	$A_2=\frac{Q_p*3600}{k_s*A_b}$	**(5)**
Variation of hydraulic conductivity around the axis of the infiltration well (k_1)	$k_1=\frac{0{,}5283*[\log(C_{ar,b})]^2-0{,}8117*\log(C_{ar,b})}{C_{ar,b}}$	**(6)**
Variation of hydraulic conductivity throughout the soil depth (k_2)	$k_2=(-0{,}0111*k_1+0{,}9844)*1{,}04$	**(7)**
Interaction crushed stone-soil ($C_{b,s}$)	$C_{b,s}=\frac{0{,}1957-C_{ar,b}}{0{,}1975}$	**(8)**
Interaction of the side holes of the well with the soil around it (k_3)	$k_3=(-0{,}48k_1+1{,}4485)*0{,}993$	**(9)**

A_2 = Parameter that relates the design flow, hydraulic conductivity and bottom area of the dry-well [dimensionless]; Qp = design flow [m^3/h]; Ks = Hydraulic conductivity of the soil [m/s]; Ab = Area of the crushed stone surface of the bottom of the system [m²].

Source: Authors

The equations for the determination of the humidity in the different layers of the dry-well and the soil below it, with the incorporation of the constant interface coefficients, are presented in Table 3.

Table 4 presents the values of the proposed interface coefficients for the two design flows considered in this study.

The results obtained with the model containing the interface coefficients proposed in this study were not significantly different from the experimentally observed values for the 5% confidence level (Table 5).

Table 3: Equations of humidity with the interface coefficients.

$h_p^{m+1}=C_{ar,b}*\left[h_p^m+\left(\frac{2*k_1*k_2*k_3*k_{s,1}*A_p*\left(h_1^m-h_p^m\right)+Q_p}{\Delta X}\right)*\left(\frac{\Delta t}{A_p*\eta_p*\Delta X_p}\right)\right]$	(10)
$h_1^{m+1}=C_{b,s}*\left[h_1^m+\left(\frac{2*h_p^m-3*h_1^m+h_2^m}{\Delta X}\right)*\frac{k_1*k_2*k_3*k_{s,1}*\Delta t}{\left(\Delta X*\eta_{s,1}\right)}\right]$	(11)
$h_i^{m+1}=h_i^m+\left(\frac{h_{i+1}^m-2*h_i^m+h_{i-1}^m}{\Delta X}\right)*\frac{k_1*k_2*k_3*k_{s,1}*\Delta t}{\left(\Delta X*\eta_{s,i}\right)}$	(12)
$h_n^{m+1}=h_{n-1}^m+\left(\frac{h_{n-1}^m-h_n^m}{\Delta X}\right)*\frac{k_1*k_2*k_3*k_{s,n}*\Delta t}{\left(\Delta X*\eta_{s,x}\right)}$	(13)

Subtitles:
Ap = permeable gravel in the well [m^2];
$C_{ar,b}$ = gravel-water interaction coefficient [dimensionless];
Cb,s = gravel-soil interaction coefficient [dimensionless];
h_i^m = moisture in the soil layer "i" at time "m" [%];
h_i^{m+1} = moisture in the soil layer "i" at time "m + 1" [%];
h_{i+1}^m = moisture in the soil layer "i + 1" at time "m" [%];
h_{i-1}^m = moisture in the soil layer "i-1" at time "m" [%];
h_{n-1}^m = moisture in the soil layer "n-1" at time "m", [%];
h_n^m = moisture in the soil layer "n" at time "m" [%];
h_n^{m+1} = moisture in the soil layer "n" at time "m + 1" [%];
h_p^m = moisture in the gravel layer "p" at time "m" [%];
h_p^{m+1} = moisture in the gravel layer "p" at time "m + 1" [%];
h_1^m = moisture in layer "1" at time "m" [%];
h_2^m = moisture in layer "2" at time "m", [%];
h_1^{m+1} = moisture in the soil layer "1" at time "m + 1" [%];
$K_{s,i}$ = hydraulic conductivity in the soil layer "i" [m/s];
$K_{s,n}$ = hydraulic conductivity in the soil layer "n" [m/s];
$K_{s,1}$ = hydraulic conductivity in the soil layer "1" [m/s];
k_1 = coefficient of interface between layers around the well [dimensionless];
k_2 = coefficient of interface along the soil layers below the well [dimensionless];
k_3 = coefficient of interface of the lateral holes [dimensionless];
Qp = design flow rate [m^3/h];
η_b = porosity of the gravel layer [%];
$\eta_{s,i}$ = drainable porosity of the soil layer "i" [%];
$\eta_{s,n}$ = drainable porosity of the soil layer "n" [%];
$\eta_{s,1}$ = drainable porosity of the soil layer "1" [%];
Δt = time interval used for each iteration [s];
ΔX = thickness of the soil layer [cm];
ΔXp = thickness of the gravel layer [cm].

Source: Authors

Table 4: Values of the interface coefficients for the design flows under study.

Design Flow (m^3/h)		2,68	11,01
Interface Coefficients	Interaction air-crushed stone ($C_{ar,b}$)	0,446	2,230
	Variation of hydraulic conductivity around the axis of the dry-well (k_1)	0,782	0,913
	Variation of hydraulic conductivity along the axis of the dry-well regarding the depth direction. (k_2)	1,048	1,013
	Interaction crushed stone-soil ($C_{b,s}$)	1,270	1,122
	Interaction of the lateral holes of the well with the soil around it.(k_3)	1,066	1,003

Source: Authors

Table 5: Parameters of t-paired test for $p < 0,05$.

Design Flow (m^3/h)	2,68	11,01
Average sample of the residues (cm)	$2,231 \times 10^{-2}$	$1,280 \times 10^{-3}$
Sample variance of residues (cm)	$1,672 \times 10^{-1}$	$3,796 \times 10^{-2}$
Data number (dimensionless)	247	64
t-paired of the experimental data (dimensionless)	0,9996	0,9998
Degrees of freedom (dimensionless)	246	63
Significance level (%)	5,0	5,0
t-student with N degrees of freedom (dimensionless)	-1,96; +1,96	-1,96; +1,96
Confidence interval – Lower Limit (dimensionless)	-0,043	-0,011
Confidence interval – Upper Limit (dimensionless)	+0,043	+0,011

Source: Authors

Table 6 presents the filling time determined in [2] and those obtained with the incorporation of the interface coefficients proposed in this study.

Table 6: Dry-well filling times.

Design flows (m^3/h)	**filling times**		**Difference (%)**
	According to [2]	**Proposed in this study**	
2.68	40 min 50 sec	45 min 40 sec.	+14%
11.01	10 min. 30 sec	9 min 24 sec.	-10%

From this, considering the values of the filling times obtained for each simulated design flow in the experimental installation, an equation for the determination of the filling time of dry-wells was proposed by using the Least Squares Method:

$T_{e,M,PI}$=8.239,7$Q_p^{-1,118}$ (14)

Thus:

$T_{e,E,PI}$ = total filling time of the experimental dry-well. [s];
Q_p = design flow [m^3/h].

5 Conclusion

The equation proposed in this study incorporated coefficients of interface to the previously proposed model, to represent the interactions between the air and the crushed stone of the bottom of the well; the variation of the hydraulic conductivity around and along the well depth; the interaction between the lateral holes and the soil, and the interaction of the crushed stone of the bottom of the well and the soil.

Considering two design flows under study, the values obtained for the heights of the water level by the proposed model were not significantly different from those observed experimentally, for a confidence level of 5%

The equation for determining the filling time of the dry-well proposed in this work can be used elsewhere if it has similar physical and hydrological characteristics.

6 Acknowledgments

CNPq - Conselho Nacional de Desenvolvimento Científico e Tecnológico (National Council for Scientific and Technological Development); FAPESP – Fundação de Amparo à Pesquisa do Estado de São Paulo (Foundation for Research Support of the State of Sao Paulo); Instituto Federal de Educação, Ciência e Tecnologia de São Paulo (Federal Institute of Education, Science and Technology of São Paulo); Eng. MS. Ricardo P. A. Reis

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8 Presentation of Author(s)

Armando Traini Ferreira is professor at the Federal Institute of Education, Science and Technology of São Paulo, São Paulo, SP, Brazil (at the time that this research was conducted, graduate student in the School of Civil Engineering, Architecture and Building Design, University of Campinas, Sao Paulo, Brazil).

Dr. Marina Sangoi de Oliveira Ilha is professor at the Department of Architecture and Building Construction, School of Civil Engineering, Architecture and Urban Design, University of Campinas, Campinas, SP, Brazil. She is the Dean of the School of Civil Engineering, Architecture and Urban Design since 2014 and the head of the Building Services Research Group.

PP14 - Survey to review the calculation standards for domestic wastewater treatment plants in the rest-areas of expressway

Tetsuya Niimi (1), Atsushi Umayahara(2), Kyosuke Sakaue(3), Saburo Murakawa(4), Keizou Niki(5)

1. t.niimi.aa@ri-nexco.co.jp
2. a.umayahara.aa@c-nexco.co.jp
3. sakaue@isc.meiji.ac.jp
4. muraka@hiroshima-u.ac.jp
5. niki@jeces.or.jp

(1)Research Engineer, Nippon Expressway Research Institute, Japan
(2)Research Engineer, Nippon Expressway Research Institute, Japan
(3)Professor, Meiji University, Japan
(4)Professor Emeritus, Hiroshima University, Japan
(5)Director, Japan Education Center of Environmental Sanitation, Japan

Abstract

Over 800 rest-areas are located on more than 8,000km in the Japanese expressways. Many of these rest-areas are in mountainous areas, requiring around 400 of them to have domestic wastewater treatment plants. Today, with various types of rest-areas in operation and more water-saving toilets being used, a need has arisen to review the calculation standards for these treatment plants. Therefore, a survey was carried out to grasp the number of users and the amount and quality of wastewater drained at 14 typical nationwide rest-areas. The survey showed that the size of domestic wastewater treatment plants could be reduced from the existing standard, and contributed to establish a calculation standard in conformity with how to be used.

Keywords

Expressway; Rest-area; Domestic wastewater treatment plant; Survey; Behavioral characteristics of users; Drainage characteristics.

1 Introduction

At present, the scale of domestic wastewater treatment plants for expressway rest-areas is determined by calculating factors such as planned wastewater amount and planned water quality using the “Design Standards for Domestic Wastewater Treatment Plants at Expressway Rest-areas” (June 1999, Japan Highway Public Corporation) (referred to below as "current standards"). However, more than 15 years have passed since current standards were established, and due to changes in the situation surrounding rest-areas, such as diversification of rest-areas and dissemination of water-saving type toilets during that period, there is expected to be some deviation between calculations based on current standards and actual conditions.

The purpose of this research is to contribute to the implementation of domestic wastewater treatment plans conforming to actual conditions, by reviewing current standards to ensure scale calculation standards for domestic wastewater treatment plants correspond to the actual conditions of rest-areas.

2 Changes in the situation surrounding expressway rest-areas

2.1 Diversification of rest-areas

In terms of commercial facilities of rest areas prior to privatization, service areas (referred to as "SA" below) were composed of restaurants, snack corners (udon, soba) and shops. Parking areas (referred to as "PA" below) were composed of snack corners (udon, soba) and shops. Since privatization of the Japan Highway Public Corporation, efforts have been made to improve customer satisfaction by the various expressway companies, and as a result there has been an increase in convenience stores, cafes and other eating/drinking establishments, and food courts made up of various types of eating/drinking establishments not following the previous style of operation.

2.2 Adoption of water-saving type toilets

Rest-area toilets are used by more than 70% of rest-area visitors, and the amount of water used accounts for about half of the total. Just as with commercial facilities, there has been progress in renovation of toilets due to efforts to improve customer satisfaction after privatization, and the latest water-saving type toilets have been used for toilets installed during renovation. The amount of flushing water per time when standards were established and with current water-saving type toilets is as shown in Table 1, and it has been confirmed that today the amount is significantly reduced.

Table 1 Changes in amount of toilet flushing water

	1999	Current
Toilet stool	13 L	6 L
Urinal	5 L	2–4 L

3 Composition of the calculation standards for domestic wastewater treatment plants

3.1 Coefficients provided for calculating scale of domestic wastewater treatment plants

Current standards are based on four items: Daily average wastewater amount, maximum wastewater amount over time, inflow water quality, and number of persons for treatment. Approaches for calculating each item are as given in (1) through (4) below. Of the coefficients provided for these calculations, focus is placed in the current review on those likely to change due to the actual use situation.

(1) Daily average wastewater amount
The number of persons per hour visiting the rest facility is found by multiplying the number of parking slots by the vehicle type (large car, small car, bus) composition rate, parking turnover rate, and average vehicle ridership. The number of users per day is found by taking into account the rush rate in the number of persons per hour. The daily average wastewater amount is calculated by multiplying the above values with the toilet, snack corner, and restaurant use rate, and the wastewater intensity of each facility.

(2) Maximum wastewater amount over time
This is calculated by multiplying the amount of flushing/washing water per person with the turnover rate found from the toilet and restaurant use time.

(3) Inflow water quality
The average inflow water quality of mixed drain water flowing into each facility is calculated using a weighted average of the wastewater amount and pollutant load amount of each facility.

(4) Number of persons for treatment
For toilets and snack corners, this is calculated using the ratio between parking slots and the number of persons for treatment, and for restaurants, it is calculated using the ratio between total floor area and number of person for treatment.

3.2 Categories based on rest-area characteristics

Rest areas are defined to have four categories based on their facility characteristics and site characteristics, and the coefficients described in 3.1 are defined for each category.

(1) SA (urban area, general area)
SAs near large metropolitan areas or in general, non-tourist areas.

(2) SA (tourist area)
SAs located on the outskirts of tourist spots, ski areas or other leisure facilities, expected to be visited by many tourist buses.

(3) PA (with shops)
All PAs with commercial facilities, regardless of site.
(4) PA (without shops)
PAs with toilets only, regardless of site.

4 Overview of plan for fact-finding survey

4.1 Selection of survey locations

In selecting rest-areas to be surveyed, many food court type eating/drinking establishments have been established in renovated and new commercial facilities, as indicated in 2.1, and thus, with regard to the categories of rest-areas in current standards indicated in 3.2, SAs and PAs were classified into seven categories as indicated in Table 2, taking the food court type to be a new type, and taking the previous snack corners (udon, soba) to be the old type. The survey was conducted by selecting two facilities, representative of the entire country in each of the seven categories, from among the rest-areas at over 800 locations nationwide.

Table 2 Selected survey locations

Type	Site condition category	Location	Survey date
1-1	SA (urban area, general area) (New type)	Shizuoka SA (Inbound)	2014.12.20
		Dangozaka SA (Outbound)	2015.1.10
1-2	SA (tourist area) (New type)	Nasukogen SA (Inbound)	2014.12.20
		Yamada SA (Inbound)	2014.12.21
2-1	SA (urban area, general area) (Old type)	Obasute SA (Outbound)	2015.1.10
		Kamigo SA (Inbound)	2014.12.19
2-2	SA (tourist area) (Old type)	Akagikogen SA (Inbound)	2015.1.12
		Shiozawa Ishiuchi SA (Outbound)	2015.1.10
3	PA (with shops) (New type)	Fujieda PA (Inbound)	2014.12.20
		Kakegawa PA (Outbound)	2014.12.20
4	PA (with shops) (Old type)	Nihonzaka PA (Inbound)	2014.12.19
		Ashitaka PA (Outbound)	2014.12.19
5	PA (without shops)	Yamato PA (Inbound)	2014.12.19
		Kurohime Nojiriko PA (Outbound)	2015.1.10

4.2 Survey items

The fact-finding survey was performed for the following items (1)–(7). Items (1)–(3) relating to the parking lot, number of persons using the area, and waste water amount were surveyed at all 14 locations; items (4)–(6) relating to pollutant load were surveyed at Shizuoka SA, Yamada SA, Kamigo SA, Akagikogen SA, Kakegawa PA, Nihonzaka PA, and Yamato PA from each category in Table 2; and item (7) relating to the toilet turnover rate was surveyed at one location from each expressway company, i.e., Shizuoka SA, Nasukogen SA, and Yamada SA.

(1) Fact-finding survey on parking lot
Survey time was taken to be 24 hours, from 7:00 a.m. on the day of the survey to 7:00 a.m. on the following day. Also, the survey was conducted by vehicle type (large bus, large truck, small car).

a. Survey of number of parked vehicles
The total number of all vehicles visiting the rest area was visually counted, by vehicle type.

b. Survey of vehicle ridership
Vehicle ridership was determined by visually counting 20 or more vehicles in one hour for each vehicle type. For large buses, tour conductors or other staff were asked about vehicle ridership.

c. Survey of parking time
Parking time was determined by counting 20 or more vehicles in one hour for each vehicle type.

(2) Fact-finding survey on number of facility users by type of use
Survey time was taken to be 24 hours, from 7:00 a.m. on the day of the survey to 7:00 a.m. on the following day. For each facility of the rest-area (toilets, snack corner, food court, restaurant, convenience store), the total number of users was visually counted. The number of persons was counted separately for men's and women's toilets.

(3) Survey of wastewater amounts by type of use
Survey time was taken to be 24 hours, from 7:00 a.m. on the day of the survey to 7:00 a.m. on the following day. Wastewater amounts were measured for each facility of the rest-area (toilets, snack corner, food court, restaurant, convenience store). Assuming that the amounts of supplied water and wastewater are the same, the individual waters meters for each facility were visually gauged every hour, on the hour.

(4) Survey of pollutant load (wastewater quality) by type of use
Specimens were sampled using the spot system for each facility of the rest-area (toilets, snack corner, food court, restaurant, convenience store).

a. Survey items
These were taken to be: BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), T-N (Total Nitrogen), T-P (Total Phosphorus), SS (Suspended Solids), normal hexane extracts.

b. Specimen types
Types were toilet drain water, kitchen drain water from snack corner etc., convenience store drain water, and mixed drain water in pre-treatment tank.

c. Sampling times
For toilets and commercial facilities, sampling was done five times, at 9:00, 11:00, 13:00, 15:00, and 17:00. Mixed drain water was sampled three times, at 9:00, 13:00, and 17:00.

(5) Survey of treated water pollutant load
Specimens of septic tank treated water were sampled using the spot system.

a. Survey items
Same as in (4) Survey of pollutant load by type of use.

b. Sample types
Regulating tank water, tertiary treatment water.

c. Sampling times
Three times, at 9:00, 13:00, and 17:00.

(6) Survey of toilet turnover rate

The survey time was taken to be 16 hours from 7:00 a.m. to 23:00 p.m. on the day of the survey. To investigate the turnover rate, use time of toilets and related facilities was measured visually for 20 or more subjects in 1 hour. The survey was conducted for men's urinals, men's toilet stools (Japanese and Western style), women's toilets (Japanese and Western style), and wash basins.

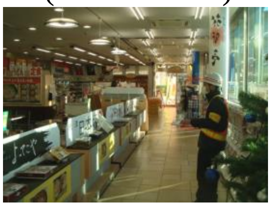
Survey of number of parked vehicles	**Survey of number of persons using toilet**
	
Survey of number of persons using facility	**Survey of amount of waste water (Gauging water meter)**
(Snack corner) 	(Toilet water meter) 
Survey of pollutant load (Drain water sampling)	
(Kitchen drain water) 	(Regulating tank water) 

Figure 1 Situation of fact-finding survey

5 Toilet fact-finding survey, results and discussion

5.1 Toilet use rate

Table 3 shows results due to the wastewater survey. Analysis was conducted at four locations (Shizuoka, Obasute, Nasukogen, and Yamato) with a smart interchange (referred to below as "SIC"), while excluding a number of persons corresponding to vehicles passing out of the SIC. For Yamato PA, the toilet use rate based on the number of persons, subtracting the number using the SIC, is 1.10, and thus this was excluded as an abnormal value. This is thought to be because SIC users use toilets. Also, the use rate for the Shin-Tomei Expressway (Shizuoka, Fujieda, Kakegawa), which was newly constructed in recent years, is higher than elsewhere, and thus it is likely that the use rate improves for toilets that are clean and easy to use.

Table 3 Results of fact-finding survey on toilet use rate (Toilet users/Rest-area users)

*Parentheses indicate current standards.

SA (general, urban area)				SA (tourist area)			
Shizuoka	Dangozaka	Kamigo	Obasute	Nasu-kogen	Yamada	Akagi-kogen	Shiozawa Ishiuchi
0.96	0.79	0.57	0.67	0.87	0.67	0.62	0.69
0.76 (0.75)				0.72 (0.80)			
PA (with shops)				**PA (without shops)**			
Fujieda	Kakegawa	Nihonzaka	Ashitaka	Yamato		Kurohime Nojiriko	
0.90	0.89	0.55	0.61	1.10		0.71	
0.74 (0.75)				0.71 (0.58)			

5.2 Toilet turnover rate

Table 4 shows the results of the wastewater survey and toilet counter survey. For toilet stools, it was confirmed for both men and women that the use time of the Western type is longer than the Japanese type, but overall, use time and turnover rate are the same as in current standards. The results of the survey are roughly equal to current standards, and validity was confirmed.

Table 4 Toilet turnover rate

*Parentheses indicate current standards.

Toilet type	Average use time [seconds]	Toilet turnover rate [person/hour-toilet]	Toilet turnover rate [persons/ hour-toilet]
Men's urinal	37.8	95.2	95 (90)
Men's toilet stool (all)	243.9	14.8	15 (15)
Men's toilet stool (Japanese)	199.1	18.1	
Men's toilet stool (Western)	254.7	14.1	
Women's toilet stool (all)	95.9	37.5	40 (40)
Women's toilet stool (Japanese)	80.4	44.8	
Women's toilet stool (Western)	97.6	36.9	

5.3 Toilet turnover rate

To calculate the maximum wastewater amount over time, it is necessary to determine the amount of toilet flushing water per person (amount of flushing water per stool/urinal × flush count). In this survey, flush counts were surveyed in a rest area under the following four conditions.

(1) Survey period: January 20, 2015 to February 5

(2) Survey location: Shizuoka SA (Inbound)

(3) Number surveyed: 5 for both men's and women's toilets (Japanese 1, Western 4)

(4) Survey method: For flush count, total use count is measured by mounting a sensor on the flush valve, and the total number of users is measured with a toilet count sensor.

Table 5 shows the survey results. For both men and women, the Western type is greater than the Japanese type. On the average, the count was 1.54 for men, and 1.20 for women. Women's toilets are equipped with flushing sound simulators.

Table 5 Toilet flush count per person

	Type	Flush count	Number of users	Flush count per person
Men	Western	4,912	3,230	1.52
	Japanese	822	501	1.64
Women	Western	4,459	3,781	1.18
	Japanese	586	443	1.32
Men, average				1.54
Women, average				1.20

6 Fact-finding survey on use rates of commercial facilities, results and discussion

6.1 Use rates of commercial facilities

Table 6 shows results due to the wastewater survey. The use rate was calculated using the percentage of all persons who used the toilet. In current standards, the use rate of shops (udon, soba) is 0.18, but in the survey results, the use rates of food courts and snack corners were, respectively, 0.215 and 0.185. The restaurant use rate at 0.047 was smaller than the current standard of 0.16. Convenience stores are not covered in the current standards, but a high use rate of 0.519 was confirmed. These values are thought to match the use situation at current rest areas, and validity was confirmed.

Table 6 Use rates of commercial facilities

*Parentheses indicate current standards.

	SA (urban, general area) average	SA (tourist area) average	PA (with shops) average
Food corner use rate	0.218	0.199	0.230
	0.216 (0.18)		
Snack corner use rate	0.188	0.162	0.204
	0.185 (0.18)		
Restaurant use rate	0.036	0.058	-
	0.047 (0.16)		
Convenience store use rate	0.437	-	0.601
	0.519		

6.2 Restaurant turnover rate

Table 7 shows results due to the wastewater test. Stay time in current standards was 18 minutes, but this was 30 minutes in survey results. This matches the use situation for current rest areas, and validity was confirmed.

Table 7 Restaurant turnover rate

*Parentheses indicate current standards.

Rest area name	Stay time (minutes)	Turnover rate [persons/hour-seat]
Obasute	28.8	-
Akagikogen	30.3	-
Average	29.6 (18.2)	2.0 (3.3)

6.3 Time maximum coefficient of snack corner and food court

The time maximum coefficient is calculated as "maximum users over time/users per day." The results due to the waste water survey are shown in Table 8 and Table 9. The survey results are roughly equal to current standards, and validity was confirmed.

Table 8 Snack corner time maximum coefficient

*Parentheses indicate current standards.

Rest area name	Snack corner time maximum coefficient
Kamigo	0.206
Obasute	0.144
Akagikogen	0.098
Shiozawa Ishiuchi	0.185
Nihonzaka	0.234
Ashitaka	0.155
Average	0.17 (0.164)

Table 9 Food court time maximum coefficient

*Parentheses indicate current standards.

Rest area name	Food court time maximum coefficient
Shizuoka	0.202
Dangozaka	0.106
Nasukogen	0.181
Yamada	0.206
Fujieda	0.206
Kakegawa	0.164
Average	0.178 (0.164)

7 Fact-finding survey on rain water amount and water quality, results and discussion

7.1 Wastewater intensity

Table 10 shows the results due to the wastewater survey. When compared with current standards, values have decreased for toilets due to the adoption of water-saving type toilets; for food courts there are differences due to shop type, but values are roughly the same; snack corner cooking is often done on the spot, so there is an increase; and for restaurants values were the same. These results are thought to conform with the current situation based on toilet performance and the results of a questionnaire for restaurants on menu items, etc. Also, it was not possible to secure the necessary amount of water when sampling for convenience stores, and thus this will be an item for examination in the future.

7.2 Inflow water quality

Table 11 shows the results due to the wastewater survey. Regarding the BOD which has a major effect on septic tank design, it was confirmed, in a comparison with current standards, that the value was the same for toilets, and pollutant load decreased for restaurants and other commercial facilities. Also, although it is not defined in current standards, water quality was also surveyed after outflow from a grease blocking and collecting device, with regard to the normal hexane extracts which are a major load on septic tanks, but the value was confirmed to be sufficiently low at septic tank inflow. Toilet water quality in Table 11 gives values including three locations (Shizuoka, Yamada, Kakegawa) where septic tank treated water (recycled water) is used for toilet flushing water, and this will be an item for examination in the future.

Table 10 Wastewater intensity for each facility

*Parentheses indicate current standards.
[Units: m^3/person]

	SA (urban, general area) average	SA (tourist area) average	PA (with shops) average	PA (without shops) average
Toilet	0.008	0.011	0.008	0.010
	0.0093 (0.01)			
Food court	0.020	0.034	0.015	-
	0.023 (0.021)			
Snack corner	0.029	0.014	0.046	-
	0.030 (0.021)			
Restaurant	0.051	0.046	-	-
	0.049 (0.05)			

Table 11 Drain water quality by facility

*Parentheses indicate current standards.

Usage name / Water quality item	Toilet [mg/L]	Food court [mg/L]	Snack corner [mg/L]	Restaurant [mg/L]
BOD	300 (300)	350 (590)	540 (590)	250 (350)
COD	240 (210)	300 (220)	280 (220)	130 (140)
SS	300 (350)	440 (130)	350 (130)	120 (90)
T-N	230 (110)	50 (25)	40 (25)	20 (12)
T-P	15 (12)	6 (4)	6 (4)	5 (5)
Normal hexane	- (-)	46 (-)	79 (-)	73 (-)

8 Conclusion

A fact-finding survey clarified behavioral characteristics of users such as the use rates of toilets and commercial facilities (restaurants, food courts, snack corners) at rest-areas, toilet turnover rates and flush counts per person; and drainage characteristics such as waste water intensity and drain water quality. Toilet use rates vary depending on the facility site and facility development level, and in terms of the use rate of commercial facilities, compared with current standards there was confirmed to be a decrease in the restaurant use rate, and an increase in the food court and snack corner use rate. Inside of toilets, it was confirmed that the turnover rate calculated from toilet use time was roughly equal to the current standards from 1999, and it was determined that it is necessary to take into account the fact that the flush count per person, which had previously not been considered, is 1 flush or more for both men and women, and that there have been changes in water use amounts and water quality accompanying diversification of commercial facilities such as a decrease in toilet water use due to adoption of water-saving type toilets.

Going forward, the authors plan to proceed further with the analysis, and examine calculation and design standards for the proper scale of domestic wastewater treatment plants suited to the characteristics of rest-areas.

Acknowledgments

This research was carried out by the "Committee for Surveys and Investigation Relating to Design Standards for Domestic Wastewater Treatment Plants at Expressway Rest-areas." The authors would like to express their gratitude for the tremendous cooperation of the committee members, and all of the staff at the surveyed rest-areas.

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10 Presentation of Authors

Tetsuya Niimi is a research engineer at Nippon Expressway Research Institute Company Limited (NEXCO RI). His field is design standards for domestic wastewater treatment plants in rest-areas of expressway. His study is verification of validity reduction rate for maximum calculated hourly wastewater volume of rest-area toilets.

Atsushi Umayahara (Dr. Eng.) is a research engineer at Nippon Expressway Research Institute Company Limited (NEXCO RI). His field is design standards for domestic wastewater treatment plants in rest-areas of expressway. His study is the influence of domestic wastewater treatment plants on the behavioral characteristics of rest-area users and the characteristics of drainage from rest-area toilets and shops.

Kyosuke Sakaue (Dr. Eng.) is a professor at Department of Architecture, School of Science & Technology, and a head of New Plumbing System Institute, Meiji University. His fields of specialization include water environment, building services and plumbing system. He is currently engaged in the studies of next drainage system, trap performance, WC, stainless steel piping, water saving systems, maintenance.

Saburo Murakawa (Dr. Eng.) is the Emeritus Professor of Hiroshima University. His special fields are building and city environment engineering, plumbing engineering and environmental psychology. He is now trying to spread the new dynamic calculation method for cold and hot water consumption in buildings using MSWC program.

Keizou Niki (Dr. Eng.) is a director at Japan Education Center of Environmental Sanitation. His fields are wastewater treatment facilities and water quality management. His studies are development of simplified measuring instrument for water quality control of domestic wastewater treatment plants and development of septic tank system for sanitary environment at the time of disaster.

PP15 - Utilization of water in a new clean technology applied in the air treatment and energy production in buildings

Eusébio Z. E. Conceição (1), Mª Manuela J. R. Lúcio (2) and Mª Inês L. Conceição (3)

1. econcei@ualg.pt
2. maria.manuela.lucio@gmail.com
3. ines.econcei@gmail.com

(1) Professor, CINTAL, FCT, Universidade do Algarve, Gambelas, 8005-139 Faro, Portugal
(2) Researcher, FCT, Universidade do Algarve, Gambelas, 8005-139 Faro, Portugal
(3) Student, Agrupamento de Escolas Tomás Cabreira, 8000-334 Faro, Portugal

Abstract

In this work is presented a clean technology applied in the polluted air treatment, water treatment and energy production. The idea of this clean technology is the simultaneous treatment of the polluted air, using a washing and drying processes, instead the traditional filters, and the production of energy, using three heat exchangers. The polluted air comes from a factory reactor, building fireplace or other source, crosses the first heat exchanger space, the washing space, the drying space and the second heat exchanger. The drying process separates the clean air, to the environment, and the polluted water effluents, to the third heat exchanger in the water storage space. The water is treated and used in the previous washing process.

In the work is developed and applied one numerical model based with energy balance integral equations, one numerical model based in water and particle mass balance integral equations and one numerical model based in one dimensional fluids dynamics. These models are applied in the polluted air treatment circulation, in the polluted water treatment circulation and in the heat exchanger water circulation.

Keywords

Water, polluted air, energy, numerical models, energy and mass balance integral equations, buildings.

1 Introduction

Most factories or other sources pollute the outside atmosphere with large amounts of off-gases at elevated temperatures. In consequence, in most situations, many indoor spaces are thus subjected to high loads of pollutants which also need to be treated.

The main idea of this work, in addition to cleaning the air through an efficient and new method, is the production of energy to provide power for HVAC systems in buildings.

The work intends to develop a clean technology applied in the air treatment and production of energy in gaseous effluents in outdoor and indoor environments.

In the helical vertical scrubber developed in this work, the gaseous effluents are treated using water (washing process), instead of the traditional filters, and hot water is produced, using three different heat exchangers.

In air treatment, besides the outside air handling, this equipment may still be used within the air handling both in manufacturing indoor environments (such as carpentry) or in indoor environments built in polluted environments. The heated water is used in heating, during winter conditions, and cooling and air conditioning systems, during summer conditions, through ecological air conditioning by absorption systems.

When no heated polluting source is used, this system can operate independently from biomass. However, in this case, in addition to traditional heating this system still has the ability to further treatment of the gaseous effluents.

2 Methodology

This work will develop a helical vertical scrubbers applied in the air treatment and energy production in gaseous effluents.

In this work is presented a clean technology applied in the polluted air treatment, water treatment and energy production. The idea of this clean technology is to make the simultaneous treatment of the polluted air, using washing and drying processes, instead the traditional filters, and the production of energy, using three heat exchangers. The polluted air, comes from a factory reactor, building fireplace or other source, crosses the first heat exchanger space, the washing space, the drying space and the second heat exchanger. The drying process separates the clean air, to the environment, and the polluted water effluents, to the third heat exchanger in the water storage space. The water is treated and used in the previous washing process.

In this work is developed and applied a new numerical model, using a coupling of energy, mass and one dimensional fluids dynamics. It was developed one numerical model based in energy balance integral equations, one numerical model based in water and particle mass balance integral equations and one numerical model based in one dimensional fluid dynamics.

These models are applied in the polluted air treatment circulation, in the polluted water treatment circulation and in the heat exchanger water circulation.

This new cleaning technology works from an air washing process and heat exchanger without filters. This scrubber is constituted by five parts (see figure 1):
1) Storage chamber of liquid effluent and lower heat exchanger (heating stage I);
2) Entrance hall and formation of the helical flow and the central heat exchanger (heating phase III);
3) Washing chamber to be treated the gaseous effluent and uniformed chamber;
4) Drying hall and superior heat exchanger (phase II heating) and extraction chamber;
5) Ring chamber of effluent liquid transportation.

In the heat recovery are used three heat exchangers:
- one located in the storage chamber of the liquid effluent and lower heat exchanger (phase heating I);
- one located in the drying chamber, treatment and superior heat recovery (phase heating II)
- one located in the central heat recovery chamber (phase heating III).

The water inlets in the first heat exchanger (I) go to the second heat exchanger (II) and to the third heat exchanger (III). The air inlet is made in the entrance chamber and the air outlet is made in the extraction chamber.

The new clean technology is developed using a simplified construction process and the construction process is carried out from a versatile and economic system.

The vertical scrubber, in general, is built by plastic and copper. The plastic is used in the main structure and the copper is used to the heat exchange. The process is developed using a 3D printer.

3 Numerical Simulation

The numerical simulation is divided in two parts, namely the heat and mass transfer numerical model and the fluids mechanics numerical model. The last numerical model includes the air recirculation and the water circulation.

3.1 Heat and mass transfer numerical model

In this work a numerical methodology is used. This work is a continuation of previously developed numerical models (see [1],[2],[3],[4],[5],[6] and [7]).

In [1] the implementation of the Runge-Kutta-Fehlberg method in the simulation of the human thermal system is made. The integral simulation of the human thermal system is developed in [2]. In [3] is analyzed the integral simulation of the thermical behaviour of anaerobic biodigester used in biogas production. The numerical simulation of buildings thermal behaviour and human thermal comfort multi-node models is developed in [4]. In [5] is shown the numerical simulation of passive and active solar strategies in buildings with complex topology. The comfort and airflow evaluation in spaces equipped with mixing ventilation and cold radiant floor is analyzed in [6]. Finally, in [7] is made the study of the evaluation of thermal comfort conditions in a classroom equipped with cooling radiant systems and subjected to uniform convective environment.

The numerical model used in the clean technology development is presented in figure 1. In this clean technology scheme are presented the five parts and the three heat exchangers.

The reactor is shown using the designation R, the entrance space is shown using the number 2, washing space is shown using the number 3, water effluent space is shown using the number 1, ring space is shown using the number 5, drying space is shown using the number 4, first heat exchanger space is shown using the number w1, second heat exchanger space is shown using the number w2 and third heat exchanger space is shown using the number w4.

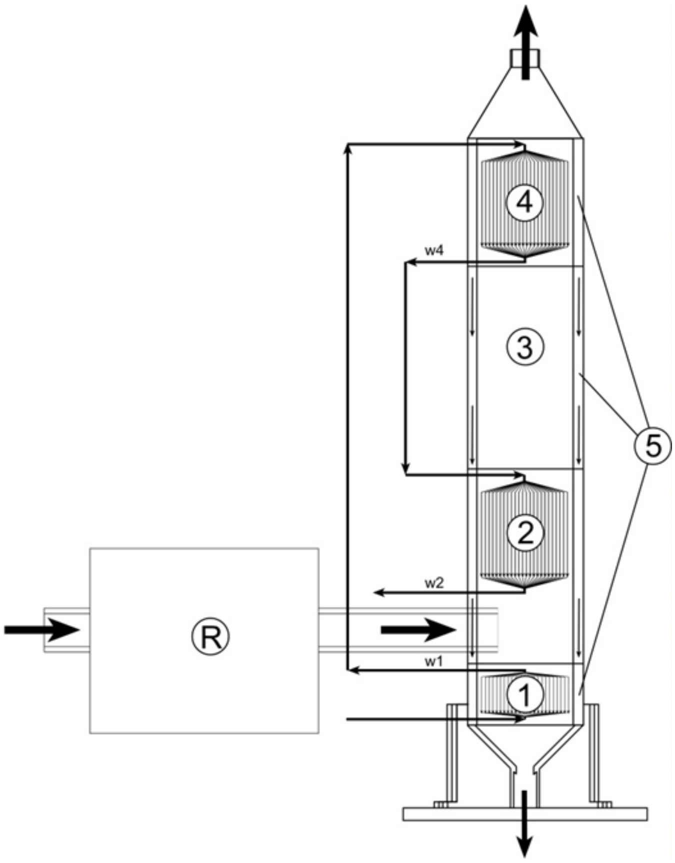

Figure 1 Clean technology scheme used in the numerical model

The heat and mass transfer numerical model considered is built with the energy and mass integral equations for the reactor, R, and spaces 1, 2, 3, 4 and 5 and the energy integral equations for the water ducts.

3.1.1 Integral equations for the reactor

$$m_{air_R} C_{p_{air_R}} \frac{dT_R}{dt} = \dot{Q}_R + \frac{T_0 - T_R}{R_{R0}} + m_0 C_{p_0} T_0 - \dot{m}_{R2} C_{p_R} T_R \quad (1)$$

$$\frac{dm_{v_R}}{dt} = \dot{m}_{v_R} + \dot{m}_{v_{0R}} - \dot{m}_{v_{R2}} \quad (2)$$

$$\frac{dm_{p_R}}{dt} = \dot{m}_{p_R} + \dot{m}_{p_{0R}} - \dot{m}_{p_{R2}} \quad (3)$$

3.1.2 Integral equations for the space 1

$$m_{air_1} C_{p_{air_1}} \frac{dT_1}{dt} = \dot{m}_{51} C_{p_5} T_5 + \dot{m}_{21} C_{p_2} T_2 - \dot{m}_{10} C_{p_1} T_1 + \frac{T_0 - T_1}{R_{10}} + \frac{T_{w_1} - T_1}{R_{w_{11}}} \quad (4)$$

$$\frac{dm_{v_1}}{dt} = \dot{m}_{v_{51}} + \dot{m}_{v_{21}} - \dot{m}_{v_{10}} \quad (5)$$

$$\frac{dm_{p_1}}{dt} = \dot{m}_{p_{51}} + \dot{m}_{p_{21}} - \dot{m}_{p_{10}} \quad (6)$$

3.1.3 Integral equations for the space 2

$$m_{air_2} C_{p_{air_2}} \frac{dT_2}{dt} = \dot{m}_{R2} C_{p_R} T_R + \dot{m}_{32} C_{p_3} T_3 - \dot{m}_{21} C_{p_2} T_2 - \dot{m}_{23} C_{p_2} T_2 + \frac{T_5 - T_2}{R_{52}} + \frac{T_{w_2} - T_2}{R_{w_{22}}} \quad (7)$$

$$\frac{dm_{v_2}}{dt} = \dot{m}_{v_{R2}} + \dot{m}_{v_{32}} - \dot{m}_{v_{21}} - \dot{m}_{v_{23}} \quad (8)$$

$$\frac{dm_{p_2}}{dt} = \dot{m}_{p_{R2}} + \dot{m}_{p_{32}} - \dot{m}_{p_{21}} - \dot{m}_{p_{23}} \quad (9)$$

3.1.4 Integral equations for the space 3

$$m_{air_3} C_{p_{air_3}} \frac{dT_3}{dt} = \dot{m}_{23} C_{p_2} T_2 - \dot{m}_{34} C_{p_3} T_3 - \dot{m}_{32} C_{p_3} T_3 + \dot{m}_{43} C_{p_4} T_4 + \frac{T_5 - T_3}{R_{53}} - \dot{m}_v H \quad (10)$$

$$\frac{dm_{v_3}}{dt} = \dot{m}_{v_{23}} - \dot{m}_{v_{34}} - \dot{m}_{v_{32}} + \dot{m}_{v_{43}} + \dot{m}_v \quad (11)$$

$$\frac{dm_{p_3}}{dt} = \dot{m}_{p_{23}} - \dot{m}_{p_{34}} - \dot{m}_{p_{32}} + \dot{m}_{p_{43}} \quad (12)$$

3.1.5 Integral equations for the space 4

$$m_{air_4} C_{p_{air_4}} \frac{dT_4}{dt} = \dot{m}_{34} C_{p_3} T_3 - \dot{m}_{40} C_{p_4} T_4 - \dot{m}_{45} C_{p_4} T_4 - \dot{m}_{43} C_{p_4} T_4 + \frac{T_5 - T_4}{R_{54}} + \frac{T_{w_2} - T_4}{R_{w_{24}}} \quad (13)$$

$$\frac{dm_{v_4}}{dt} = \dot{m}_{v_{34}} - \dot{m}_{v_{40}} - \dot{m}_{v_{45}} - \dot{m}_{v_{43}} \quad (14)$$

$$\frac{dm_{p_4}}{dt} = \dot{m}_{p_{34}} - \dot{m}_{p_{40}} - \dot{m}_{p_{45}} - \dot{m}_{p_{43}} \quad (15)$$

3.1.6 Integral equations for the space 5

$$m_{air_5} C_{p_{air_5}} \frac{dT_5}{dt} = \frac{T_0 - T_5}{R_{50}} + \frac{T_4 - T_5}{R_{54}} + \frac{T_3 - T_5}{R_{53}} + \frac{T_2 - T_5}{R_{52}} + \dot{m}_{45} C_{p_4} T_4 - \dot{m}_{51} C_{p_5} T_5 \quad (16)$$

$$\frac{dm_{p_5}}{dt} = \dot{m}_{p_{45}} - \dot{m}_{p_{51}} \quad (17)$$

$$\frac{dm_{v_5}}{dt} = \dot{m}_{v_{45}} - \dot{m}_{v_{51}} \quad (18)$$

3.1.7 Integral equations for the water ducts

$$m_{w_1} C_{p_{w_1}} \frac{dw_1}{dt} = \dot{m}_{w_2} C_{p_{w_2}} T_{w_2} - \dot{m}_{w_1} C_{p_{w_1}} T_{w_1} + \frac{T_1 - T_{w_1}}{R_{w_{11}}} \quad (19)$$

$$m_{w_4} C_{p_{w_4}} \frac{dw_4}{dt} = \dot{m}_{w_1} C_{p_{w_1}} T_{w_1} - \dot{m}_{w_4} C_{p_{w_4}} T_{w_4} + \frac{T_4 - T_{w_4}}{R_{w_{44}}} + \dot{m}_{v_{45}} H \quad (20)$$

$$m_{w_2} C_{p_{w_2}} \frac{dw_2}{dt} = \dot{m}_{w_4} C_{p_{w_4}} T_{w_4} - \dot{m}_{w_2} C_{p_{w_2}} T_{w_2} + \frac{T_2 - T_{w_2}}{R_{w_{22}}} \quad (21)$$

3.1.8 Balance equations for the airflow rate

$$\dot{m}_{10} = \dot{m}_{v_{10}} + \dot{m}_{p_{10}} \quad (22)$$

$$\dot{m}_{R2} = \dot{m}_{v_{R2}} + \dot{m}_{p_{R2}} \quad (23)$$

$$\dot{m}_{21} = \dot{m}_{v_{21}} + \dot{m}_{p_{21}} \quad (24)$$

$$\dot{m}_{32} = \dot{m}_{v_{32}} + \dot{m}_{p_{32}} \quad (25)$$

$$\dot{m}_{23} = \dot{m}_{v_{23}} + \dot{m}_{p_{23}} \quad (26)$$

$$\dot{m}_{43} = \dot{m}_{v_{43}} + \dot{m}_{p_{43}} \quad (27)$$

$$\dot{m}_{34} = \dot{m}_{v_{34}} + \dot{m}_{p_{34}} \quad (28)$$

$$\dot{m}_{45} = \dot{m}_{v_{45}} + \dot{m}_{p_{45}} \quad (29)$$

$$\dot{m}_{40} = \dot{m}_{v_{40}} + \dot{m}_{p_{40}} \quad (30)$$

$$\dot{m}_{51} = \dot{m}_{v_{51}} + \dot{m}_{p_{51}} \quad (31)$$

The main symbols are:
m – Mass;
Q – Heat flux;
Cp – Specific heat at constant pressure;
ṁ – Air flow;
T – Temperature;
R – Thermal resistance.

The complete symbols are:
ṁv – Injected water flow;
H – Vaporization latent heat.

The sub-indexes are:
0 – Associated to outdoor environment;
1 – Associated to liquid effluent;
2 – Associated to inlet chamber;
3 – Associated to washing chamber;
4 – Associated to drying chamber;
5 – Associated to liquid effluent transport channel;
air – Associated to air;
v – Associated to vapor;
p – Associated to particles;
w – Associated to water.

In these equations system are calculated 9 temperatures, 12 vapor and particles flow rates and 10 total flow rates. The other flow rates are obtained using empirical equations.

3.2 Fluids mechanics numerical model

The equation of energy conservation is given by the following expression:

$$\frac{P_a}{\rho g} + \frac{V_{A^2}}{2g} + Z_a = \frac{P_b}{\rho g} + \frac{V_B}{2g} + Z_b - h_f + h_b \quad (32)$$

Where:
P_A – Pressure at the point A;
P_B – Pressure at the point B;
V_A – Velocity at the point A;
V_B – Velocity at the point B;
Z_A – Height at the point A;
Z_B – Height at the point B;
ρ – Air density;
g – Gravity acceleration;
h_F – Total load losses;
h_B – Pump maximum height.

The total load losses are given by:

$$h_f = \sum_i k_i \frac{v_i^2}{2g} + \sum_j f_j \frac{\Delta L_j . v_j^2}{d_{eq} . 2g} \tag{33}$$

Where the first term is associated with the localized losses and the second is associated with continuous losses and the symbols are:
k_i – Load loss coefficient;
v_i – Velocity at the segment i;
f_j – Friction coefficient at the segment j;
v_j – Velocity at the segment j;
ΔL_j – Lenght at the segment j;
d – Segment diameter.

The friction coefficient is obtained from Moody's diagram in function of a Reynolds's number for the studied section and for the relative roughness.
The expression of the fan characteristic curve to be used is given by:

$$h_B = a\dot{m} + b \tag{34}$$

Where:
$\dot{m}$ - is the flow rate, given by the product by of the air velocity and the area of the duct;
a - is constant.
b - is constant.

The airflow rate balance, in each node, is given by the:

$$\sum_i \dot{m}_{in_i} A_{in_i} = \sum_i \dot{m}_{out_i} A_{inout_i} \tag{35}$$

Where:

A is duct section area;

in is associated to the inlet airflow in each duct;

out is associated to the outlet airflow in each duct.

In this section the project of the air recirculation and the project of the water circulation is made.

3.2.1 Project of the air recirculation

The project of the air recirculation is made using the previous energy and flow equations, from the inlet (v_R) to the outlet (v_0), passing from the areas 2 (v_2), 3 (v_3) and 4 (v_4). In the areas 2 and 4 are considered the local losses due to the heat exchanger and in the area 3 is considered the continuous losses.

In this calculus the point A is placed near the inlet and the point B is placed near the outlet. Thus, the pressure in the point A is equal to the pressure in the point B and the air velocity in the point A is equal to the air velocity in the point B.

In accordance with this simplification the numerical model is done by:

$$Z_a - Z_b + f\frac{\Delta L_2}{d}\frac{{v_2}^2}{2g} + f\frac{\Delta L_3}{d}\frac{{v_3}^2}{2g} + f\frac{\Delta L_4}{d}\frac{{v_4}^2}{2g} +$$
$$+K_R\frac{v_R}{2g} + K_2\frac{{v_2}^2}{2g} + K_3\frac{{v_3}^2}{2g} + K_4\frac{{v_4}^2}{2g} + K_0\frac{{v_0}^2}{2g} = a(A.v) + b \quad (36)$$

$$A_R v_R = A_2 v_2 \quad (37)$$

$$A_2 v_2 = A_3 v_3 \quad (38)$$

$$A_3 v_3 = A_4 v_4 \quad (39)$$

$$A_4 v_4 = A_0 v_0 \quad (40)$$

3.2.2 Project of the water circulation

The project of the water recirculation is made using the previous energy and flow equations. However, in this case is considered the water velocity upstream in the heat exchanger 1 (w1), heat exchanger 4 (w4) and heat exchanger 2 (w2) and the water velocity inside the 24 ducts of the heat exchanger 1, heat exchanger 4 and heat exchanger 2. Thus, 75 water velocities are considered.

In this calculus the point A is placed exactly in the point B. So:

$$P_A = P_B$$
$$V_A = V_B$$
$$Z_A = Z_B$$

Thus, the energy and mass equation is simplified using:

$$\sum_i ki\frac{vi^2}{2g} + \sum_j f_j \frac{\Delta Lj}{d_{eq}}\frac{vj^2}{2g} = a(A.v) + b \tag{41}$$

$$\sum_i Q_{w_i} A_{w_i} = \sum_i Q_{w_i} A_{w_i} \tag{42}$$

4 Results

In this work a clean technology applied in the air treatment and energy production in buildings is numerically simulated. The clean technology is equipped with an air ventilator and one water pump. An S&P air ventilator is used in the air circulation in the clean technology main system and the Grundfos water pump is used in the water circulation in the ducts system. In this system the water injection is used in the air treatment. The water used in the air cleanness is treated itself in the clean technology base area.

This clean technology, applied in the air treatment and energy production in buildings, has a height 1.12 m, an internal diameter of 9 cm and an external diameter of 13 cm. In the internal water circulation, in accordance with the figure 1, three main ducts and three main heat exchangers are used. In accordance to figure 1, each main heat exchanger is built with 24 heat exchangers ducts. Thus, the internal water circulation considers 75 ducts, 3 main ducts and 72 heat exchangers ducts. The duct water exchanger, used in this work, has a diameter of 12 mm.

In this study the coupling of the heat and mass transfer numerical model and the one dimensional fluids mechanics numerical model are used. The heat and mass transfer numerical model calculates the air and water temperature and airflow rate, while the fluids mechanics numerical model calculates the air and the water velocity.

In table 1 are presented the air and water temperature distribution in the several spaces and ducts, in table 2 is shown the water vapor and particles flow rates exchanged between the different spaces, in table 3 are presented the results of the water velocity in the main system, in table 4 is shown water velocity circulation in the heat exchanger main ducts and in table 5 is presented the water velocity circulation in the heat exchanger ducts.

Table 1 Air and water temperature (ºC) distribution in the several spaces and ducts.

T_0	T_1	T_2	T_3	T_4	T_5	T_R	T_{W1}	T_{W2}	T_{W4}
20	61,89	193	102,5	114,5	107,7	578	61,92	193	114,5

Table 2 Water vapor and particles flow rates (m^3/h) exchanged between spaces.

	10	21	23	32	34	40	34	45	51	R2
m	0,468	0,02304	0,73116	0,0288	0,73836	0,2952	8,676E-26	0,44316	0,44316	0,90684
m_v	0,02628	0,01152	0,00288	0,0144	0,02448	0,009792	8,676E-27	0,0144	0,0144	0
m_p	0,43992	0,01152	0,72828	0,0144	0,71388	0,285552	7,3476E-24	0,4284	0,4284	0,7254

Table 3 Water velocity in the main system

V_R (m/s)	V_0 (m/s)	V_2 (m/s)	V_3 (m/s)	V_4 (m/s)
0,322	0,332	0,1322	0,1322	0,1322

Table 4 Water velocity circulation in the heat exchanger main ducts

V_1 (m/s)	V_2 (m/s)	V_3 (m/s)
0,5764	0,5764	0,5764

Table 5 Water velocity circulation in the heat exchanger ducts

$V_{1(1)} \ldots V_{1(24)}$	$V_{2(1)} \ldots V_{2(24)}$	$V_{3(1)} \ldots V_{3(24)}$
0,02745	0,02745	0,02745

In accordance to the presented results, the air flow rate of particles and water vapor that inlet in the clean technology is 0.91 m^3/h. The value of 0.47 m^3/h is treated and the value of 0.30 m^3/h is not treated. The water flow rate value in the water circulation system is 0.24 m^3/h.

The air temperature decreases, from 578 ºC, in the reactor area, from 114,5 ºC, in the clean technology exit area. The water temperature in the first, second and third heat exchangers are, respectively, 61.9 ºC (water storage space), 114.5 ºC (drying space) and 193 ºC (entrance polluted air space).

5 Conclusions

This new clean technology, without filters, is applied in the polluted air treatment, water treatment and energy production. A new numerical model, using a coupling of energy, mass and one dimensional fluids dynamics, was developed.

A virtual prototype, with a 1.12 m higher, was developed. In accordance to the obtained results, a polluted flow rate of particles and water vapor with a temperature of 578 ºC guarantees an water temperature in the first, second and third heat exchangers of, respectively, 61.9 ºC (water storage space), 114.5 ºC (drying space) and 193 ºC (entrance polluted air space).

In the future an experimental setup, using tridimensional prototyping, will be made. This experimental setup will be used in the development of experimental tests in order to validate this numerical model and develop other empirical coefficients.

6 Acknowledgments

The authors acknowledge the collaboration of the:
- 2016-2017 ASHRAE Undergraduate Senior Project Grant Program (from American Society of Heating, Refrigerating and Air-Conditioning Engineers).
- "WIDER – Green Growing of SME: Innovation and Development in the Energy Sector in the Mediterranean Area" co-funded by the Transnational Cooperation Programme – Mediterranean, in which the University of Algarve participated as project partner.

- Students of the Master in Environmental Engineering of the FCT of the University of Algarve.

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8 Presentation of Author(s)

Eusébio Conceição is an Assistant Professor at Sciences and Technology Faculty of University of Algarve. His Ph.D. was finished in 1996, in the University of Coimbra. Is Director of the Master in Renewable Energy and Energy Management and Responsible for several disciplines. The Areas of interest are the Energy, Renewable Energy, Air Quality, Water Treatment, Building Thermal Simulation, Computational Fluids Dynamics and Thermal Comfort.

Mª Manuela Lúcio is a Senior Reseacher. The Areas of Interest are the Air quality, Thermal Comfort, Building Thermal Simulation, Information and Communication Technologies and School Success Methodologies areas.

Mª Inês Conceição is a very Young Reseacher. The Areas of interest are the Design, Prototyping and Computational Fluids Dynamics areas.