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SYMPOSIUM WELCOME

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45th CIB W062
Organising Chairman

The 45th International Symposium on Water Supply and Drainage for Buildings, CIB W062, is organised by an Australian CIB Member, Mr Brad Williams and his company "Hydraulic Solutions By Design" in collaboration with KE Creative Events together with the support of the International Council for Research and Innovation in Buildings and Construction (CIB) and in particular, the Chair of CIB W062, Professor Lynne Jack from Heriot-Watt University, Malaysia.

This Symposium will take place in Melbourne, Australia from 8th to 10th September 2019 prior to the triennial World Plumbing Conference also being held in Melbourne, Australia from 11th to 13th September 2019.

The purpose of this Symposium is to disseminate global research and innovation in water supply and drainage for buildings which will contribute to the ongoing progression of this field of expertise.

The proceedings contain 38 papers, presented in eight technical sessions. The sessions cover topics that are important to our profession, including "Health and Hygiene", "Modelling of Water" and "Sustainability" amongst others. We thank all the Authors for their contributions and presentations and also their efforts to make the long journey to Australia. We trust you will enjoy our Country, and in particular Melbourne.

We would like to thank the Chair of the International Scientific Committee for reviewing all of the abstracts and papers to ensure they meet the criteria for this commission.

Our appreciation is also extended to our Sponsors for their gratitude in supporting this event.

KE Creative Events must also be commended for their efforts to make the event something to remember for all delegates. We trust that it is a success and our Australian attendees get an insight into what research and development is occurring globally.

We encourage any CIB Non Members attending, to embrace membership and continue to contribute to the ongoing success of CIB W062 in Taiwan 2020.

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Date 12 July 2019

Designing Legionella-safe Houses

W.G. van der Schee (1)

(1) Croonwolter&dros, Amersfoort, member TVVL Expert group Sanitary Technologies, The Netherlands

Abstract
Preventing undesired heating of drinking water is a constant point of attention in residential drinking water systems. If drinking water pipes are concealed in the screed or walls, there is a chance that the drinking water pipes cross the heating pipes. Especially when the drinking water stagnates in the pipe, a so-called hot spot is created. At that spot the temperature of the drinking water can exceed 25 °C, which increases the risk of the growth of legionella and other bacteria.
In the Netherlands guideline ISSO-SBR-811 pays attention to the prevention of hot spots and offers solutions for common situations where hot spots can arise. Guideline ISSO-SBR-811 serves as a practical tool for all parties involved in the construction of new houses and apartments. Guideline ISSO-SBR-811 includes tables with an overview of floor constructions with the minimum required horizontal and vertical distance between drinking water pipes and heating pipes.

Keywords
Cold water systems, hot water systems, legionella prevention

1 Introduction

This paper differs from the regular papers in the CIB W062 symposium reporting the results of new research. This paper presents an existing guideline (ISSO-SBR-811), laid down in April 2011. The content of this guideline is important enough to share the information through a paper and a presentation on the CIB W062 symposium 2019. Guideline ISSO-SBR-811 consists of 96 pages and is therefore too extensive to describe in a paper. Instead, the author has chosen some interesting issues to present in this paper. The author did not participate in a working group during the development of the guideline concerned.

Over the past years guidelines have been developed to prevent the growth of legionella in drinking water systems. An important aspect is the prevention of hotspots in the drinking water installation and in the single hot drinking water pipes.

A trend in the construction of drinking water systems and heating pipes in houses is that pipes are concealed wherever possible in architectural constructions such as floors, walls, pre-walls, shafts and false ceilings. In the new construction of new houses, the pipes are usually positioned in the screed. In case of refurbishment of houses, the position of pipes depends on the new lay-out. In case of an extensive refurbishment and big changes in the lay-out, a situation arises that is comparable to new construction. A popular solution is to position the pipes above false ceilings, behind pre-walls or on the wall.

In almost all situations, this leads to concentrations of cold and hot pipes that make it difficult to meet the temperature requirements required by Dutch standard NEN 1006: below 25 °C. A single hot drinking water pipe cools to ambient temperature and is not considered a continuous hot pipe.

Guideline ISSO-SBR-811 targets designers, builders, installers and building managers to offer practical and easy guidance for the realization of hotspot-free drinking water installations. Together with other aspects in design and implementation, a hotspot-free drinking water installation contributes to the realization of legionella-safe buildings.

Guideline ISSO-SBR-811 was established in a cooperation between installers, consultants and architects. In this way support was created for all parties involved in the construction of legionella-safe houses.

2 Prevention of Hotspots in the Design Phase

Prevention of the growth of legionella and other bacteria starts at the design phase. The technician has to be aware of the risks of the growth of legionella and other bacteria when undesirable heating of drinking water is caused by hot pipes in the construction.

Guideline ISSO-SBR-811 offers model solutions for common situations in housing where hotspots may arise. However, no two houses are the same. Differences occur due to the specific housing lay-out, the choice for a heating or distribution system, etc. That's why concepts are developed that can be integrated by designers, builders and contractors in different situations.

The most important principle to avoid undesirable heating of drinking water is the creation of so-called drinking water zones in the construction. In the design phase zones are determined in which the drinking water pipes will be installed.

In the first variant, the drinking water pipes and the heating pipes are installed in the floor; either the same layer or another layer. The drinking water pipes are installed in a cool area to prevent crossings and to guarantee minimum distances between drinking water and heating pipes. Before the screed is poured, the location of both the drinking water pipes and heating pipes can be checked to prevent crossings and to check the minimum distances between the different pipes. It is also possible to position the drinking water pipes in the construction floor (under the screed).

In the second variant, the drinking water pipes and heating pipes are installed in different layers; a) the construction floor and the screed or b) above a false ceiling and the screed. In that case the entire layer constitutes a cool surface.

The tables in this paper focus on the solutions for pipes in the screed and the construction floor. Guideline ISSO-SBR-811 also offers solutions for drinking water pipes and heating pipes above false ceilings.

3 Types of Houses and Heating Systems

Guideline ISSO-SBR-811 provides model solutions for common housing types:
- Terraced houses
- Apartments
- Detached houses

The basis for the solutions is a model floor plan of a reference house from NL Agency. In addition, a number of floor plans from the refurbishment practice were used for the model solutions. These floor plans are not standard but offer a solution for more complex situations.

The model solutions focus on heating systems with radiators, because in that case cool drinking water zones are required. Guideline ISSO-SBR-811 provides solutions for underfloor heating systems in the form of generally applicable recommendations.

4 Concept of Water Zones

The concept of water zones is based on a strict separation of the drinking water system and central heating system. The separation is the result of a zoning of the house floor plan. A separate water zone is reserved for the drinking water installation, and a separate hot zone for the central heating installation.
With this concept it is also possible to safeguard the minimum distance between drinking water and central heating or underfloor heating pipes. After the sanitary contractor has drawn the drinking water installation within the limits of the drinking water zone, he indicates a cool zone around the drinking water pipe strip or a cool surface on the drawing. The boundaries of a cool strip describe the minimum distance to maintain between the drinking water and central heating pipes to prevent hot spots. In case of a cool surface (floor or ceiling), the entire surface has to remain free from central heating pipes. Finally, the central heating installation has to be installed outside the strip or the cool surface. The result is a hotspot-free tap water installation.

Guideline ISSO-SBR-811 distinguishes three options for solutions:

4.1 Cool Strips in the Screed of the Floor

This concept focuses on situations in which both the drinking water pipes and heating pipes are installed in the screed (figure 1). In that case, the drinking water pipes are installed in the cool floor strips. In this way, minimum distances between drinking water pipes and central heating or underfloor heating pipes can be guaranteed and crossings can be avoided. In most circumstances crossings of drinking water pipes and heating pipes are not permitted. This applies to the entire floor, including situations where the drinking water pipes are situated in the construction floor and central heating pipes are situated in the screed. Drinking water pipes situated in the screed are the most common practice in current Dutch building practice.

Figure 1 Drinking water and heating pipes in the screed

4.2 Cool Strips above a False Ceiling

In this concept, both the drinking water pipes and heating pipes are installed above a false ceiling (figure 2). To install the pipes according to this concept, free space is needed between the construction floor and the false ceiling. Guideline ISSO-SBR-811 therefore always assumes a false ceiling.

Figure 2 Drinking water and heating pipes above a false ceiling

Heating of drinking water pipes in the false ceiling should also be avoided by maintaining minimum distances between drinking water pipes and heating pipes. To avoid crossings and to guarantee the minimum distances, drinking water pipes have to be situated in cool ceiling strips.
Laying pipes above a false ceiling is not a very common practice in new houses, but it can be a solution in the case of refurbishment of houses. Because of the length of guideline ISSO-SBR-811, the concept of cool strips above a false ceiling is not elaborated in this paper.

4.3 Cool Surfaces in the Floor or above a False Ceiling

In this concept the drinking water pipes and heating pipes are laid in different layers on different levels:

- The drinking water pipes in the screed and the heating pipes above the false ceiling (see figure 3);
- The heating pipes in the screed and drinking water pipes above the false ceiling (see figure 4).

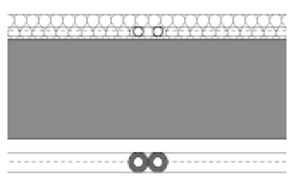

Figure 3 Drinking water in the screed and heating pipes above a false ceiling

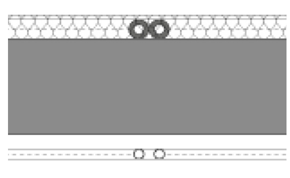

Figure 4 Heating pipes in the screed and drinking water and above a false ceiling

With this approach both the hot and cold pipes are separated and heating of the drinking water will be avoided. Application of this concept in stacked apartments is in some cases not permitted due to the short distance between pipes above the false ceiling and the screed on top of the construction floor. This applies in particular to rooms with a high design room temperature (like bathrooms).

This concept can be applied if the concept with cool strips is not possible. This can arise from design wishes or if the floor plan and therefore also the water zones are fixed in case of refurbishment of houses.
When applying the concept of cool surfaces, water and central heating pipes can run freely over the floor plan, so there are no restrictions on the layout of the floor plan.

To install the drinking water pipes in water zones, the architect has to take into account the position of the drinking water pipes during the design of the floor plan. Once the lay-out of a floor plan is established, crossings of drinking water pipes and heating pipes in a later phase of the building process are not allowed.

Because of the length of guideline ISSO-SBR-811, this concept is not elaborated in this paper.

5 Organization

During the design process of a house, the architect has to take into account that the floor plan has to be divided into two separate zones: a cool drinking water zone and a hot zone for the heating pipes. Both these zones lie either on the same level or on different levels. The position of the kitchen, toilet, bathroom, boiler, water meter and technical shafts plays an important role.
The architect defines the drinking water zone and heating zone based on the position of the taps on the floor plan. This has to be indicated on the contract drawings.
Three types of zones are distinguished; Zone type angle (Figure 5), Zone type node (Figure 6) and Zone type island (Figure 7). A home can comprise different types of zones that can be stacked.

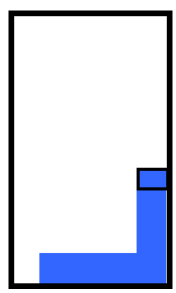

Figure 5 Zone type corner

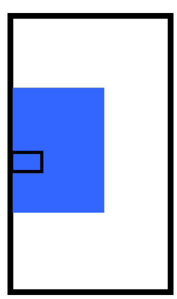

Figure 6 Zone type node

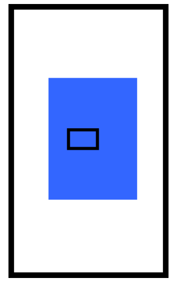

Figure 7 Zone type island

Figure 8 shows a combination of multiple types of zones within one house. The zones are connected by separate cold and warm shafts.

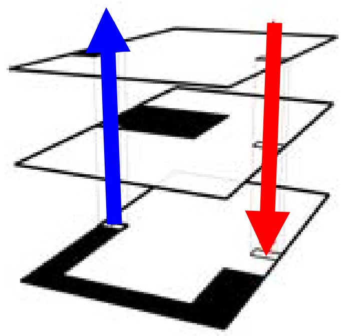

Figure 8 Multiple zones one above the other connected by a cold and warm shaft.

In the elaboration phase, the engineer of the drinking water installation and the engineer of the central heating installation coordinate their installation. The result is a coordination drawing with minimum distances with which the engineers on site can construct the hot-spot-free drinking water installation. To come to a coordination drawing with minimum distances two steps need to be taken:

Step 1. The designer of the drinking water installation draws the installation within the boundaries of the water zone on the floor plan and indicates the cool strips or areas for the drinking water pipes on the drawing. For the cool strips, the minimum distance between the drinking water and single hot drinking water pipes is indicated that must be maintained between drinking water pipes and heating pipes. The drinking water pipes are drawn as far as possible from the boundaries from the hot zone. See figure 9 with the drinking water zones in blue.

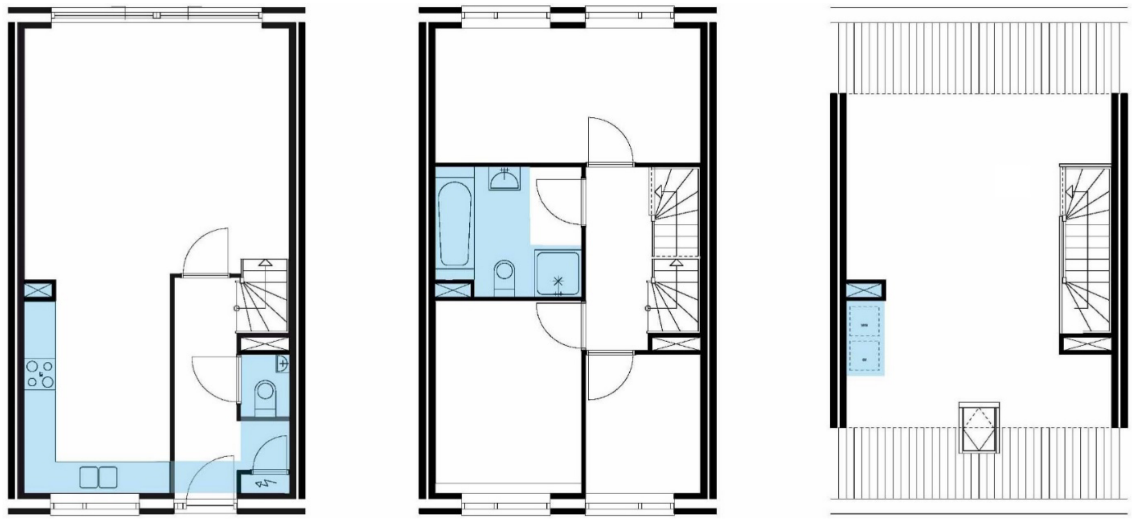

Figure 9 Floor plan with cool zones for drinking water pipes

Tap points with a low frequency of use have to be connected in such a way that a regular flow is guaranteed. To ensure this, it is advisable to install frequently used taps at the end of each pipe.

Table 1 shows the minimum distances between drinking water pipes and heating pipes in the screed. Figure 10 shows two examples of compositions with the minimum distance. The minimum distance between the drinking water pipes and central heating pipes depends on:
- Thermal insulation around the heating pipes (column 1);
- Temperature of the supply and return of the heating pipes (column 2);
- Room temperature above the floor (column 3);
- Room temperature under the floor (column 4).

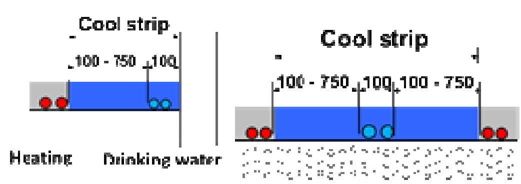

Figure 10 Two examples with drinking water pipes and heating pipes in the screed. The cool strip is blue

Tables 2a and 2b show the minimum distance between the drinking water pipes in the screed and underfloor heating pipes. Figure 11 shows a cross-section of the floor construction with (left) and without thermal insulation (right) underneath the underfloor heating. The distances mhd1, mhd2, mhd and mvd refer to the values shown in table 2a and 2b.

The minimum distance between the drinking water pipes in the screed and underfloor heating pipes depends on:

- The finishing of the floor (column 2): tiles, flag stones or thin carpet;
- Temperature of the supply of the underfloor heating pipes (column 3);
- Room temperature above the floor (column 4);
- Room temperature under the floor (column 5);
- The layer of thermal insulation underneath the underfloor heating
  - With thermal insulation, thickness 20 mm, λ = 0,04 W/m.K (Table 2a).
  - Without thermal insulation (Table 2b).

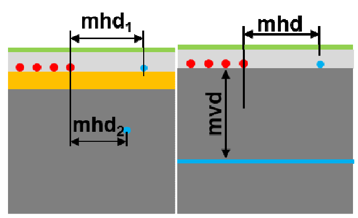

Figure 11 Cross-section of the floor construction with (left) and without thermal insulation (right) underneath the underfloor heating

Step 2. The designer of the heating installation draws the heating pipes outside the cool strips or areas in the floor plan. See figure 12. The water technical installer provides a coordination drawing on which the water and heating pipes are dimensioned with respect to each other and with respect to the walls.
In bathrooms there is generally a room temperature of 22 °C, which means that the temperature on the ceiling can be 25 °C. It is then not possible to install the water pipes in the floor. In those cases, the water pipes must be mounted behind pre-walls.

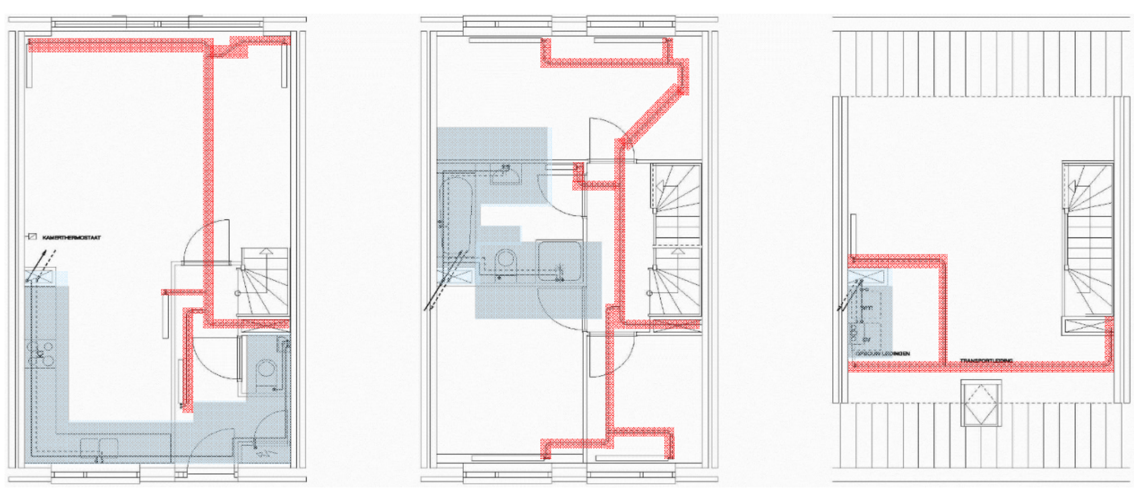

Figure 12 Floor plan with drinking water pipes and heating pipes (red marked)

Table 1. Guidelines for the minimum distance between drinking water pipes and heating pipes for radiators and / or circulation pipes for hot drinking water in the screed.

insulation / pipe protection around heating pipe	**temperature [°C]**			**minimum horizontal distance mhd [mm]**	**crossing water pipes in construction floor allowed?**
	medium supply/return	**room above floor**	**room under floor**		
1	**2**	**3**	**4**	**5**	**6**
Heating pipes in the floor					
Insulation 10 mm	80/60	20	23	450	no
	55/40	20	22	200	No
	40/30	20	22	100	Yes mvd 100 [1])
Pipe protection	80/60	20	22	750	No
	55/40	20	22	350	No
	40/30	20	22	150	Yes mvd 150 [1])
Insulation 10 mm	80/60	22	25	Not applicable [2])	no
	55/40	22	24	450	no
	40/30	22	24	200	no
Pipe protection	80/60	22	25	Not applicable [2])	no
	55/40	22	24	650	no
	40/30	22	24	350	no
Circulation pipes for hot drinking water in the floor					
Insulation 10 mm	70	20	23	400	no
Pipe protection	70	20	23	650	no
Insulation 10 mm	70	22	25	Not applicable [2])	no
Pipe protection	70	22	25	Not applicable [2])	no

[1]) mvd = minimum vertical distance (mm) to the hot pipe in the screed. Only achievable with sufficient floor thickness and if the construction floor is suitable for concealing pipes.

[2]) Beyond a distance of 1.5 m, the influence of the hot pipe is virtually zero and the water pipe can be installed.

Table 2a Guidelines for the minimum distance between the outer water pipe of underfloor heating and the drinking water pipe; situation **with** thermal insulation underneath the underfloor heating.

Heating room underneath	**Carpeting**	**Temperature [°C]**			**Minimum horizontal distance A_{min} [mm]**	**Water pipes and in construction floor allowed?**
		Supply underfloor heating	**Room above floor**	**Room under floor**		
1	**2**	**3**	**4**	**5**	**6**	**7**
Underfloor heating as main heating	Tiles, flag stones	50	20	20	250	Yes
		50	22	22	300	Yes mhd 150 [3])
		50				
		40	22	22	250	Yes
		30	22	22	150	Yes
	thin carpet	50	20	20	250	Yes
		50	22	22	350	Yes mhd 150 [3])
		50	24	24	500	Yes mhd 500 [3])
		40	20	20	200	Yes
		40	22	22	250	Yes
		40	24	24	400	Yes mhd 400 [3])
		30	20	20	100	Yes
		30	22	22	150	Yes
		30	24	24	250	Yes
combination with radiators	Tiles, flag stones	50	20	23	250	Yes mhd 500 [3])
		50	22	25	300	No
		50	24	27	550	No
	thin carpet	50	20	23	300	ye mhd 250 [3])
		50	22	25	400	No

[3]) mhd = minimum horizontal distance (mm) to the underfloor heating on top of the thermal insulation.

Thermal insulation thickness 20 mm, λ = 0,04 W/m.K.

Table 2b Guidelines for the minimum distance between the outer water pipe of underfloor heating and the drinking water pipe; situation **without** thermal insulation underneath the underfloor heating.

Heating room underneath	**Carpeting**	**Temperature [°C]**			**Minimum horizontal distance mhd A_{min} [mm]**	**Water pipes and in construction floor allowed?**
		Supply underfloor heating	**Room above floor**	**At ceiling under floor**		
1	**2**	**3**	**4**	**5**	**6**	**7**
Underfloor heating as main heating	thin carpet	50	20	20	250	No
		50	22	22	350	No
		40	20	20	150	Yes mvd 150 [4])
		40	22	22	250	No
		40	24	24	500	No
		30	20	20	50	Yes mvd 50 [4])
		30	22	22	100	Yes mvd 100 [4])
		30	24	24	250	No

[4)] mvd = minimum vertical distance (mm) to the underfloor heating on top of the floor.

6 Practical tips

Beside the solutions mentioned above guideline ISSO-SBR 811 provides some practical solutions. Installing a combi-boiler at a certain distance between the drinking water and heating pipes has to be taken into account to avoid heating of the drinking water pipes:

- If the combi-boiler is positioned in a casing in an apartment. See figure 13.
- If the combi-boiler is positioned on a loft of a house. See figure 14.

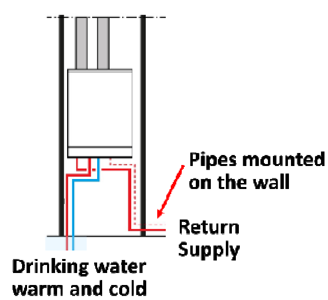

Figure 13 View of a combi-boiler in a casing

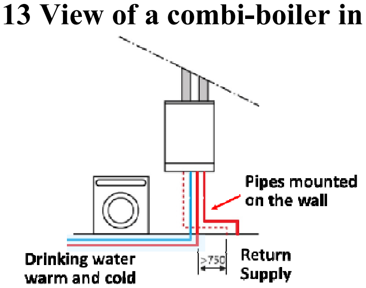

Figure 14 View of a combi-boiler on a loft in a house

7 Conclusion

At the start of a project, it is important to pay attention to the prevention of hot spots in drinking water installations. Once the drinking water pipes are concealed in floors, behind pre-walls or in casings, it is difficult to correct errors. Opening and closing the screed and changing the position of the drinking water or heating pipes leads to high costs. And if the error is discovered when the houses have already been occupied, the costs and inconveniences cannot be foreseen.

Guideline ISSO-SBR 811 pays attention to multiple phases in the design and implementation process as an integral chain. The guideline contains examples for the most common types of dwellings and renovations, as well as a number of specific issues with, for example, collective heating or district heating.

Following the solutions provided by guideline ISSO-SBR-811 will save failure costs.

Acknowledgments

Establishing guideline ISSO-SBR 811 was made possible with the support of: Uneto-VNI, SBR, ISSO, OTIB, Eneco, Nuon, Vitens and WTH.

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2. NEN 1006, General requirements for water supply installations, 1st September 2015.

9 Presentation of author

Walter van der Schee BSc is an employee of Croonwolter&dros based in Amersfoort, the Netherlands. He is responsible for mechanical and plumbing design and construction in commercial buildings.

As member of the Dutch Technical Association for Building Installations (TVVL), he is one of the experts consulting for Plumbing technologies. For his work within the TVVL he was awarded the BJ Max Award in 2006.

For further information about Walter's employer or the TVVL association consult their websites. www.croonwolterendros.nl www.tvvl.nl

E-mail: walter.vanderschee@croonwolterendros.nl

Experimental and numerical study of aerosol generation rates for showerheads

Y. Zhou (1), K.W. Mui (2), L.T. Wong (3), P.H. Tsui (4), W.K. Chan (5)
1. yang.zhou@connect.polyu.hk
2. behorace@polyu.edu.hk
3. beltw@polyu.edu.hk
(1), (2), (3), (4), (5) Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

Abstract

Aerosolization of water from discharging water appliances provides a transmission medium for Legionnaires' disease. The quantity of aerosolized droplets influences the infection of Legionnaires' disease. This study investigates the aerosol generation rates of four sample showerheads experimentally in a mechanically ventilated test chamber, assisted by computational fluid dynamics (CFD) simulations. The results show that the aerosol mass generation rates determined for the sample showerheads are in the ranges of 1.42×10^{-5} to 5.52×10^{-5} gs^{-1}. Furthermore, the aerosol mass generation rate decreases with the showerhead resistance factor but increases with the water supply pressure, nozzle area ratio, flow rate, spray jet velocity, momentum and force. There is no significant correlation between aerosol mass generation rate and water spray uniformity ($p>0.05$, *t*-test).

Keywords

Aerosol generation; showerhead; chamber test; computational fluid dynamics (CFD); Legionnaires' disease (LD).

1 Introduction

It has been recognized that aerosols are generated with showerhead discharging, which provide a transmission medium of Leionnaires' disease (LD), a severe pneumonic illness caused by bacterium *Legionella pneumophila*. Like any other airborne disease, the infection of LD is affected by several factors, such as contaminated aerosol concentration, aerosol size distributions, breathing rate, exposure time and immunity [1,2]. Among these factors, size distribution of aerosols generated by discharging showerheads has been investigated in several studies [3-5]. As washroom is usually small, it can be assumed that the space is well-mixed/filled up entirely with aerosols. Therefore, aerosol concentration in bathroom is significantly more important when considering the LD transmission, in which for definite ventilation condition, the aerosol concentration in bathroom is related to aerosol generation rate of showerheads. Among the several factors that influence the LD infection, this study focuses on the aerosol generation rate of showerheads only.

Installation of water efficient appliances is one demand-side water management policy that favored by water provides/water utilities managers [6,7]. As low flow showerheads usually break up water into a fine mist which can be inhaled easily [8], they enhance the transmission of LD. Hence, the installation of low flow showerheads brings new concerns related to aerosol generation rate by showerheads.

This study investigates experimentally the aerosol generation rates of four sample showerheads in a mechanically ventilated test chamber, assisted by computational fluid dynamics (CFD) simulations. The aerosol mass generation rates are determined. Correlations between aerosol mass generation rate and showerhead attributes are analyzed, with expressions of aerosol generation rate by water supply pressure, spray jet momentum and nozzle area are proposed.

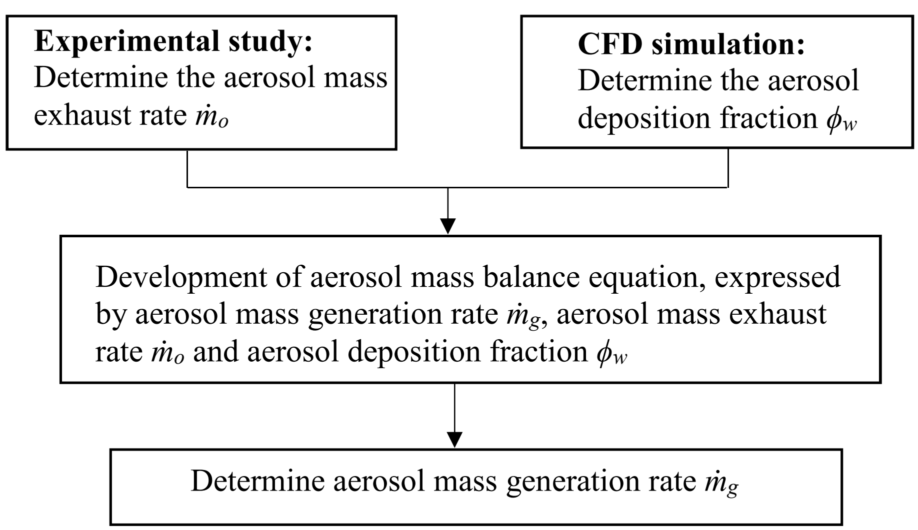


Figure 1 - Logical diagram of the methodology

2 Methodology

The methodology is divided into three parts, namely the experimental study of aerosol generation in a chamber, CFD simulation of aerosol deposition on chamber walls, and development of aerosol balance equation in the chamber. The logic of these three part is as shown in Figure 1, and details are described below.

2.1 Experimental study

Aerosol generation rates of sample showerheads were investigated experimentally in a glass chamber of size 0.914m×0.61m×0.508m, as shown in Figure 2. Air was filtered and moistened before supplying through the chamber inlet, which was 0.155 m in diameter, at a steady air velocity of 0.25 ms^{-1} (60 air changes per hour). The sample showerhead was fed from an enclosed tank filled with 2% saltwater solution at pressure P_s (kPa).

In the experiment, a dry and clean filter paper with a pore size of 0.2 μm was placed at the chamber outlet to collect aerosolized saltwater for 3 hours (i.e. τ =10800 s). The filter paper sample was then dried in an oven at 100ºC for 30 minutes. As the total salt mass m_t (g) is the salt mass collected on the dried filter paper sample, the aerosol mass exhaust rate $\dot{m}_o$ can be determined by Equation (1), where ρ_d (=1000 kg m^{-3}) and ρ_t (=1020 kg m^{-3}) are the densities of water and saltwater respectively.

$$\dot{m}_o = ((\phi_t + 1)m_t)/\phi_t\tau \text{ ; } \phi_t = (\rho_t - \rho_d)/\rho_d \quad (1)$$

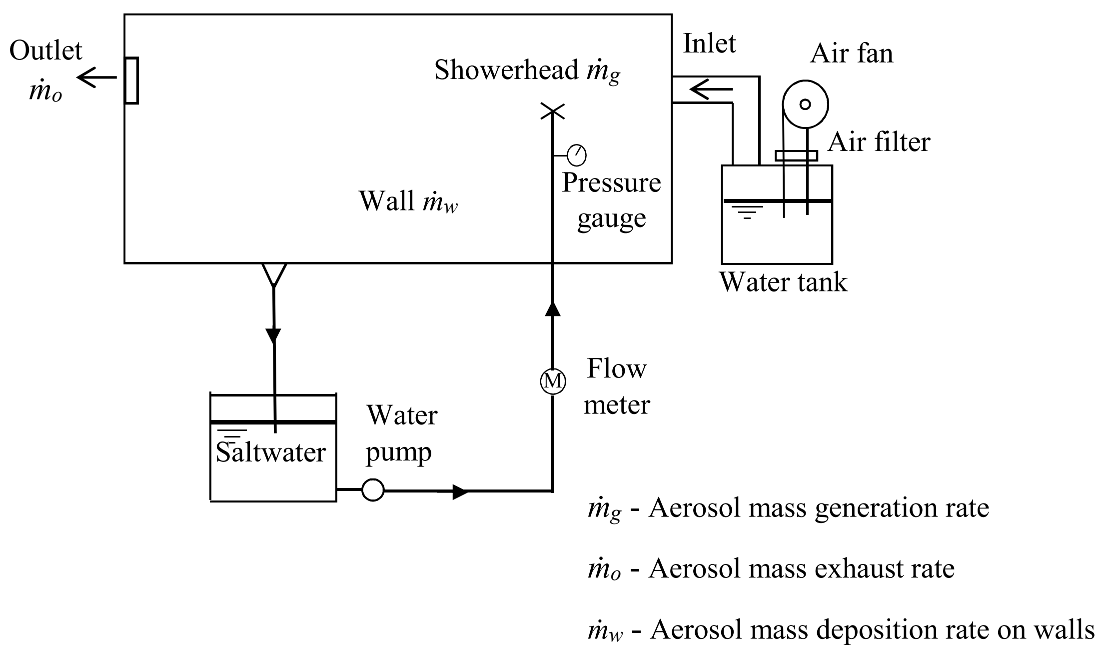


Figure 2 - Experimental setup for showerhead aerosol generation study

2.2 Computational fluid dynamics (CFD) simulation

The aerosol deposition fraction on chamber wall was acquired by CFD simulations [9]. Figure 3 shows a geometric model chamber that was built based on the experimental setup described above. In this study, a cubic zone with size of 0.01m×0.01m×0.01m was used to represent the discharging showerhead in the chamber. The model chamber was automatically 'medium' meshed using the Relevance Center setting in ANSYS Fluent 13.0, and the suitability of the mesh size was verified by comparing simulated aerosol deposition fractions in different mesh sizes until there was no significant difference. Finally, 91007 calculation cells and 17449 nodes were set for the chamber.

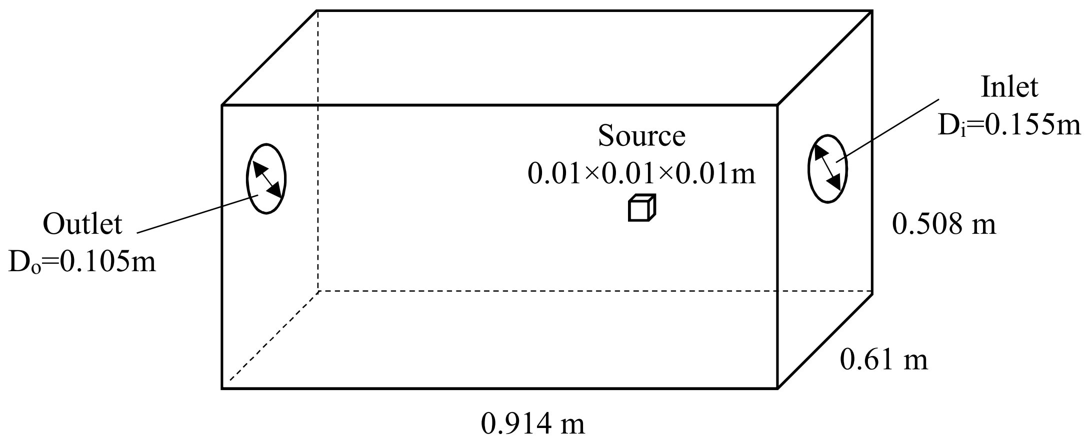


Figure 3 - Geometric model setup for CFD simulations

The air phase motion was described by the Navier-Stokes equations, and a Lagrangian discrete phase model (DPM) was employed to separately track a number of stochastic aerosols from the source. As the mass and momentum loadings of the aerosol phase were low in the chamber, uncoupled DPM was adopted. The number of stochastically tracked aerosols was verified by comparing with the ensemble average of the trajectories, namely simulated aerosol deposition fraction in this study. Finally, a statistical sample size of 12000 tracked aerosols was confirmed to represent the full range of aerosol behavior in this study.

For the simulation with Lagrangian DPM, the aerosol injection from the source was just at the beginning of the computation of the continuous phase (i.e. air phase). A velocity inlet boundary condition was chosen for inlet, and outflow boundary condition were set at the outlet. The chamber wall was the 'stationary' boundary condition. The discrete phase boundary condition type of both inlet and outlet was set as 'escape', and 'trap' discrete phase boundary condition was chosen for the chamber walls. Source was set as 'reflect' discrete phase boundary condition, and the refection coefficients in the normal and tangent directions were 1. Standard k-ε Model was adopted since it is proper for airflow simulation in the space and good agreement between simulation results and measured data has been achieved [10]. Besides, no aerosol aggregation and breakage were assumed.

At steady state, total tracked aerosols (i.e. 12000 tracers) is the sum of the aerosols deposited on chamber walls and exhausted from outlet. The number of aerosols that deposited on chamber walls n_w and exhausted from outlet n_o were acquired from the CFD simulation, and aerosol deposition fraction ϕ_w is determined by following expression,

$$\phi_w = \frac{n_w}{n_w + n_o} \tag{2}$$

2.3 Aerosol mass balance model in the chamber

Inside a well-mixed ventilated chamber, the aerosol concentration of a generation source is given by the aerosol mass balance as expressed in Equation (3), where $\dot{m}_c$ (gs^{-1}) is the aerosol mass change rate, $\dot{m}_g$ (gs^{-1}) is the aerosol mass generation rate, $\dot{m}_i$ (gs^{-1}) is the aerosol mass inflow rate, $\dot{m}_o$ (gs^{-1}) is the aerosol mass exhaust rate, and $\dot{m}_w$ (gs^{-1}) is the wall deposition rate of the aerosol mass.

$$\dot{m}_c = \dot{m}_g + \dot{m}_i - \dot{m}_o - \dot{m}_w \tag{3}$$

Let the aerosol deposition fraction on the chamber walls be $\phi_w=\dot{m}_w/\dot{m}_g$, the aerosol mass generation rate at steady state (i.e. $\dot{m}_c$=0) and without any aerosols from inflow (i.e. $\dot{m}_i$=0) is given by,

$$\dot{m}_g = \dot{m}_o + \dot{m}_w = \dot{m}_o/(1 - \phi_w) \tag{4}$$

The aerosol mass exhaust rate $\dot{m}_o$ in Equation (4) can be determined in the experimental study while the aerosol deposition fraction on the chamber walls ϕ_w can be acquired from the CFD simulations above.

3 Sample showerheads

Figure 4 shows the four sample showerheads adopted in this study. Samples 3 and 4 were Water Efficiency Labelling Scheme (WELS) labelled Grade 1 showerheads with reduced nominal flow rates [11]. The physical properties of all sample showerheads are summarized in Table 1 [12]. The selected four sample showerheads cover a wide range of primarily operating characteristics, e.g. pressure, resistance factor K_s and flow rate.

1 2 3 4

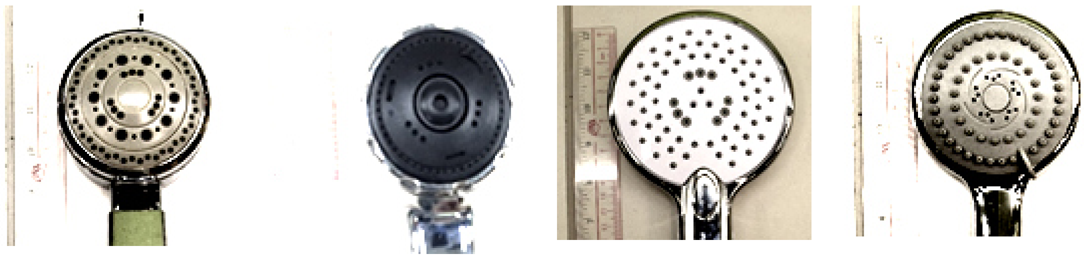


Figure 4 - Sample showerheads

Table 2 - Showerhead physical properties, spray attributes and aerosol generation rates

Parameter	Sample showerheads			
	1	**2**	**3**[a]	**4**[a]
Showerhead				
Diameter, D_s (m)	0.080	0.045	0.115	0.085
Number of 1/2/3 mm nozzles, $n_1/n_2/n_3$	48/19/10	48/9/0	59/9/0	53/15/0
Nozzle area ratio, ϕ_A	0.0334	0.0415	0.0072	0.0156
Resistance factor, K_s (kPa min^2 L^{-2})	1.82	1.90	16.50	3.36
Shower water spray measured at P_s=100 kPa (at 150 kPa)				
Flow rate, Q_s (L s^{-1})	0.13 (0.16)	0.12 (0.14)	0.04 (0.05)	0.10 (0.12)
Spray spread angle, θ_s (°)	11 (11)	2 (2)	11 (11)	9 (9)
Spray jet velocity, v_s (m s^{-1})	0.77 (0.95)	1.82 (2.12)	0.56 (0.70)	1.13 (1.35)
Momentum, M_s ($\times10^{-4}$ m^4 s^{-2})	1.01 (1.52)	2.18 (2.97)	0.24 (0.36)	1.13 (1.62)
Uniformity, ϕ_u	0.21 (0.62)	5.95 (0.58)	0.68 (0.52)	0.33 (0.51)
Spray jet force, F_s (N)	0.75 (1.06)	1.05 (1.32)	0.34 (0.44)	0.62 (0.98)
Aerosol mass generation rate, $\dot{m}_g$ ($\times10^{-5}$ gs^{-1})	2.85 (3.92)	3.03 (5.52)	1.42 (3.03)	2.14 (3.38)

[a]WELS labelled Grade 1 showerhead.

4 Results and discussions

Aerosol mass generation rates of four sample showerheads are summarized in Table 1, which are in the ranges of 1.42×10^{-5} to 5.52×10^{-5} gs^{-1}. Table 1 shows that aerosol mass generation rate increased with water supply pressure at showerhead. The ratios of aerosol mass generation rate to water supply pressure for the four sample showerheads were plotted in Figure 5, in which a reference line indicates perfectly linear increase of aerosol generation rate with water supply pressure at showerhead. By defining acceptable error range, linear increase of aerosol generation rate with water supply pressure at showerhead can be concluded from Figure 5.

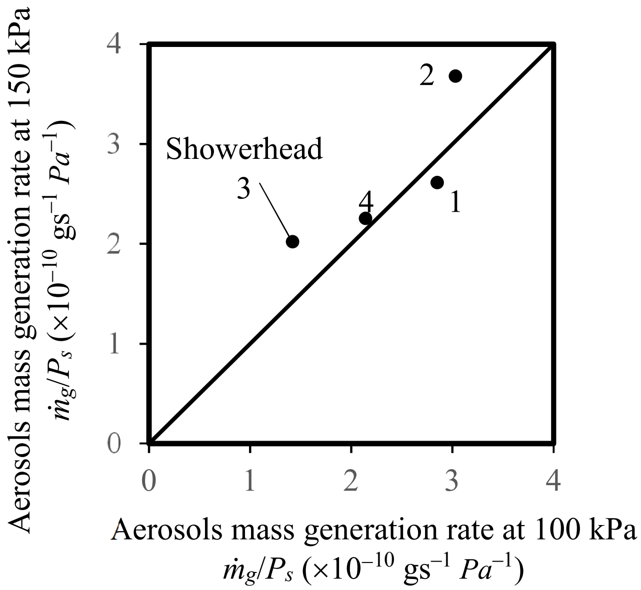


Figure 5 -Ratio of aerosol mass generation rate to water supply pressure at showerhead

Figures 6(a) to 6(g) illustrate the ratio of aerosol mass generation rate to water supply pressure $\dot{m}_g/P_s$ ($\times10^{-10}$ gs^{-1} Pa^{-1}) against the nozzle area ratio ϕ_A, showerhead resistance factor K_s (kPa min^2 L^{-2}), water supply flow rate Q_s (L s^{-1}), spray jet velocity v_s (m s^{-1}), spray jet momentum M_s (m^4 s^{-2}), uniformity ϕ_u and spray jet force F_s (N) respectively. All parameters except uniformity show a significant correlation with the aerosol mass generation rate ($p\leq0.05$, t-test). As shown in Figures 6(a) to 6(e) and Figure 6(g), the aerosol mass generation rate decreases with the showerhead resistance factor but increases with the water supply pressure, nozzle area ratio, flow rate, spray jet velocity, momentum and force. While water supply pressure, nozzle area ratio, flow rate, spray jet velocity and momentum are all related to the showerhead itself, spray jet force is exerted by the spray-surface interaction. The spray jet force is an indicator of the splashing effect caused by water spray jet impaction on a surface; a greater force produces a greater splashing effect and thus more aerosols.

The relationship between aerosol mass generation rate and showerhead attributes can be expressed by,

$$\dot{m}_g/P_s \sim (\phi_A, K_s, Q_s, v_s, M_s, F_s);\ M_s \sim (Q_s, v_s);\ K_s \sim (P_s, Q_s);\ F_s \sim (Q_s, v_s) \qquad (5)$$

It can be rewritten as,

$$\dot{m}_g/P_s \sim (\phi_A, M_s) \tag{6}$$

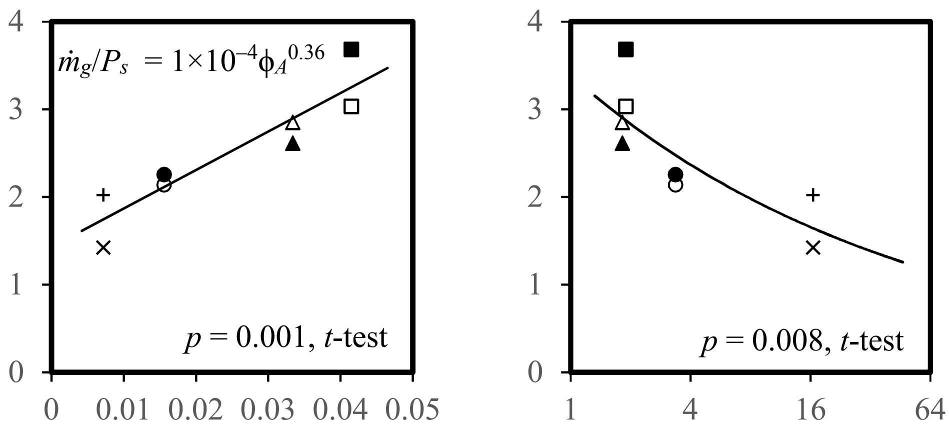
Equations for the trend lines in Figure 11(a) and Figure 11(e) were given as following,

$$\dot{m}_g/P_s = 1\times10^{-4}\phi_A{}^{0.36}\ ;\ \dot{m}_g/P_s = 0.004M_s{}^{0.3} \tag{7}$$

As Equation (7) shows that $\dot{m}_g/P_s \sim \phi_A{}^{0.36}$ and $\dot{m}_g/P_s \sim M_s{}^{0.3}$, the aerosol mass generation rate $\dot{m}_g/P_s$ against $M_s{}^{0.3}\phi_A{}^{0.36}$ was plotted in Figure 6 for analysis. Figure 6 gives the expression of aerosol mass generation rates $\dot{m}_g$ (gs^{-1}) by water supply pressure, spray jet momentum and nozzle area ratio, with p=0.001 (t-test).

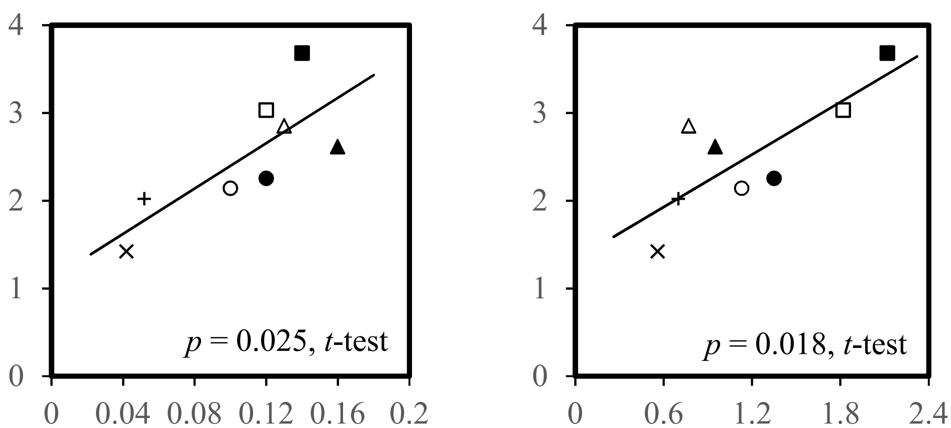
$$\dot{m}_g = 0.00022P_sM_s{}^{0.16}\phi_A{}^{0.19} \tag{8}$$

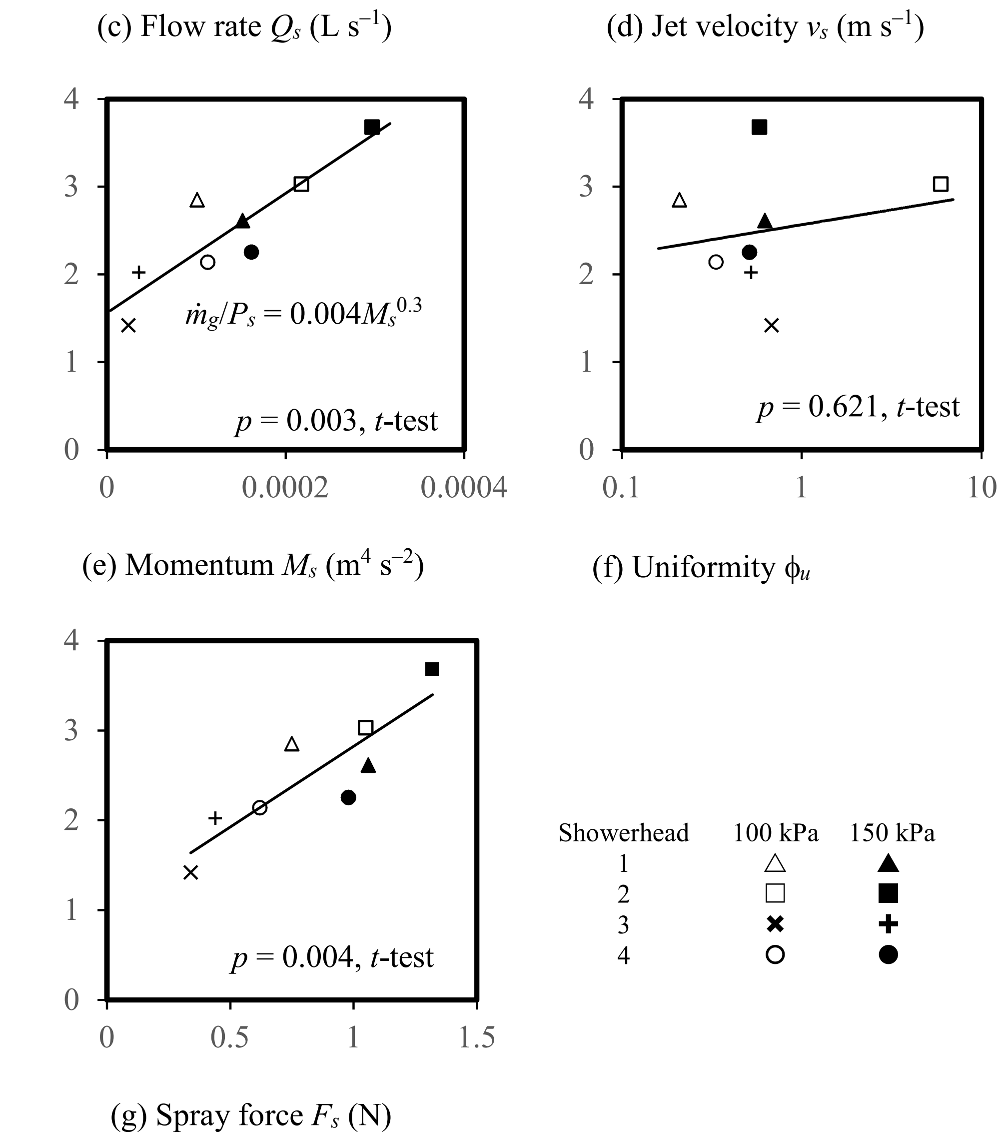
As the results are from the test range, which delinked from the graded showerheads. Therefore, Equation (8) can be the referenced guidance for future showerhead design to limit the aerosol generation rate.



(a) Nozzle area ratio ϕ_A

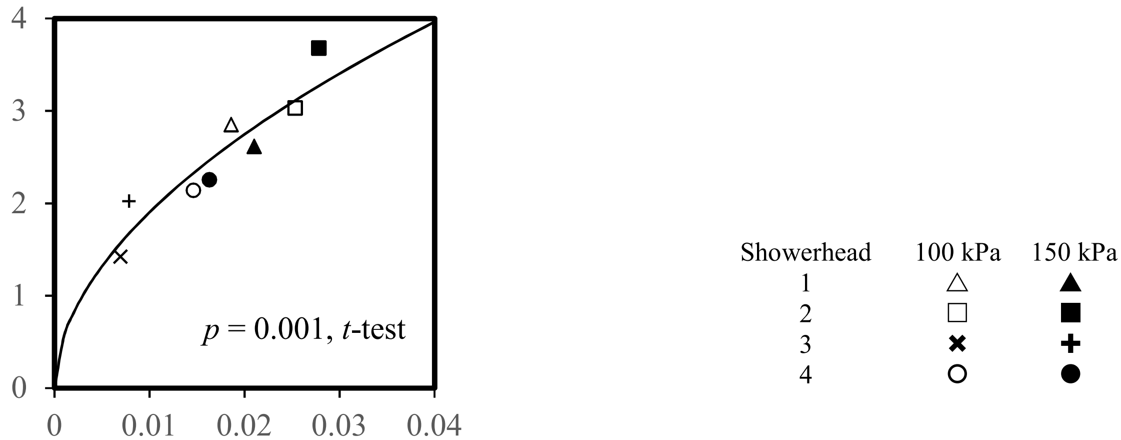
(b) Resistance factor K_s (kPa min^2 L^{-2})





y-axis: Aerosol mass generation rate $\dot{m}_g/P_s$ ($\times 10^{-10}$ gs^{-1} Pa^{-1})

Figure 6 - Correlations for aerosol mass generation rate



x-axis: $M_s^{0.3}\phi_A^{0.36}$; y-axis: Aerosol mass generation rate $\dot{m}_g/P_s$ ($\times 10^{-10}$ gs^{-1} Pa^{-1})

Figure 7 - Aerosol mass generation rate as a function of $M_s^{0.3}\phi_A^{0.36}$

Table 1 shows that when all sample showerheads were operating at the same pressure, the aerosol generation rates of the WELS labelled Showerheads 3 and 4 were less than those of Showerheads 1 and 2. Our previous study [12] revealed that the optimum pressure of WELS labelled showerheads was larger than that of conventional showerheads; however, the aerosol generation rate of a WELS labelled showerhead can still be controlled by the adjustment of momentum M_s and nozzle area ratio ϕ_A as demonstrated by Equation (16).

5 Conclusion

Aerosolization of water from discharging water appliances provides a transmission medium for Legionnaires' disease. In this study, the aerosol generation rates of four sample showerheads in a mechanically ventilated test chamber were investigated experimentally, assisted by CFD simulations. The aerosol mass generation rates determined for the sample showerheads were in the ranges of 1.42×10^{-5} to 5.52×10^{-5} gs^{-1}. The results showed that aerosol mass generation rate decreased with the showerhead resistance factor but increased with the water supply pressure, nozzle area ratio, flow rate, spray jet velocity, momentum and force. No significant correlation was found between aerosol mass generation rate and water spray uniformity ($p>0.05$, *t*-test). Furthermore, an expression of aerosol mass generation rate by water supply pressure at showerhead, spray jet momentum and nozzle area ratio was proposed, which can be used as a referenced guidance for the showerhead design to limit the aerosol generation rate. It was also reported that the low flow showerheads generated fewer aerosols while operating at the same pressure as conventional showerheads.

Acknowledgments

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7 Presentations of Authors

Dr. Y. Zhou is a PhD graduate from the Department of Building Services Engineering, The Hong Kong Polytechnic University. Now he is a senior research associate at the Department of Architecture and Civil Engineering, City University of Hong Kong.

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.

Ms. P.H. Tsui is a graduate from the Department of Building Services Engineering, The Hong Kong Polytechnic University.

Mr. W.K. Chan is a graduate from the Department of Building Services Engineering, The Hong Kong Polytechnic University.

Difficulties encountered during the evaluation of a *Legionella* contamination level in a sanitary installation

K. Dinne (1), B. Bleys (2), O. Gerin (3)
(1) karla.dinne@bbri.be
(2) bart.bleys@bbri.be
(3) olivier.gerin@bbri.be

(1), (2), (3) Belgian Building Research Institute (BBRI), Belgium.

Abstract

Monitoring of Legionella bacteria is important for public health reasons in order to identify the environmental sources which can pose a risk of legionellosis, such as hot and cold water distribution systems and associated equipment. Different international standards describe how to take water samples and which technique can be used to analyze these water samples. Worst case scenario's for sampling indicate that the first liter, without a flush, should be taken to evaluate the risk.

During our research we evaluated different sampling protocols. The full- scale test facility at BBRI, contaminated with *Legionella pneumophila* bacteria served as case-study [6-7].

Samples were taken on a regular base from the sampling valves (Depart & Return) and from the faucets (shower or kitchen faucet). The sampling ball valves on the depart and return were mounted on T- pieces. This means that a small water volume (~4 ml) from the circulation loop is trapped in the connection, presenting a small "dead zone" suitable for biofilm development. The study included "first liter" samples, taken at once (volume 1liter), as well as fractionised water samples (collecting the first 200 ml water separately from the 800 ml water). Also biofilm measurements were included to evaluate the contamination level of the circulation loop [7].

This article will point out the influence of the sampling protocol on the interpretation of the 'Legionella contamination level 'within a sanitary installation. The study indicates the importance of a well described sampling strategy and protocol, in compliance with the information needed for a risk assessment.

Keywords

Drinking water installation, Legionella development, water sampling, analysis

1 Introduction

Much has been leaned about 'Legionnaires disease' ant its causative agent *Legionella* since the outbreak in 1976 meeting of the American Legion in Philadelphia. Because of the dedication of scientists worldwide, we now have advanced knowledge of the clinical and epidemiological aspects of Legionnaires disease, we know the sources and reservoirs for *Legionella* organisms and the environmental conditions under which they grow and die. We also have state-of the art technology to detect the *Legionella* bacteria in water systems and we have some knowledge on how to control *Legionella* organisms in water systems.

Different specific guidelines are available for the management of water systems associates with buildings. The "European Technical Guidelines for the Prevention, Control and Investigation of infections caused by Legionella species" [1] updates advice on risk assessment and the management of different sources of infection and offers a standardised approach to procedures for preventing and investigating *Legionella* infections. This guideline aims to further harmonise these procedures among Member States but national laws on specific aspects of control and prevention differs between these European guidelines and regulations in force in Member States.

Until now, no scientific information is available on the concentration of *Legionella* bacteria in water necessary to cause illness. There is no safe level of *Legionella* in water systems. The ultimate objective is to either not have any *Legionella* in the system or to rid a system of all *Legionella* bacteria. However, minimising the *Legionella* concentration in the water of the building system is one of the major challenges for building owners, maintenance staff, plumbers and service firms. The advisory report from the Superior Health Council of Belgium [2] for Health Care Premises, reported a maximum level of 1000 cfu/l *Legionella pneumophila* bacteria in order to minimise the risk of infections.

The major similarity in all the regulations and guidelines is the importance of the risk assessment. The risk assessment should provide adequate information for the user and the investigator about the risks from each system and the measures necessary to ensure that the water systems are safe and without risks to health. The risk assessment is a critical component, which aims to identify weak points in a system where waterborne hazards could enter, and which might increase within the system to levels which pose a risk to users and anyone else who could be exposed. The information generated by the risk assessment will be used to develop a management scheme to manage the hazards and mitigate the risks by implementing appropriate remedial works and control measures. If microbiological samples are to be taken as a part of the risk assessment process, the assessor should have been trained to know how and when to take samples and where from. The assessor must be aware of how the sampling protocol applied at different technical equipment and components in a system can influence the result of the *Legionella* concentration in the water, reported by the laboratory.

During our research we evaluated the importance of some technical details (as connections) present in the installation, responsible for stagnation of small water volumes. Different sampling protocols are analyzed in order to estimate / evaluate the real concentration of *Legionella* bacteria circulating in the test facility. The full- scale test facility at BBRI, contaminated with *Legionella pneumophila* bacteria served as case-study. The test facility and the applied drawn-off profile are described in our previous articles [6-7].

2 Test setup

2.1 General description

Generally, water samples should be taken for routine sampling as the results are comparable over time and therefore useful for trend analysis. There are many published methods for the detection of *Legionella* from water samples, including those in both international and national standards. The International Standardization Organization (ISO) produces standard methods including for the detection of *Legionella* by culture (ISO 11731: 2017 [3]). Within Europe, CEN (Committee for European Standardization) has adopted this ISO 11731 standard, what means that different countries in Europe must adopt them for use.

It is important to understand that a sample taken from a water system is only a small portion of the total system volume and that a negative *Legionella* result does not necessarily mean the entire system is under control. Microorganisms are not uniformly distributed throughout the water system all the time, especially in areas with poor flow and stagnation or where controls are not effectively maintained.

Samples should be taken, transported and conserved in accordance with nationally and internationally accepted methods (Water Analyses Compendium A 001-004, and 10 [4]; ISO 5667 Part 1,3 and 5; ISO 19458 [5]).

In Belgium, worst case scenario’s for sampling indicate that the first liter of water, just after opening the tap (without a flush, without disinfection of the tap) should be taken to evaluate the risk.

2.2 Sampling campaigns

During the study of the disinfection procedures on the test facility [6-7], the evolution of the *Legionella* concentration is analyzed at different sampling points (depart pipe, return pipe, kitchen draw-off pipe and shower draw-off pipe). The first liter of water, directly after opening the tap from the sampling point is collected in a sterile bottle and analyzed in the laboratory. The evolution of the *Legionella* concentration in the system during different disinfection procedures (thermal shocks) is presented in the previous articles.

Tapping the first liter of water could give higher concentrations of *Legionella*, due to a small volume of stagnation in the tap point, which will not be representative for the concentration circulating in the system.

A consecutive sampling is applied at two taps (depart and return pipes)

- the first liter, just after opening the sampling tap is collected in a sterile bottle.
- the next 4 liters water are flushed away,

- a second sample is taken (= 5th liter water).
- another liter is flushed away
- the last sample is taken (= 7th liter water).

Figure 1 shows the results of the *Legionella* concentration in the different water samples: the first liter, the 5th liter and the 7th liter as well as the mean value (all water samples from the return pipe).

The connections of the sampling tap on the return pipe host a small volume of water (~4 ml) which is stagnating and will not rise in temperature during heat chocks. In order to evaluate the possible *Legionella* concentration in this volume of trapped water, the tap is removed, and the volume was collected with a sterile pipet for further analysis. Table 1 shows the *Legionella* concentration in the dead zone of 4 ml water, and the *Legionella* concentration circulating in the return pipe.

Figure 1: Picture showing how the dead water volume is collected using a sterile pipet

As the *Legionella* concentration in the test facility fluctuates due to the consecutive heat chocks, the sample of the ‘first liter’ was analyzed more in detail. To evaluate if the small volume of water trapped in the sampling valve influences consequently the results, the first liter sample is collected in 2 portions (the first 200 ml separately from the following 800 ml water) and analyzed separately. Figure 2A and 2B show the results of the *Legionella* concentration in the different water samples, over a sampling period of 4 months with the hot water production at 45°C and heat shocks at 65°C, the depart pipe and return pipe.

The sensitivity of the method should be such that the laboratory can reliably recover 50 cfu/l.

3 Results

3.1 Concentration of *Legionella* bacteria in the water, circulating in the test facility

Figure 1 shows the results from consecutive water sampling at the return pipe. The first liter, the 5th and 7th liter, as well as the mean value of the *Legionella* concentration (of the 3 samples) are listed. Sampling the first liter, without flushing, as required in Belgium for worst case scenario analyses, will indicate most of the time (72%) a higher concentration of *Legionella* bacteria.

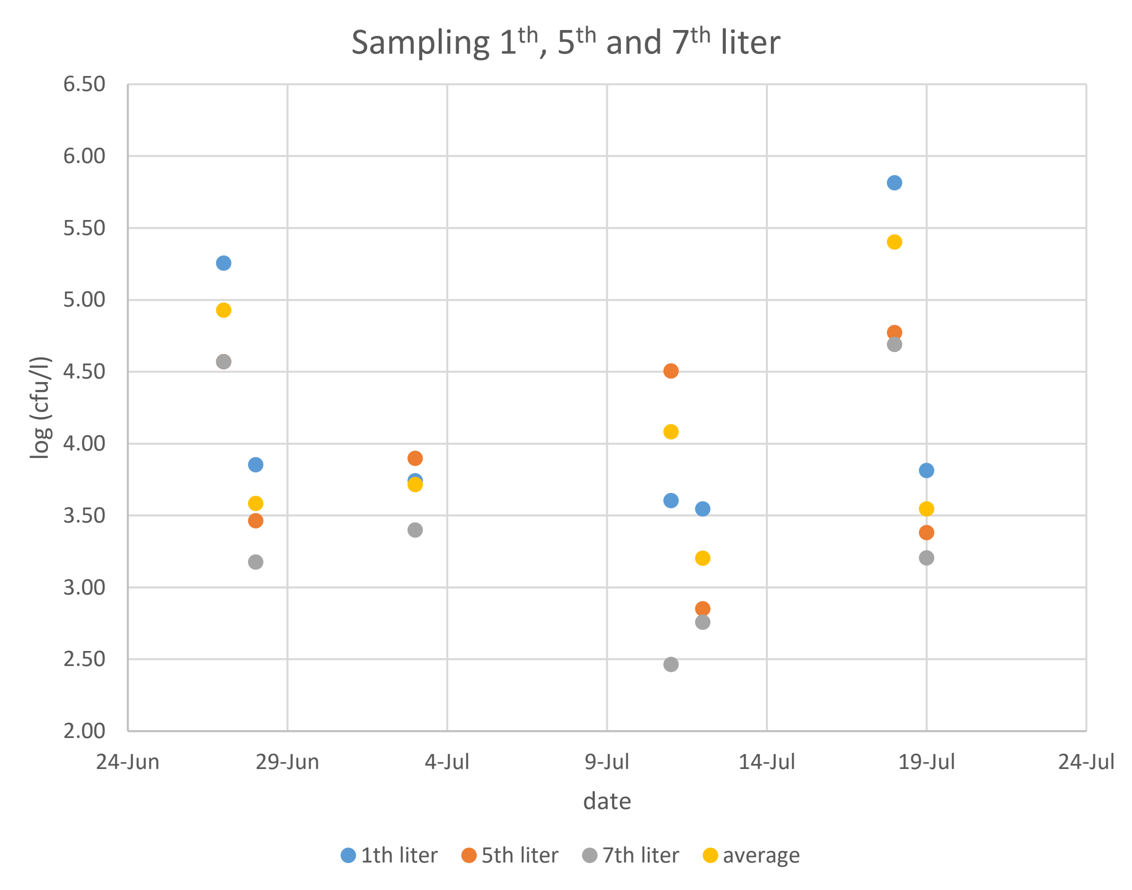

Figure 1: Consecutive sampling at the return pipe (the first liter, the 5th liter and the 7th liter)

3.2 Presence of *Legionella* in a small dead zone

In a sanitary installation, small water volumes can be trapped at connections zones. These dead zones won't be treated during automatic heat shocks without forced drain-off. After removing the tap, the trapped water volume is collected and analyzed. In order to evaluate the concentration of *Legionella* in the circulation system at that moment, the tap is reinstalled, and consecutive water samples are taken (1st liter draw-off, 5the liter draw-off and 7th liter draw-off). The analysis of the trapped water volume showed the presence of *Legionella pneumophila* in the small water volume. (see table 1).

Water Sample from the return pipe (03.07.17)	**Concentration (cfu/l) *Legionella pneumophila* (sg 1)**	**Log10 (concentration) *Legionella pneumophila* (sg1)**
volume of water (4 ml) trapped in the sampling tap	280	2.4
First liter draw-off	5100	3.7
5th liter draw-off	7900	3.9
7th liter draw -off	2500	3.4

Table 1: Legionella concentration in the system (return pipe) and in the trapped volume of water (4 ml) from the return pipe

In this test situation, the trapped water volume is very small, and should not influence/falsify the concentration of the first liter draw-off (in case the dead water volume was not removed). As a larger dead volume can be present in other situations, development in the dead zone might influence the result of a first liter draw-off.

3.3 First liter sampling

As the previous test on the homogeneity of *Legionella* bacteria circulating in the water indicates that the first draw-off liter represents most of the time (72%) the highest concentration of *Legionella* bacteria, the first liter water sample is collected in 2 portions (200 ml and 800 ml). Each portion is analyzed separately.

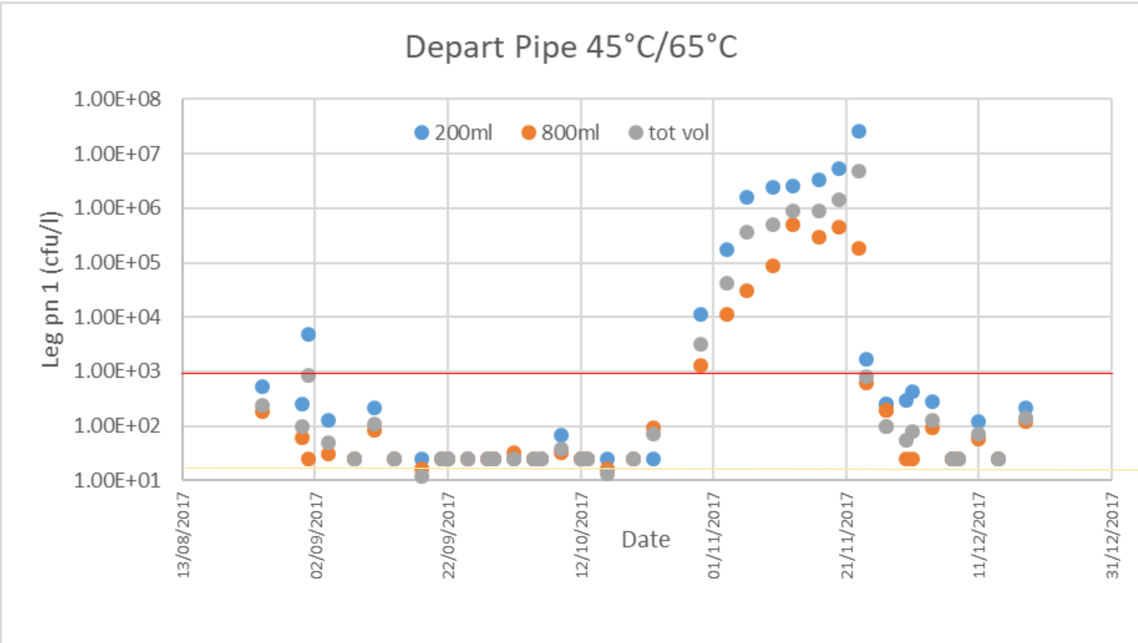

Figure 2A: Concentration of *Legionella pneumophila* in the first liter, sampled at the depart pipe, (sampling 200 ml / 800 ml)

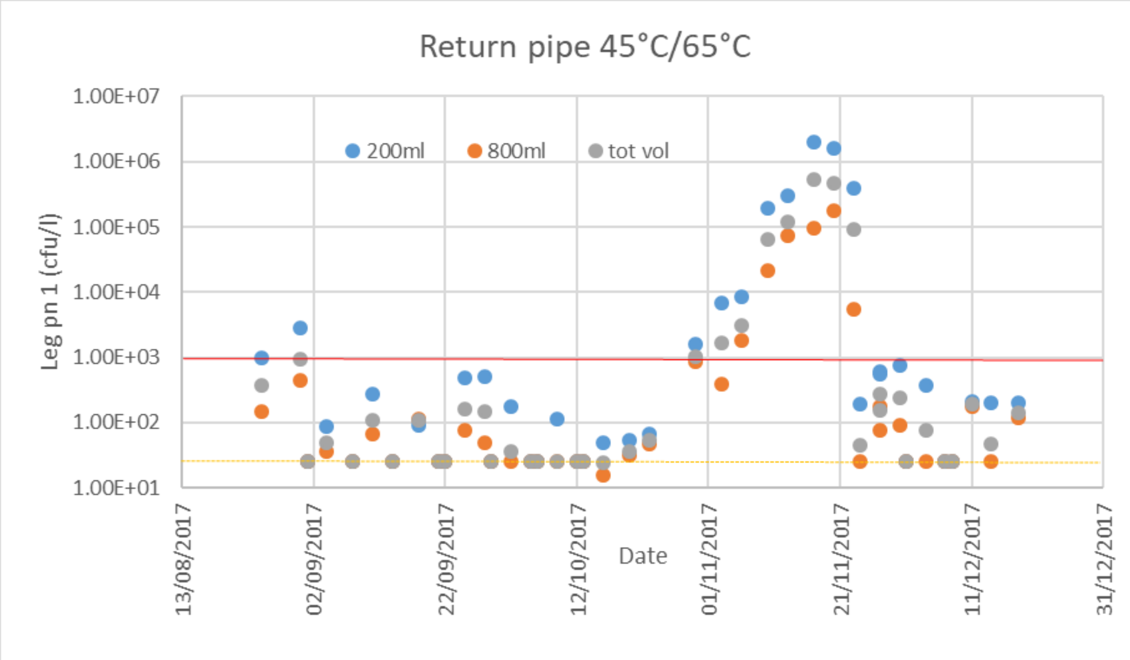

Figure 2B: Concentration of Legionella pneumophila in the first liter, sampled at the return pipe, (sampling 200 ml / 800 ml)

Figure 2A and 2B show the *Legionella* concentrations found in the first 200 ml water sample, in the 800 ml water sample and the *Legionella* concentration recalculated for the total water volume (1000 ml). These results indicate that the first 200 ml contains the highest concentration of *Legionella* bacteria compared to the next 800 ml of water.

3.4 Biofilm sampling

The return pipe contained 20 pieces of PE-x pipe with a surface ~ 20 cm² each. The DHW can flow through this littles pieces and the biofilm can grow on it. Before and after a disinfection shock, a piece of pipe was collected for biofilm analysis. As mentioned in a previous article no correlation was found between the concentration of *Legionella* bacteria in the water of the test facility and the ATP measurements on the pipe sections. The results from the ATP measurements showed that the bacterial flora on the tube was not affected by the different heat chocks [7].

4 Conclusions

Those carrying out risk assessments should understand the factors which lead to the colonization and growth of waterborne pathogens, including *Legionella*, and how these can be prevented or controlled. Those inspecting systems and taking samples should be familiar with all aspects of a water distribution system. The individual nature of each site should be considered.

If periodic sampling and testing for *Legionella* is part of the risk evaluation, a strict sampling plan should be introduced. Routine sampling at specific tap points, conform a specific sampling protocol can lead to results comparable over time and are therefore useful for trend analysis.

Sampling the first liter, directly after opening the tap without any flush, reflects the worst-case scenario. Higher concentrations are detected in the first liter compared with *Legionella* concentrations in the bulk water flow in the system. In our test facility, even the first 200 ml are enough to evaluate the worst-case.

Small volumes of trapped water can contain *Legionella* bacteria. These places should be flushed during thermal disinfection in order to minimize the *Legionella* growth.

Biofilm monitoring and ATP measurements are no valuable alternative for routine *Legionella* sampling and analysis.

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6 Presentation of Author(s)

Karla Dinne is biochemical engineer and head of the laboratory Microbiology and Microparticles 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).	

Investigation of electronic bidet usage in Chinese homes, and comparisons with Japanese usage

Kanako Toyosada (1), Li Xu (2), Mikoto Yamamoto (3)

1. kanako.toyosada@fwu.ac.jp

2. kyoku@arcnex.co.jp

3. 16ue065@mb2.fwu.ac.jp

(1) Associate Professor, Department of Environmental Science, International College of Arts and Science, Fukuoka Women's University, Japan

(2)Student, Department of Environmental Science, International College of Arts and Science, Fukuoka Women's University

(3) Student, Department of Environmental Science, International College of Arts and Science, Fukuoka Women's University

Abstract

In this study, we investigate the usage of electronic bidets in residences in China through a survey, while also comparing hygiene awareness levels in Japan and China.
The results showed that both in China and Japan the ratio of people who did not use an electronic bidet, even though it was installed, was about 40%, and also a tendency was seen that women were not using it more than men. It was found that the usage rate lowered with age in Japan, while in China age had no impact. There was a significant difference observed between countries regarding the reason for not using the electronic bidet at home: most often "not needed" was stated in Japan, but in China it was "sanitary concern".
Regarding the frequency of use of the electronic bidet at home, about 70% of Japanese men and about 60% of Chinese men answered "every time after defecation", showing a similar trend. It was also found that 20% of Japanese women use it every time during menstruation, compared with 6% of Chinese women, indicating Chinese women use the bidet less during menstruation.

Keywords

Electronic bidet, Conditions of usage, China, Questionnaire survey

1 Introduction

According to a consumption trend survey compiled by the Cabinet Office in March 2018, the prevalence of electronic bidets for households with two or more people in Japan is 80.2% [1)]– making it a common fixture in Japan. The electronic bidet seat is a product developed in Japan but, since it was exported by a Japanese company to China, it has also come to be manufactured and sold by Chinese companies and in China is mainly installed in public facilities such as hotels and airports. In residential homes, installation is progressing mainly for the wealthy – while the penetration rate is 80.2% in Japan, in China it is less than 1%. However, with the rise of GDP in China in recent years, the living standard has risen, and the penetration rates of Beijing and Shanghai reached 6% and 8% respectively in 2015[2)].

A previous study in Japan found that 78% of women who visited a urology department used an electronic bidet, and more than 40% used it for unexpected reasons such as "defecation induction" and "post urination"[(3)]. However, there is almost no research on the usage conditions (frequency of use, method) of the electronic bidet. In addition, there are few studies on electronic bidets in the Chinese context.

So, in this research, we investigate the usage conditions of electronic bidets at home in China using a questionnaire survey, and also compare hygiene consciousness in Japan and China.

2 Study methodology

An overview of the home toilet use survey in China is shown in Table 1. The survey was conducted in September 2017 for a total of 60 people in the 20s, 30s and 40s who have electronic bidets in their homes in Liaoning Province, China. In order to sample users – because the penetration rate of electronic bidets is low in China – questionnaires were distributed to visitors of a toilet distributor (one location) in Dalian, China, and filled out and collected immediately. The difference was extracted from Dalian residents of each age group. To inform comparisons between Japan and China, we conducted a questionnaire survey on female university students and their families living in Fukuoka Prefecture aged in their 10s–60s, from August to September 2017 and June to July 2018. We also compared this with data on 262 Japanese people who had electronic bidets installed.

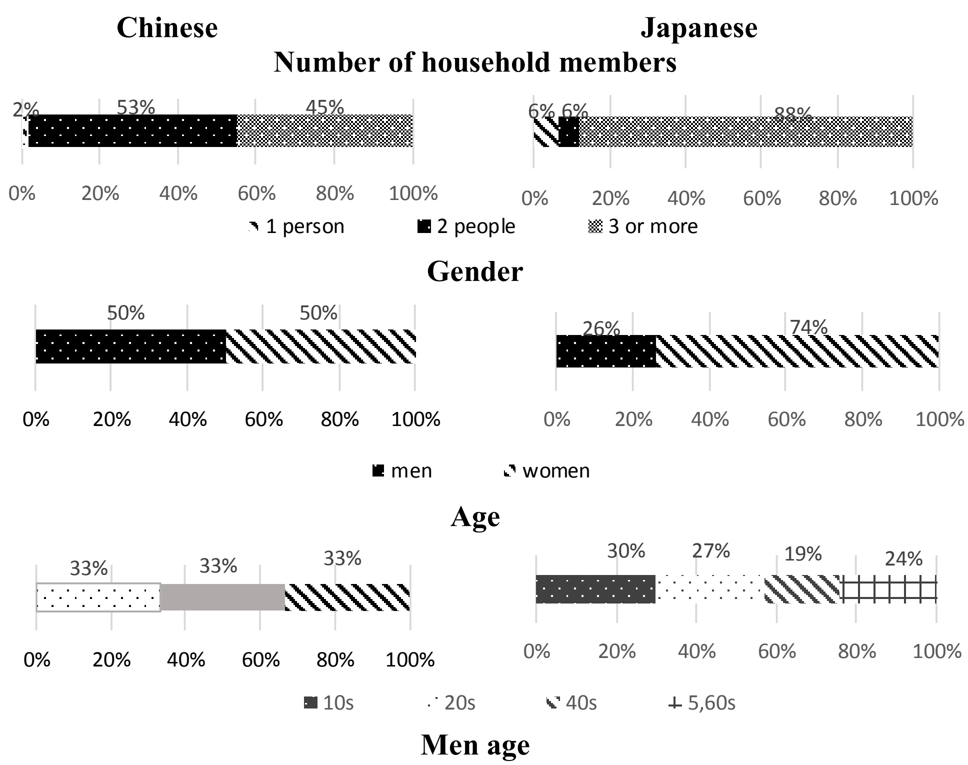
Table 1 Overview of toilet usage study in China

Time period	September 2017
Study focus	A total of 60 men and women in their 20s, 30s, 40s, living in Dalian City, Liaoning Province, China, and have electronic bidets at home.
Survey method	The questionnaire was distributed to 50 visitors to a Dalian toilet distributor (one location) + 10 residents in Dalian. The questionnaire was filled in on the spot and collected.
Survey items	・Respondent attributes (number of residents in the household, gender, age) ・Usage of the electronic bidet at home and any reasons for not using it ・Whether they paid attention to the cleanliness of the toilet seat at home

3 Results and discussion

3.1 Respondents' characteristics

Figure 1 shows the attributes of Chinese and Japanese respondents. Compared to Japan, the ratio of two-person households in China was much higher. In China, 2% were in a 1-person household, 53% in a 2-person and 45% in a 3-person or more household. Although for China, gender and age were equally extracted, the number of female respondents in Japan was greater.



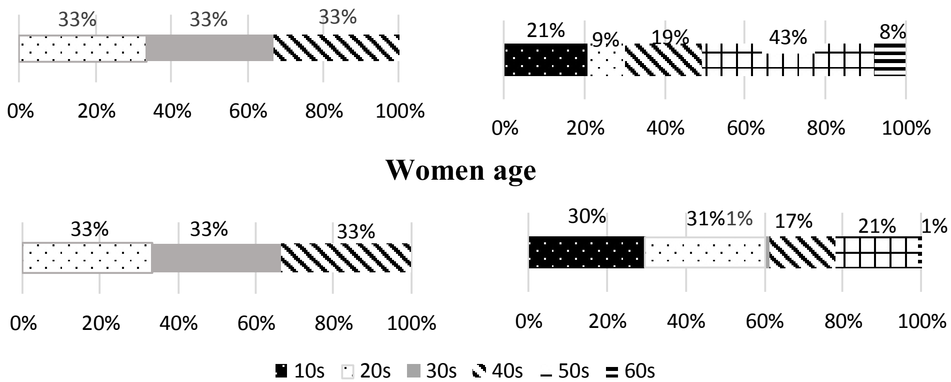


Figure 1 Respondent's attribute

3.2 Usage context of electronic bidets at home

The usage situation of electronic bidets at home in China is shown in Figures 2 and 3 by gender and age. About 60% used the bidets, and the usage rate for men was slightly higher, however, no significant difference was found depending on gender or age. In the statistical significance test in this paper, it was judged that p> 0.05 was not significant and p ≦ 0.05 was significant.

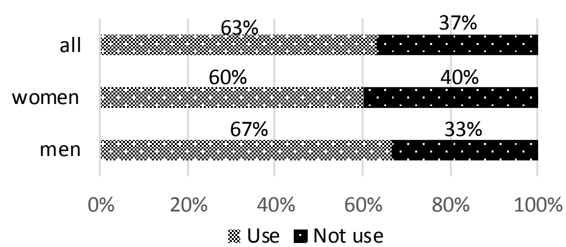


Figure 2 Usage of the electronic bidet at home (by gender)

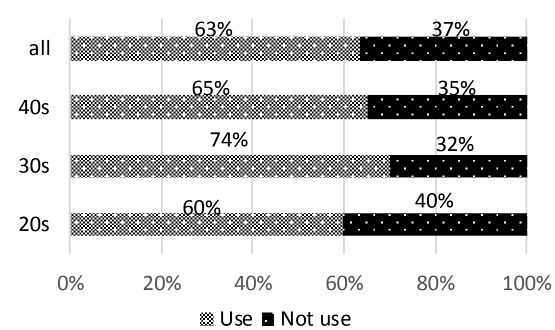


Figure 3 Usage of the electronic bidet at home (by gender)

As shown in Figure 4, it was found that there was no difference in use between the the two countries (Japanese n = 262 people) when the electronic bidet was installed at home.

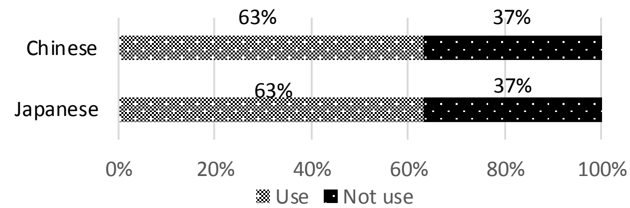


Figure 4 Usage of the electronic bidet at home（Japan-China comparison）

The Chinese people (n = 22 people: 12 women, 10 men) who answered that they do not use the electronic bidet at home were asked about the reason, and the results are shown in Figure 5 according to gender. The response rate for the reason "sanitary concerns" was the highest at 45%, followed by "unnecessary" and "paper is wasted". From the perspective of gender, about 60% of women answered that they had "sanitary concerns" and tended to worry more about sanitation than men. Men were more likely than women to answer "unnecessary" and "bothered by the start-up sound”. In the significant difference test, there were no significant differences by gender. The results analyzed by age are shown in Figure 6. The response rate for "sanitary concern" was 20% for those in their 20s, 50% for 30s, 70% for 40's, and the answer rate for "sanitary concern" increased with age. Thirty-three percent of people in their twenties and thirties answered that usage of the electronic bidet was unnecessary. In the significant difference test, there were no significant differences by age.

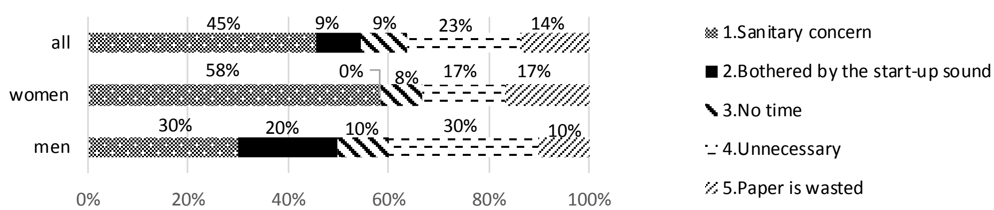


Figure 5 The reason for not using the electronic bidet at home (by gender)

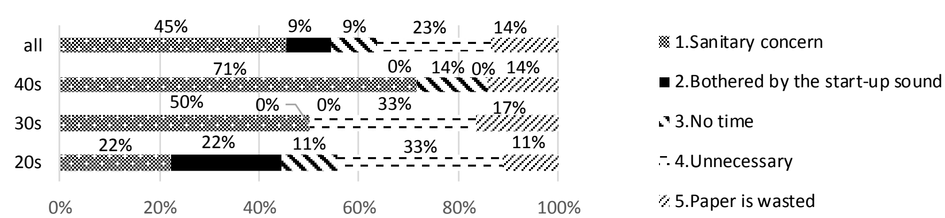


Figure 6 The reason for not using the electronic bidet at home (by age)

The comparison with the Japanese respondents who answered that they do not use the electronic bidet (n = 98 people) at home is shown in Figure 7. In the Japanese context, 74% stated that the reason for not using it was that it was “unnecessary”, while 21% answered “sanitary concern”. On the other hand, in China, “sanitary concern” was the highest at about 50%. China alone had responses of “paper is wasted” (15%) and “bothered by the start-up sound” (10%). The result of the significant difference test was $p < 0.001$, and significant differences were recognized among countries.

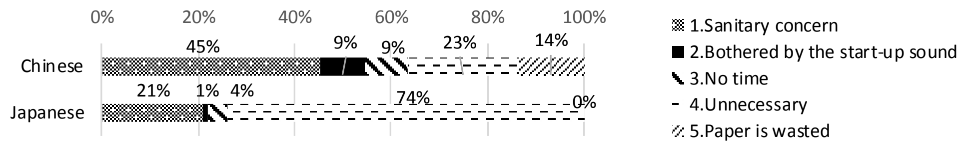


Figure 7 The reason for not using the electronic bidet at home （Japan-China comparison）

3.3 Consciousness of cleanliness of the home electronic bidet

Figure 8 shows the Chinese respondents’ responses about their consciousness of the home toilet seat’s cleanliness. About 60% of the respondents said that they would “just sit down on the toilet seat”, 20% would “wipe it with paper”, 10% would “wipe it with a sanitization sheet”, and 10% would “spread it with paper”. In the significant difference test, no significant difference was found between genders. The analysis results by age are shown in Figure 9. The smallest number of respondents who answered “just sit down on the toilet seat” were in their 20s, and those in their 20s tended to be concerned about the cleanliness of the toilet seat at home. About 30% in their 20s and 40s, and 5% in their 30s, answered “wipe with paper”. In the significant difference test, there were no significant differences by age.

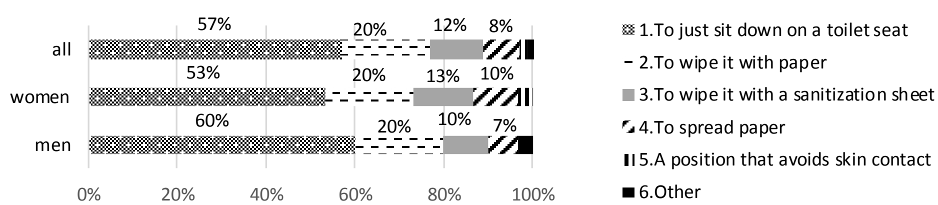


Figure 8 Awareness of the home toilet seat's cleanliness (by gender)

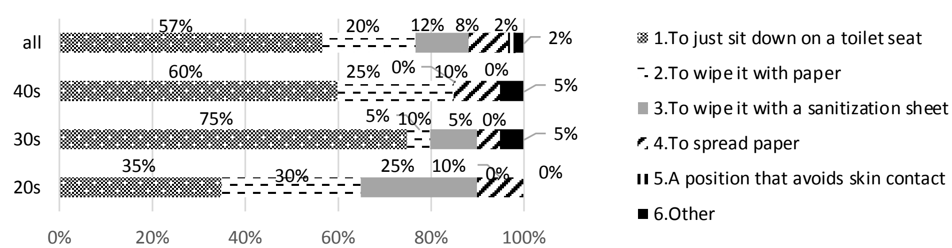


Figure 9 Awareness of the home toilet seat's cleanliness (by age)

The comparison with the Japanese respondents who have an electronic bidet installed (n = 262 people) at home is shown in Figure 10. About 90% of the Japanese respondents "just sit down on the toilet seat" at home, suggesting in Japan it was used without worrying too much about the cleanliness of the toilet seat at home. On the other hand, in China, 60% said they would “just sit down on the toilet seat” and 20% said “wipe with paper” and 10% said “wipe with a sanitization sheet”. It emerged that Chinese people are more conscious of the cleanliness of the toilet seat at home. The result of the significant difference test was p <0.001, and significant differences were recognized between countries.

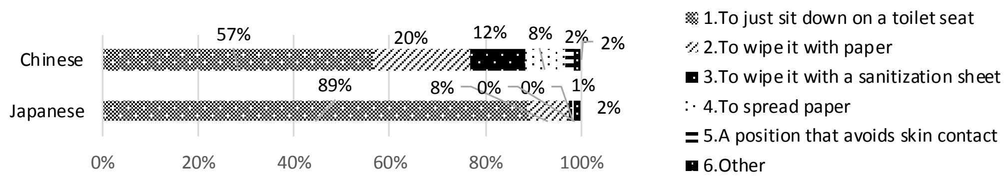


Figure 10 Awareness of the home toilet seat's cleanliness (Japan-China comparison)

3.4 Frequency of electronic bidet use at home

The frequency of use of the electronic bidet at home is shown in Figure 11. “Every time after defecation” was the highest with 60%, and 30% answered that they did not use it. Seventy-three percent of men answered “every time after defecation” and 7% answered "sometimes after defecation”. Additionally, it was found that all, except for those who did not use it, used the electronic bidet only following excretions. Thirteen percent of women answered “every time for defecation and urination”, 44% for “every time after defecation”, 34% for “don't use”, and 6% (two people) for “sometimes during menstruation” (for women only). The analysis results by age are shown in Figure 12. The respondents who answered “every time after defecation” were mainly in their 20s and 40s. The female respondents who answered “sometimes during menstruation” (Figure 11) were in their 30s.

The comparison of results regarding the frequency of use of the electronic bidet at home is shown in Figure 13. About 70% of Japanese men and about 60% of Chinese men answered "every time after defecation". For women during menstruation, about 20% of Japanese women use it compared to 6% of Chinese women.

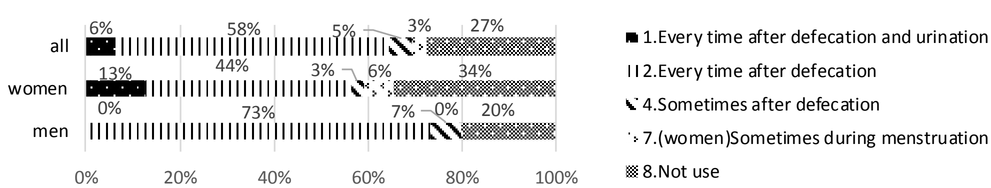


Figure 11 The frequency of use of the electronic bidet at home (gender)

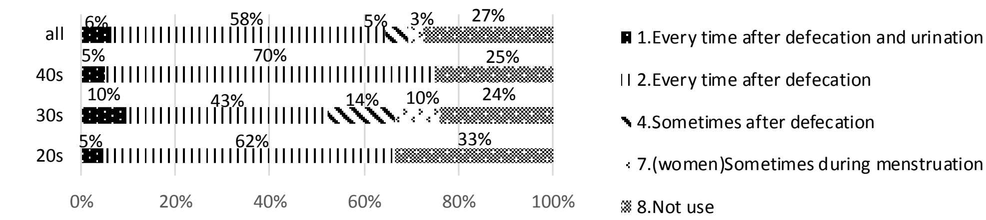


Figure 12 The frequency of use of the electronic bidet at home (age/multiple answers)

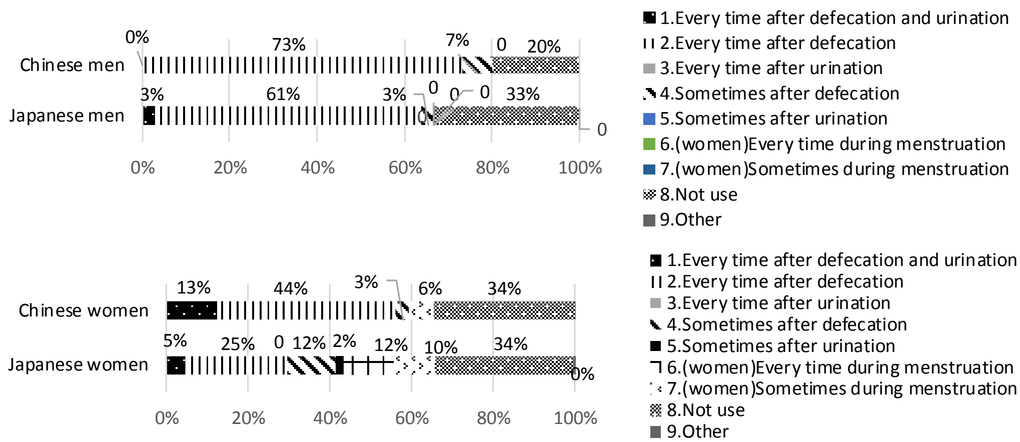


Figure 13 The frequency of use of the electronic bidet at home （Japan-China gender comparison）

4 Conclusion

In this research, while investigating the conditions of electronic bidet usage in Chinese homes, we compared Japan and China with regard to consciousness about hygiene. As a result, both in China and Japan, even with an electronic bidet installed, about 40% did not use it. Also, the tendency was seen that women were using it less. The reason for not using the electronic bidet at home was most often "unnecessary" in Japan but, in China, "sanitary concern" was the most common response. Statistically significant differences between the countries were observed. Regarding the frequency of use of the electronic bidet at home, for men, about 70% of Japanese and about 60% of Chinese answered "every time after defecation", and the trend was the same. For women, about 20% of Japanese respondents used it every time during menstruation, compared with 6% of Chinese women, who used the electronic bidet much less during menstruation.

Acknowledgments

This research was conducted as a joint research project with TOTO Ltd. To Mr Sato, Mr Amemori and others, and TOTO Ltd. colleagues, thank you very much.

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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.

Li Xu is a Student at the Department of Environmental Science, International College of Arts and Science, Fukuoka Women's University.

Mikoto Yamamoto is a Student at the Department of Environmental Science, International College of Arts and Science, Fukuoka Women's University.

- Reduce the risk of circulated hot water returning at a temperature which promotes pathogen growth

Robert Hardgrove
robert.hardgrove@viega.com.au
Technical Manager for Viega Australia Pty Ltd

Abstract

Introduction and aims: Even when the best design and installation practices have been adopted for the circulation of potable hot water under certain conditions, a pipework system can still be a breeding ground for opportunistic waterborne pathogens in the form of Bacteria, Viruses, Protozoa & Helminths, which can be passed onto humans via ingestion (drinking), inhalation/aspiration (aerosol) and contact (bathing). These pathogens' ideal living conditions are at temperatures, which are similar to our body temperature and our ideal shower and bath temperature.

When designing a conventional hot water circulation system, the supply water typically exits from the boiler at 60°C. For the returning water, the design parameter is to keep $\Delta\vartheta$ at 5°C, which is calculated at the point of return to the boiler (when the water enters the return line) or when the returning water re-enters the boiler. If $\Delta\vartheta$ is 5°C, at the point of return, it will be 55°C but will continue to drop as it returns to the boiler. This means that the water will be in the critical pathogen growth range. If the system is designed with the water returning to the boiler at $\Delta\vartheta$ =5°C, there is still a risk that the water drops below 55°C when there is demand for hot water from the connected fixtures, or the design calculation didn't quite match the reality.

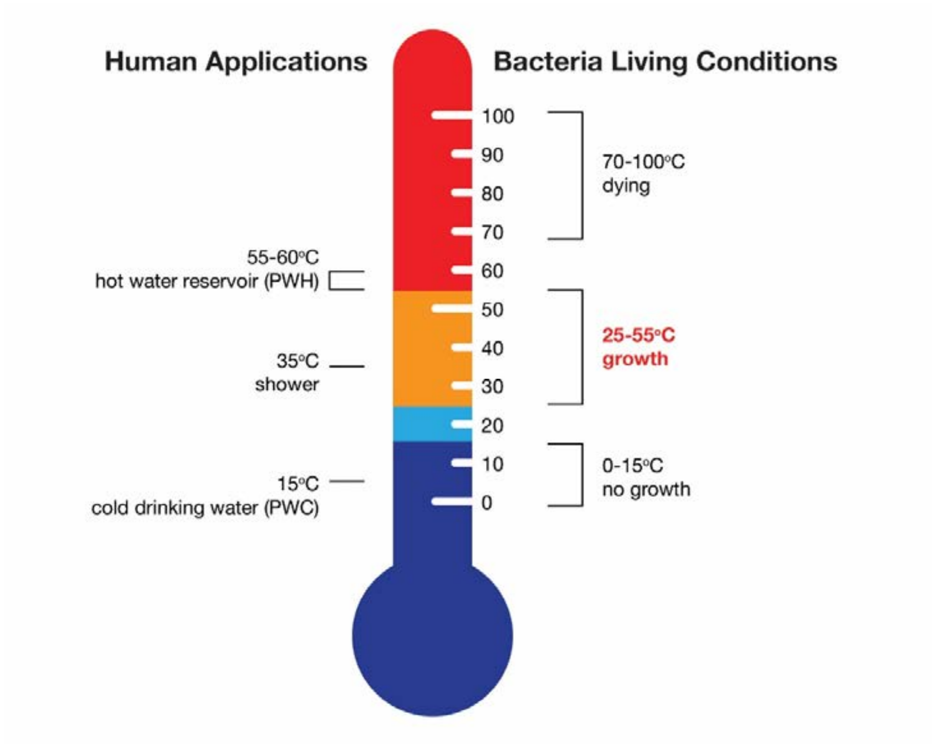
Method: With the one-pipe principal of Smartloop inliner technology, flow and return lines are combined into one pipe. A separate pipe for the circulation water is not required. The Viega Smartloop inliner system provides a way of maintaining the temperature of the returning water by preheating it. This is achieved by transferring energy from the supply line to the returning inliner, which is a pipe within a pipe.

Results: Water in the whole Smartloop inliner system is kept above 55°C, the lowest water temperature at the point of return. The returning water will continue to receive energy from the supply line even when the fixtures are in use and the returning water

is barely moving. This also allows thermostatic valves to be utilised, so when there are multiple risers, the inactive risers can draw more circulating water, while all the water in the system stays above 55°C. Other benefits of this type of design are installation costs, space savings by only having one pipe and energy savings due to the 30-40% lower heat radiation losses.

Maintaining hot water in circulation systems

The world is becoming increasingly aware of the dangers of inadequate water hygiene in potable water installations. As more research is undertaken following reported events, it is becoming clear that more can be done in this area of design.
The graphic below shows the importance of maintain hot water at a temperature above 55°C or below 25°C to avoid bacterial growth. Unfortunately, a human's body temperature is right in the middle of this temperature range, which is the ideal temperature for water borne pathogens. This is why it is important to maintain hot water circulation systems above 55°C

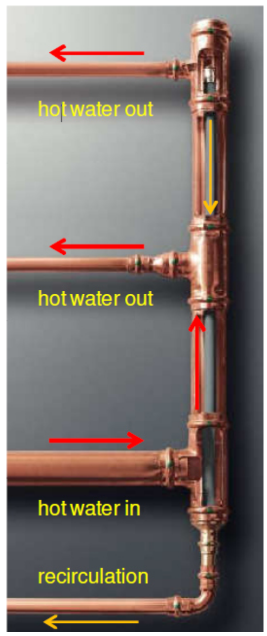


Normally, with a central hot water circulation system, the circulation pipe (return line) is installed in the riser duct parallel to the hot water feed pipe (flow line). The circulating water exiting the boiler starts losing temperature from the moment it leaves the boiler until it reaches its lowest point as it re-enters the boiler. If the temperature gets below 55°C, water borne pathogens are in an environment where growth can occur.

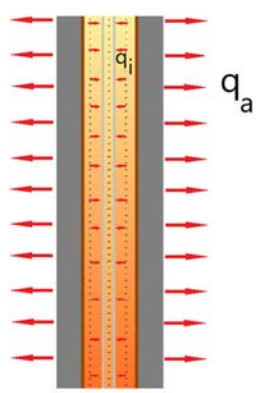
An alternative solution is to provide energy to the returning water and reduce the energy losses of the system. This can be achieved with the Viega Smartloop technology.

Viega Smartloop technology

The Smartloop system is essentially a pipe within a pipe that consists of plastic circulation pipe (return line) within a metallic feed pipe (flow line).



The below drawing illustrates how energy is transferred from the flow line in a Smartloop system. It is primarily lost to the surrounding ambient air (q_a) as would typically occur with a conventional flow line, but is also transferred to the returning inliner pipe (q_i).



The following formula shows how energy is transferred from the flow line;

$$q = q_a + q_i \quad \text{[W/m]}$$

q_a Heat loss from the ambient air
q_i Heat loss from the returning inliner pipe.

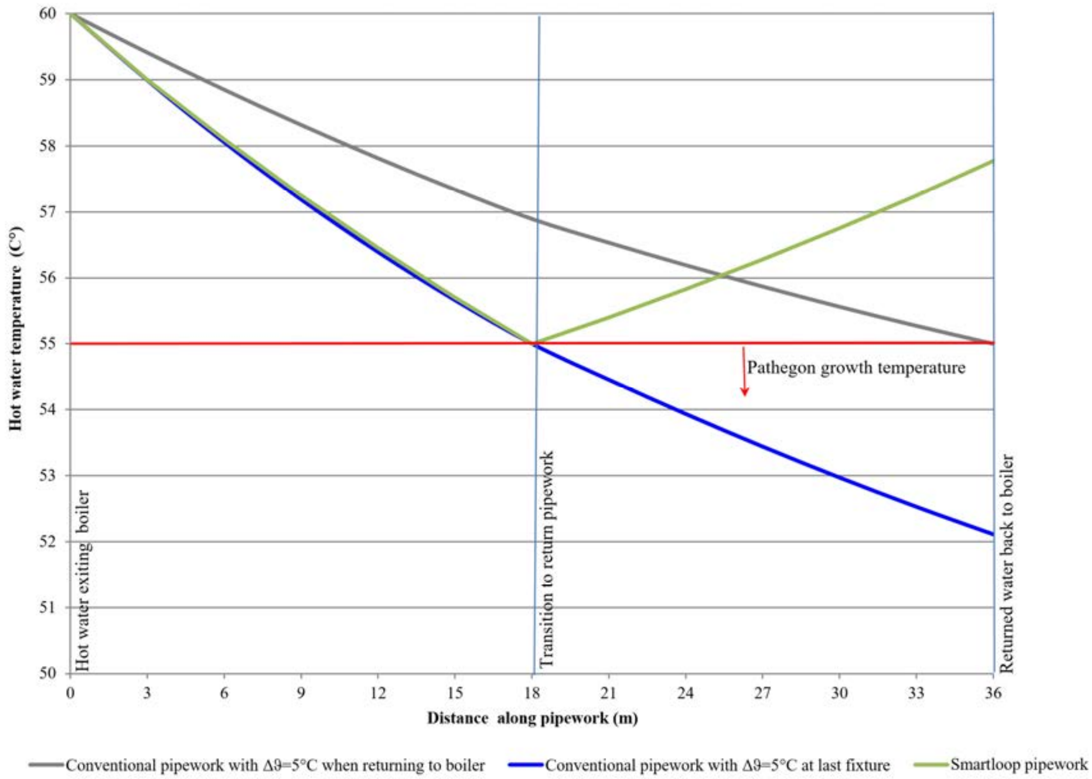
The benefit of this design is that there is only the one pipe that is losing heat to the surrounding ambient air, instead of a conventional circulated hot water system, where a second separate pipe is used for the return line. The Smartloop system has a potential energy saving of 20-30% with less radiant energy loss.

The energy that is transferred to the inliner pipe (return line) is not lost but instead used to preheat the returning water. The lowest temperature in the riser is therefore at the furthest point from the boiler, where the circulating water moves from the flow line to the return line. The returning water rises in temperature and comfortability staying out of the pathogen growth range (below 55°C)

Conventional flow and return pipework vs. Smartloop

In contrast to conventional circulation, the lowest system temperature with Smartloop inliner technology is not at the re-entry to the boiler tank, but at the point of return before the circulating water in the inliner is pre-heated.

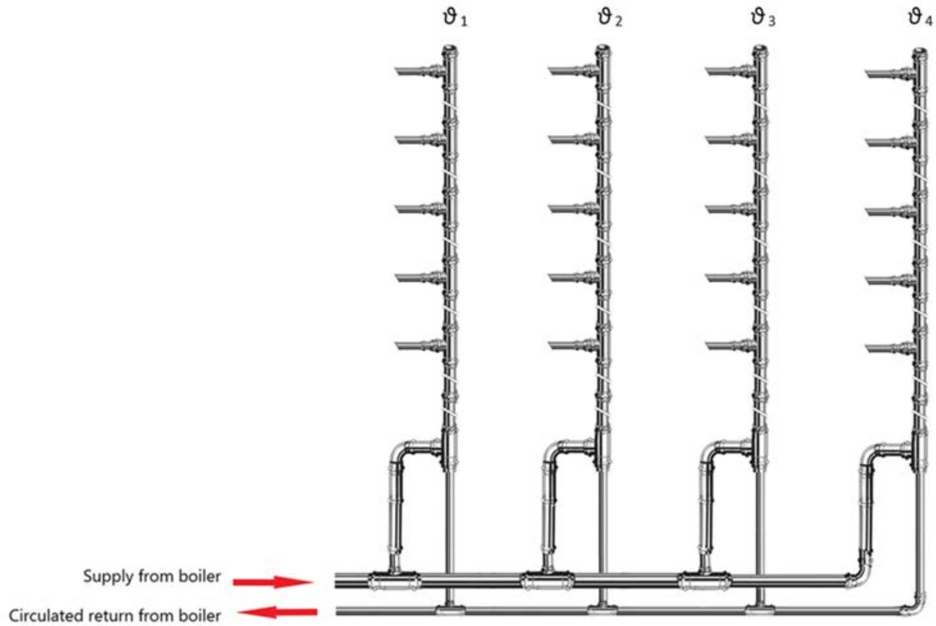
The below graph shows how conventional flow and return pipework continues to lose temperature as the water returns to the boiler, where all of the return pipework is below 55 °C and therefore a potential area for biofilms to develop. In contrast, the water temperature of the water in the Smartloop pipework increases as it returns to the boiler.



The trade-off between conventional pipework and a Smartloop system, is that a Smartloop system requires higher flow rates for the circulated water, but has approximately half of the temperature loses ($\Delta\vartheta$) when it returns to the boiler, which provide energy savings.

Ensuring multiple riser systems maintain hot water above 55°C

One of the problems of feeding multiple risers from the one boiler is the differential pressures for each riser due to pressure losses in the system. This would lead to high circulation at the riser closest to the boiler and incrementally lower circulation for risers further away from the boiler. The outcome would be much higher temperature for ϑ_1 where there is high-circulated flows, but a lower temperature for ϑ_4. This is an unbalance system, which is inefficient but most importantly allows parts of the system to fall below 55°C.



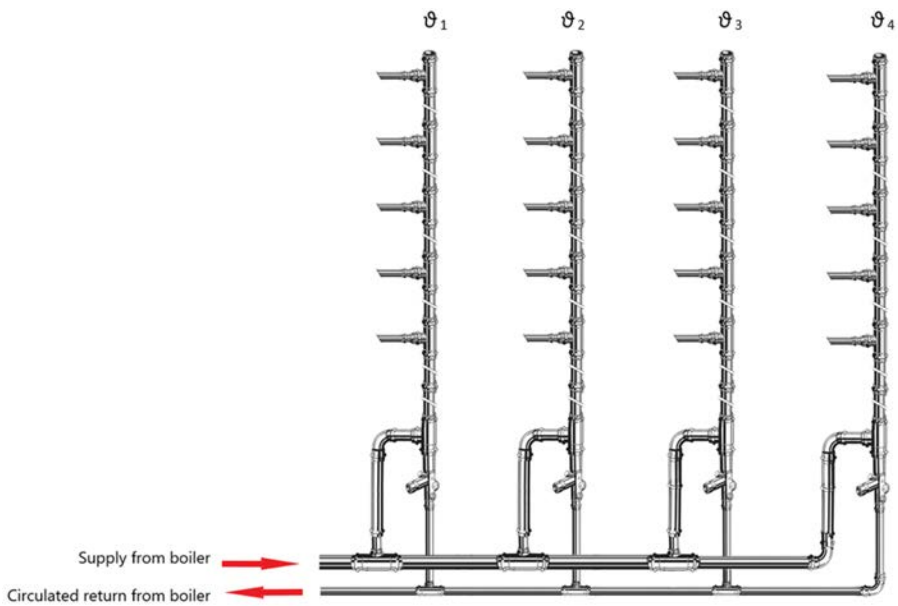
Hydraulic balancing valves

If circulation systems for potable hot water are configured with several risers, the flows must be hydraulically balanced in such a way that the target temperatures are achieved and maintained in all sections during normal operation. When a system is not balanced, the primary function of delivering hot water to all of the fixtures (showers, basins, sinks etc.) in the desired time will not be achieved and individual sections of piping will have temperatures outside the hygienically acceptable operating range for long periods. These are regarded as the decisive risk scenarios for waterborne pathogens propagation in a system, with the associated risks for potable water quality. The best way to avoid this is with the use of hydraulic balancing valves such as the Viega thermostatic regulation valves as shown below in pic.1.

pic.1 - Viega thermostatic regulation valve

Viega thermostatic regulating valves allow flows of circulation water to be prioritised to the risers that need the flows the most. The control of the thermostatic regulating valve is provided by a temperature sensitive element and spring mechanism, which reacts to temperature changes of water in the circulation loop. If the actual water temperature deviates below the pre-set target value, the flow rate increases as the mechanism lifts up and opens the valve. As the temperature increases, the thermostatic valves progressively closes thus regulating the water temperature. For hygienic reasons, it never closes completely. This also allows accurate reading of the circulated water temperature. The hydraulic/thermal compensation has occurred when the target and actual value are the same.

In the case of multi-riser designs, prioritising the circulating water to the risers that need it the most is achieved by thermostatic regulation valve which, balance the system and maintain the same set point temperature for ϑ_1, ϑ_2, ϑ_3 & ϑ_4



Author

Robert Hardgrove studied a Bachelor of Engineering at the University of Sydney and was at the forefront of the introduction of copper press-fit to Australia. He has spent the last 15 years working with Product Management at Viega's German headquarters, assessing heating and plumbing practices in Australia and possible solutions that Viega could provide through new and existing products. The Viega Smartloop system and the Viega thermostatic regulation valve are two new products for Australia that are part of a broader portfolio of products to support water hygiene in potable water installations.

From refugee camp to city; Zaatari primary school project

Hana Nekrep (1), Matjaž Nekrep Perc (2)
1. hana.nekrep@gmail.com
2. matjaz.nekrep@um.si

(1) Kottkamp + Schneider Architekten, Stuttgart, Germany
(2) Faculty of Civil Engineering, Transportation Engineering and Architecture, University of Maribor, Slovenia

Abstract

The refugee camp Zaatari was created as a result of more than seven years-long civil war in Syria. The camp is rapidly evolving from the crowd of tents and caravans, into a real city (Ledwith, 2014). Syrian families are abundant in closely related, many children were born in the camp, and it is the only home they know. Therefore, Zaatari is also called the City of children. There was a need for improved public infrastructure, which is not intended only for the basic needs of survival, but quality accommodation. For a permanent stay in the better future of the inhabitants, a better-quality architecture is needed, no longer a temporary crisis one (Jordan, 2012). It is necessary to regulate public space, build a new school in and large family homes (Howayek, 2015). Our vision is to create a permanent, sustainable architecture that covers the needs of the inhabitants in the appropriate culture frame and serve the needs of the users.
Moreover, to protect inhabitants against the climatic conditions of the desert's edge, in which the camp stands. Spatial data and analyses of camp rapid development and expansion were studied through time series of satellite images provided by UNISAT with UNITAR-United Nations Institute for Training and Research as their source from 2012 until nowadays(UNITAR, 2019). On the case study of the primary school, we introduce a sustainable architecture based on local tradition with natural ventilation, on situ materials and water preservation is presented. Rainwater from whole building area is collected and stored in the basement basin for watering greenery and maintain the climate in the building through passive cooling. Greywater is collected, processed and reused for toilet flushing and watering greenery too.

Keywords

Sustainable construction, water conservation, Zaatari, refugee camp

1 Development of the camp

Expansion of the camp Zaatari studied through time series of satellite images provided by UNISAT with UNITAR-United Nations Institute for Training and Research as their source from 2012 until nowadays (UNITAR, 2019). On **Figure1 (left)** we can see the aerial footage of Zaatari refugee camp only a good month after opening on July 28, 2012. On September 3, 2012, the main street Al Souq is clearly visible and densely installed shelters. The camp has almost **5,000** tents and **400** infrastructure facilities on an area of 0.84 km2. The area increases significantly from **0.84 km2** to **3.14 km2** until 3 January 2013 (**Figure 1 right**). On that date UNITAR's (UNISAT) satellite imagery detected **12,000** shelters and **866** infrastructure facilities.

Figure 1 The aerial footage of Zaatari refugee camp on September 3, 2012 (left) and on 3 January 2013 (right)

On February 26, 2013, we can see that the area is divided into districts, the boundaries of the area where the camp can be expanded. New shelters are caravans instead of tents. The main streets and roads Al Souq, Al Yasmin and Enab can be seen (**Figure 2 left**). In the year 2013, the camp is spreading fastest, the density in the old part remains crowded as we can see on aerial view on July 10, 2013 (**Figure 2 right)**.

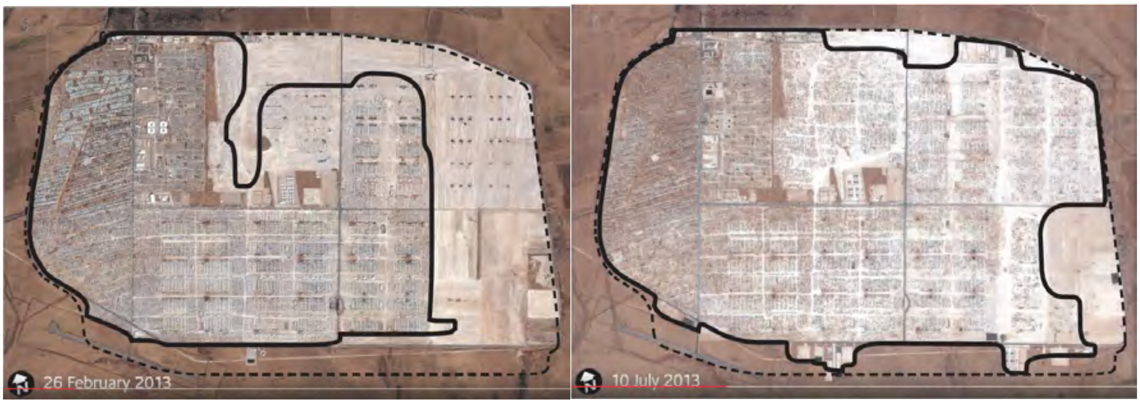


Figure 2. Aerial view of February 26, 2013 (left) and on July 10, 2013 (right).

The camp Zaater reached it final shape in the year 2014 as we can see from aerial view taken on July 6, 2014 (**Figure 3**). There were **31,280** shelters and **1,776** infrastructure and support buildings in the area of **5.34 km2**.

Figure 3. Aerial view on July 6, 2014 with UNISAT satellite.

Zaatari has currently 78,994 inhabitant (Irene Omondi, 2019), 57% of them are younger than 24 years and 19.9% younger than five years. They are living in 24000 self-modified prefabricated caravans. There is a need for at least 3000 m3 of drinking water per day. Twenty-nine schools are serving 21,405 school-aged children enrolled. The most densely populated is the oldest part of the camp (**Figure 4, Figure 5**).

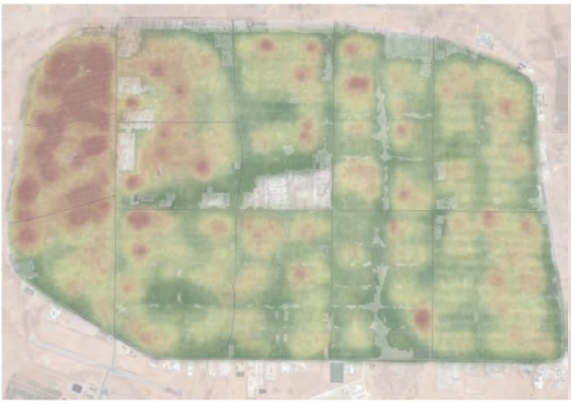


Figure 4– Population density

Figure 5– Morphological analysis

Zaatari's population peaked in April 2013 at a size of over 200,000; from mid-2012 through mid-2013 Zaatari received as many as 3,000 to 4,000 refugees per night (Ledwith, 2014) .

2 From camp to the city

Formal structure of refugee camp based on rows and columns has been soon modified into more organic, liveable form (**Figure 6)** and inhabitants self-initiated added elements like roofs, tents, fences and even gardens to their homes (**Figure 7)** and our wish was to upgrade that to contemporary sustainable architecture based on local tradition and long last knowledge of survival with lack of resources in unpleasant climate (**Figure 8**).

Figure 6– Population density

Figure 7 – Courtyard in Zaatari

Figure 8 – Development of idea

3 Zaatari primary school project

The refugee camp Zaatari was created as a result of more than seven years-long civil war in Syria. The camp is rapidly evolving from the crowd of tents and caravans, into a real city (Nabil et al., 2018). Syrian families are abundant in closely related, and many children were born in the camp, and it is the only home they know. Therefore Zaatari is also called the City of the children. There was a need for improved public infrastructure, which is not intended only for the basic needs of survival, but quality accommodation. Traffic roads have been created with some public transport, and we can also notice electric power lines (**Figure9**)

Figure 9 – Zaid Madi street - traffic

and water reservoirs (**Figure 10)**.

Figure 10 – Zaid Madi street – water reservoirs

For a permanent stay and the better future of the inhabitants, a better quality architecture is needed, no longer a temporary crisis one.
It is necessary to regulate public space, build a new school in and larger family homes. Our vision is to create a permanent, sustainable architecture that covers the needs of the inhabitants in the appropriate culture frame and serve the needs of the users, moreover to protect against the climatic conditions of the desert's edge, in which the camp stands (Milbes, 2014).

3.1 Placing the school

We have analyses positions of the existing school and detected lack of them in the newest areas of the camp (**Figure10**), and we placed our new school in the centre of that area (**Figure 11**).

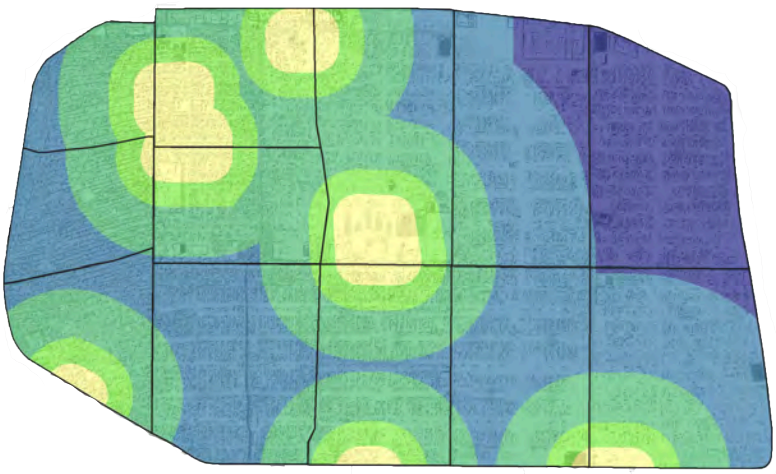


Figure 10– Areas of influence of the existing schools

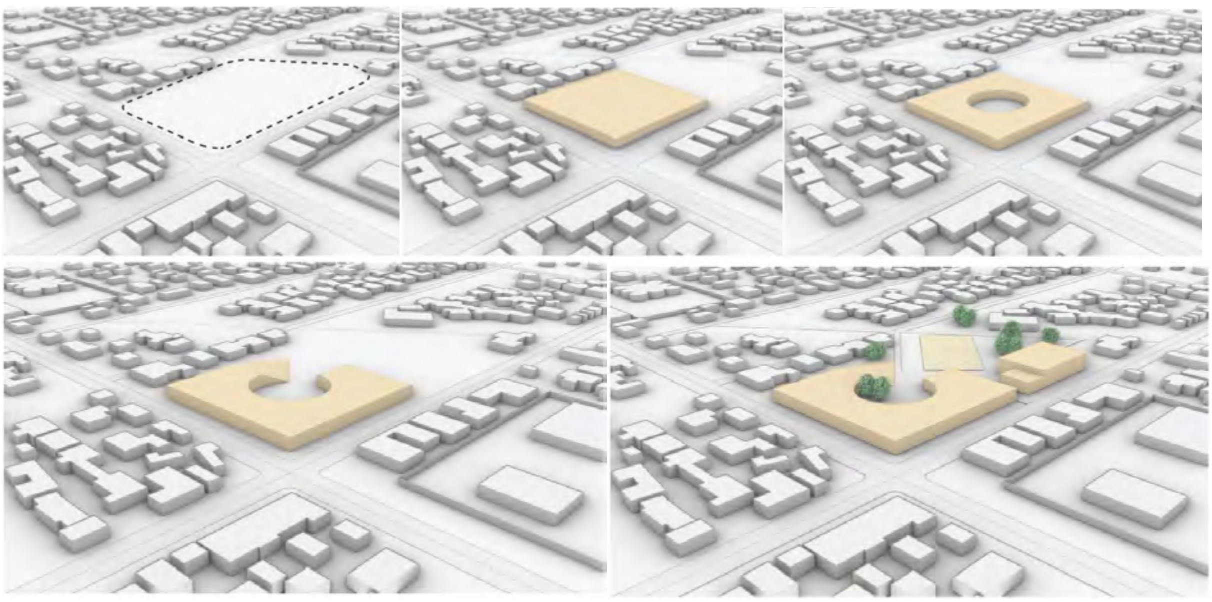


Figure 11– Developing of the solution

3.2 School complex

The school complex consists of a school building with an atrium and green roof, a gym and a school playground. The rest of the land is green. Rainwater is collected from all over the area into the reservoir below the gym (**Figures 12-16**).

Figure 12– Overview of the school complex

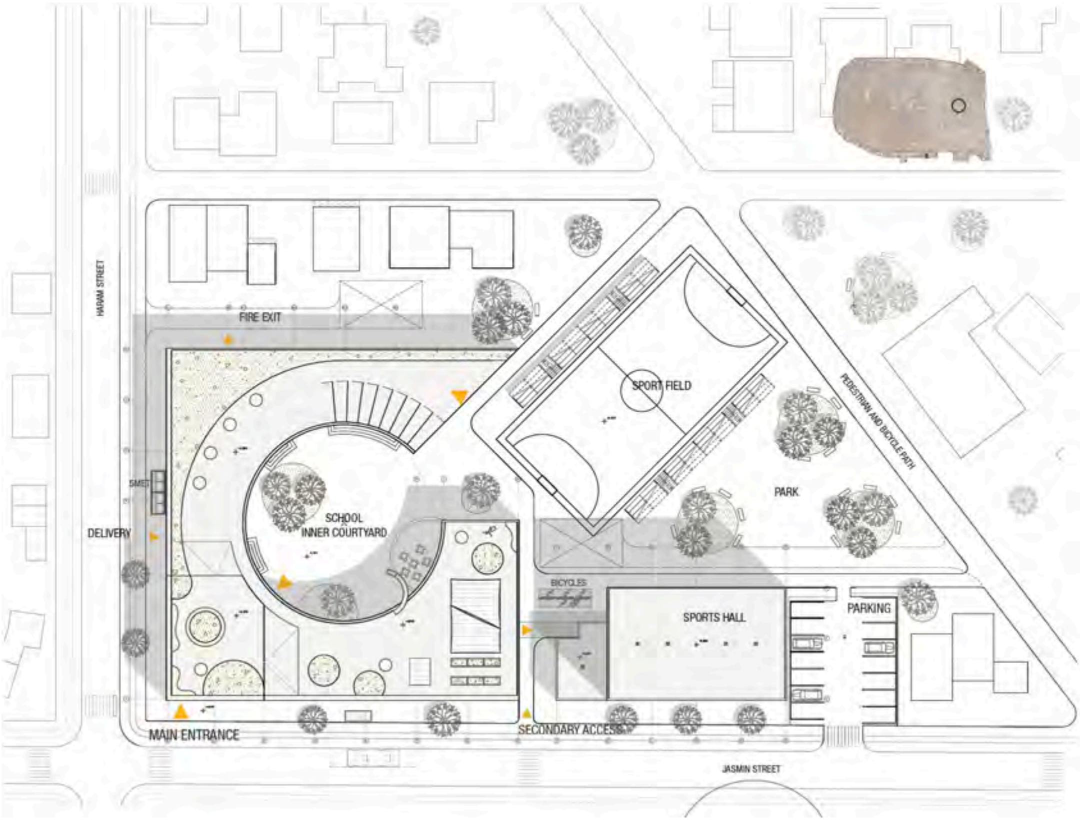


Figure 13– Situation

Figure 14– Class room

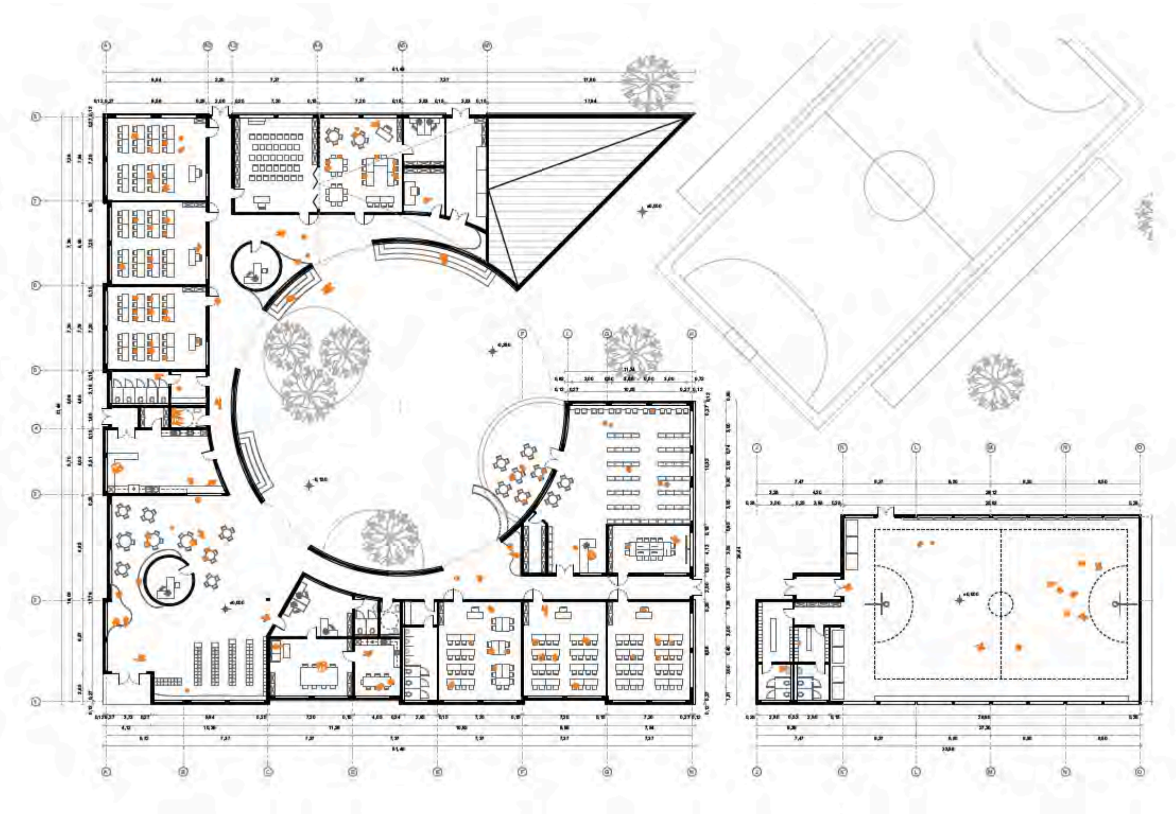


Figure 15– School complex plans

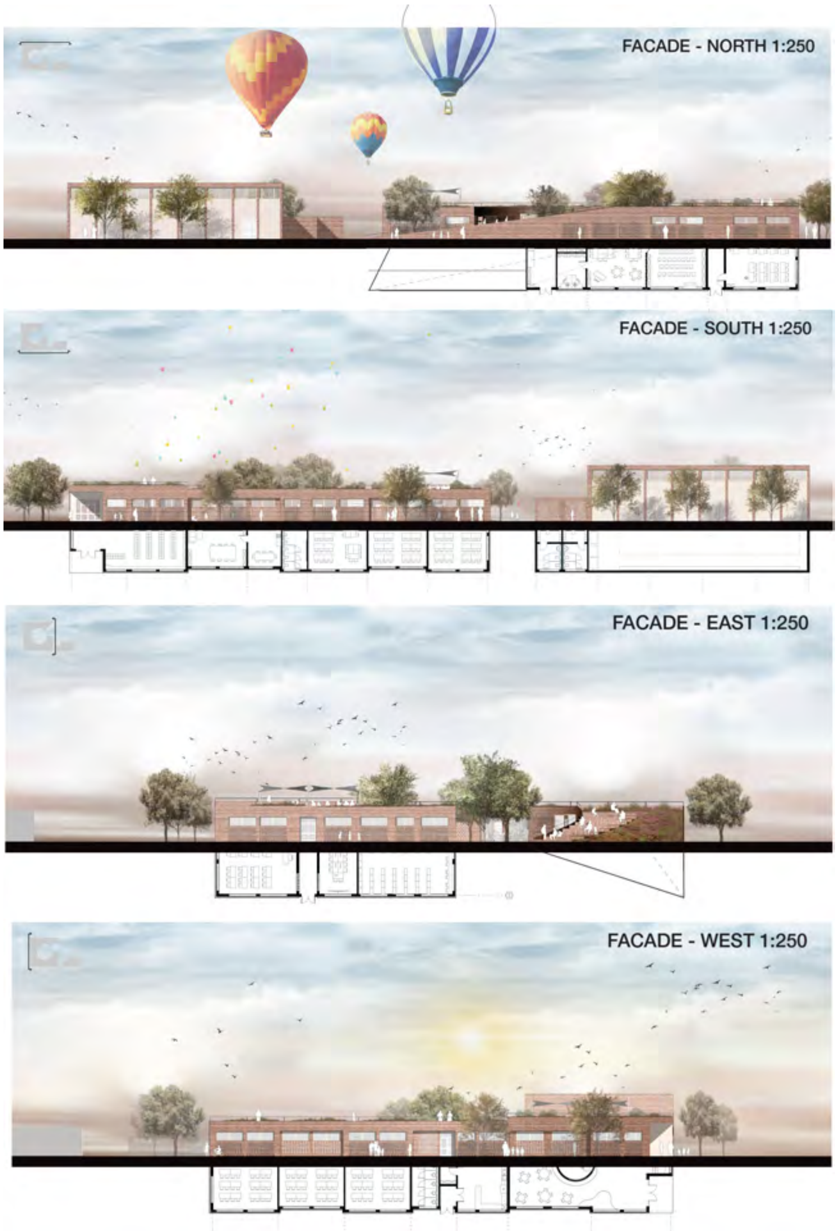


Figure 16– Facades

3.3 Fresh water in Zaatari and our solutions inspired by traditional and sustainable architecture

"Zaatari is one of the largest refugee camps in the world, in one of the most water scarce countries. Since its establishment, drinking water has been trucked to communal facilities. Wastewater has been trucked from these facilities and from self-constructed storages next to households. To improve future sustainability in equitable water and sanitation access, public health conditions, environmental conservation and operational costs, household connected water and sewage networks are implemented. This shift from emergency to sustainable phase benefitted from adaptation of urban infrastructure methods. A shift is necessary from a humanitarian approach toward a structured master planning vision. The planning urban utility perspective is essential for ensuring operational sustainability in the conception of water and sanitation systems in Zaatari refugee camp."(van der Helm et al., 2017) As 35 litres of water is required per person per day, minimum of 2800 m^3 of drinking water per day is needed (Begisheva, 2018). Until 2016 three internal wells have a combined daily capacity of 3800 m^3. Wastewater treatment plant has a capacity of 3600 m^3 per day (UNHCR, 2019).

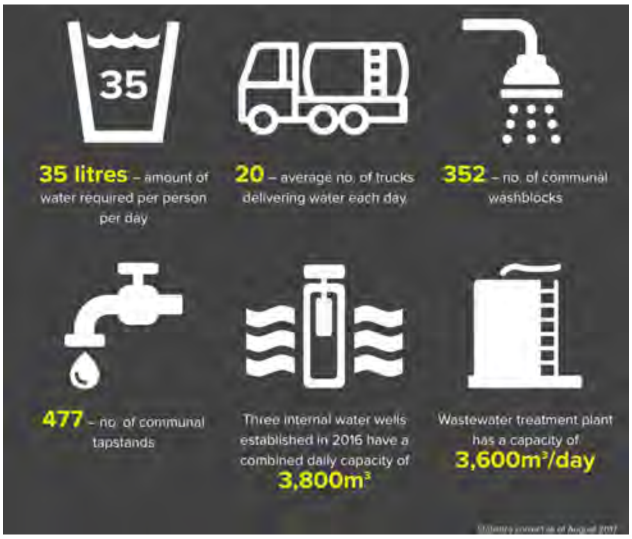


Figure 17– Need for drinking water in the camp (UNHCR, 2019)

Our project is planned self-sufficient in the area of water for flushing and flushing toilets (Nekrep, 2018). We are collecting rain water from the whole area into the basement reservoir of the gym (**Figure 18**) and quantities based on average annual precipitation (World Weather Online, 2019) can be sufficient for that purpose (**Table 1).**

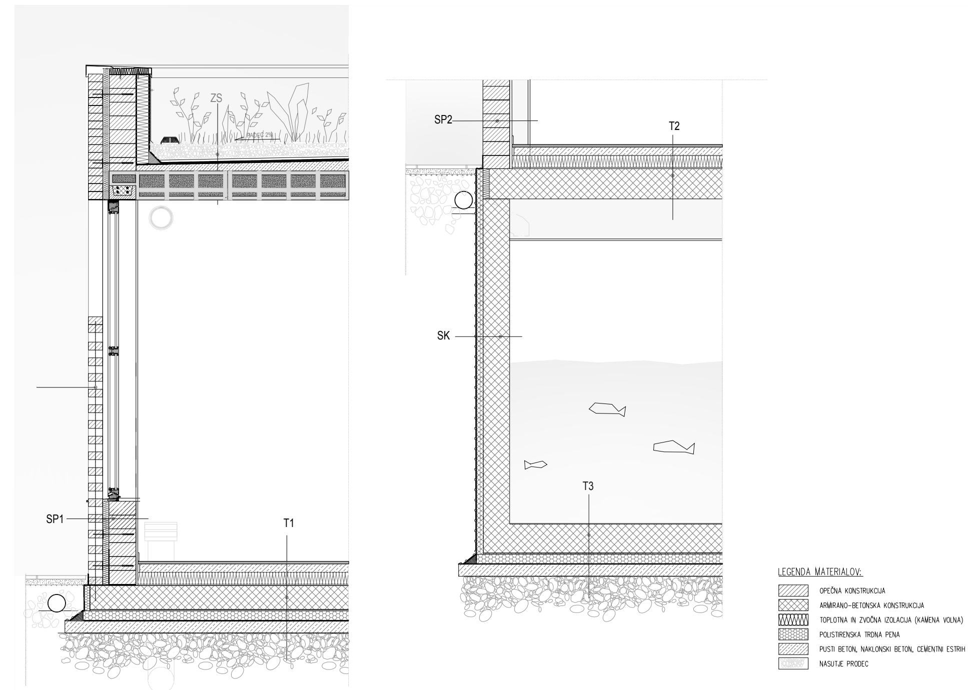


Figure 18– Green roof as a rainwater collecting area and water tank in the basement of the gym

Table 1: Estimated water collection quantities

1. precipitation

Annual precipitation: 200 mm

Collection on the surface: 3000 m2

Annual precipitation collected: 600 m3

2. gray water

250 pupils * 300 days * 20 l / day: 1500 m3

Total collected water: 2100 m3

Watering and flushing water aviable daily: 5.75 m3

4 Conclusion

Camp Zaatari naturally and organically converted from a plain and basic refugee camp into 4th biggest town in Jordan with all (and some more) problems towns have. The most serious where been lack of infrastructure as water supply, drainage an especially schools, as most of the population are young people and children. Unified rows of caravans organically evolve int more human structure, caravans into homes with greenery, courtyards, domestic animals. There was a need for improved public infrastructure, which is not intended only for the basic needs of survival, but quality accommodation. The permanent infrastructure covering all major areas (water supply, drainage, waste water treatment, streets, public transport, energy supply, schools, hospitals, ..) was gradually emerging. Recently, huge solar plant has been built. Syrian families are abundant in closely related, many children were born in the camp, and it is the only home they know. Therefore, Zaatari is also called the City of children. Our vision is to create a permanent, sustainable architecture that covers the needs of the inhabitants in the appropriate culture frame and serve the needs of the users. On the case study of the primary school, we introduce a sustainable architecture based on local tradition with natural ventilation, on situ materials and water preservation is presented. Rainwater from whole building area is collected and stored in the basement basin for watering greenery and maintain the climate in the building through passive cooling. Greywater is collected, processed and reused for toilet flushing and watering greenery too.

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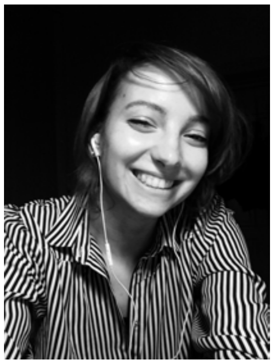
6 Presentation of Authors

Hana Nekrep is an Architect and Illustrator currently working at the Kottkamp + Schneider Architekten, Stuttgart, Germany



Matjaž Nekrep Perc is a Researcher and Senior Lecturer at the Faculty of Civil Engineering, Transportation Engineering and Architecture, University of Maribor, Slovenia

Quantification for food wastes in university canteens

L.T. Wong (1), K.W. Lai (2), K.W. Mui (3)

1. beltw@polyu.edu.hk

2. kai-wing.lai@connect.polyu.hk

3. behorace@polyu.edu.hk

(1), (2), (3) Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

Abstract

Food waste management is one of the crucial global challenges to sustainability. Dewatering food waste is not only a way to reduce waste transportation costs but also a way to decrease carbon footprint. To facilitate efficient and cost-effective food waste collection and recycling on campus, an advanced food waste collection and dewatering system (first in East Asia) has been installed for the catering facilities at The Hong Kong Polytechnic University. The system features a dewatering unit that can remove the water content from food waste and the water content collected will be discharged into the existing building drainage system. In this way, the weight and volume of food waste (and thus the transportation costs) are largely reduced. This paper analyzes the food wastes generated in one of the University canteens in order to determine the collectable food waste, its composition and generation patterns, and the probable amount of wastewater produced. Through a consumer food waste survey, this paper also examines the eating habits of 72 customers. The results reveal that food wastes are dominated by foods that could have been eaten (i.e. plate waste). Findings in this paper provide useful insights into sustainable food production practices and wastewater drainage for food waste collection in buildings.

Keywords

Food waste management, waste water, solid waste separation, catering facilities

1 Introduction

Urban food waste management is a growing global challenge as food waste is one of the major constituents of Municipal Solid Waste (MSW). In Hong Kong, the amount of food waste disposed of at landfills has increased by 22% in the past ten years, accounting for around 34% (3,662 tonnes per day) of the total MSW discarded (EPD, 2018). Reportedly, the arrangements for separating, collecting and transporting food waste were ineffective and the recycling rate of food waste in Hong Kong remained low at about 1% (40 tonnes per day) (EPD, 2018).

According to the European Commission (Thi et al., 2015), food waste can be classified into three categories, namely food loss, unavoidable food waste and avoidable food waste. Food losses take place in the production phase; unavoidable food waste refers to food products lost in the consumption phase (e.g. banana peels, fruit cores, etc.); and avoidable food waste includes products that could have been eaten, but were lost during the consumption phase.

To facilitate efficient and cost-effective food waste collection and recycling on campus, an advanced food waste collection and dewatering system (first in East Asia) has been installed for the catering facilities at The Hong Kong Polytechnic University (Mui et al., 2018). The system features a dewatering unit that can remove the water content from food waste and the water content collected will be discharged into the existing building drainage system. In this way, the weight and volume of food waste (and thus the transportation costs) are largely reduced. This paper analyzes the food wastes generated in one of the University canteens in order to determine the collectable food waste, its composition and generation patterns, and the probable amount of wastewater produced. Through a consumer food waste survey, this paper also examines the eating habits of 72 customers. Findings in this paper provide useful insights into sustainable food production practices and wastewater drainage for food waste collection in buildings.

2 Materials and methods

2.1 Catering facilities

Within the campus, there are 4 canteens (1,620 seats), 3 restaurants (530 seats) and 8 cafe kiosks (536 seats) serving 27,000 students and 5,500 full-time staff members, with an average service level of 12 users per seat. Offering an extensive range of Asian and Western cuisines to suit different needs of the University community, these catering outlets employ the commissary food service system that centralizes food preparation in an off-campus food factory (Høy Engelund et al., 2007; Eriksson et al., 2017). The kitchens on campus receive pre-processed ingredients including peeled vegetables and barbecued meats from the food factory to minimize food waste during the production phase in the kitchens. Items such as rice, noodles and soups are cooked in the kitchens. It should be noted that food wastes from all of the catering outlets are dominated by foods that could have been eaten (i.e. plate waste). In this study, a student canteen located in a catering complex with 520 seats was investigated.

2.2 Food waste quantities

A total of 75 customers (40 males and 35 females) were interviewed and asked to indicate how much food they usually left unfinished on the plates using a percentage scale by Saccares et al. (2012), i.e. <15%, 15%-29%, 30%-49%, 50%-74% and >75%. The respondents were then asked to specify the leftover item(s) at the end of their meals. The percentage scale was verified by interviewee responses to 4 sample cases (before and after food consumption). All responses were tested for normality. Three extreme responses that were more than two standard deviations away from the mean were considered invalid and excluded from subsequent analysis.

The fractional food wastes can be determined by the following expression, where w_m and w_v are the food waste fractions by mass and by volume respectively, α is the customer response value, ω_m is the adjustment constant for the mass and ω_v is the adjustment constant for the volume,

$$w_m, w_v = \alpha + \omega_m, \omega_v; \; w_m, w_v \geq 0 \qquad \ldots (1)$$

The adjustment constants are determined from the average differences between fractional respondent estimates α_m, α_v and actual fractional mass and volume residuals β_m, β_v of the sample cases n presented to the respondents.

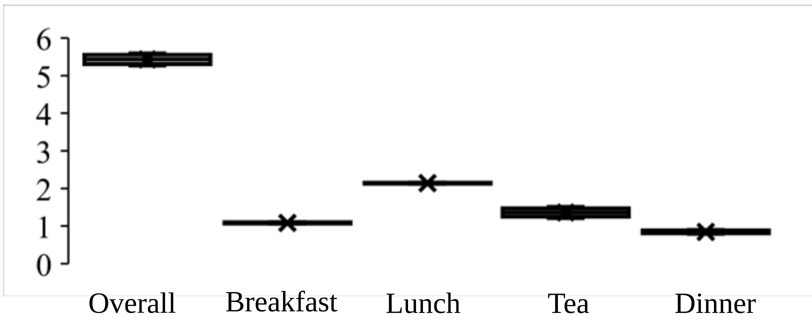
$$\omega_m, \omega_v = \sum(\alpha_m, \alpha_v - \beta_m, \beta_v) / n \qquad \ldots (2)$$

The collected food waste samples were weighted and then dried to calculate the gravimetric and volumetric moisture contents of food residuals. A total of 24 samples of typical food wastes were chosen based on the interviewee responses. Drying procedures were carried out according to AOAC standard protocol (Ahn et al., 2014). Taking x_1 (kg) and y_1 (L) as the mass and volume of the samples before drying with x_2 (kg) and y_2 (L) as those after drying respectively, the fractional gravimetric moisture content v_m and fractional volumetric moisture content v_v of the samples are given by,

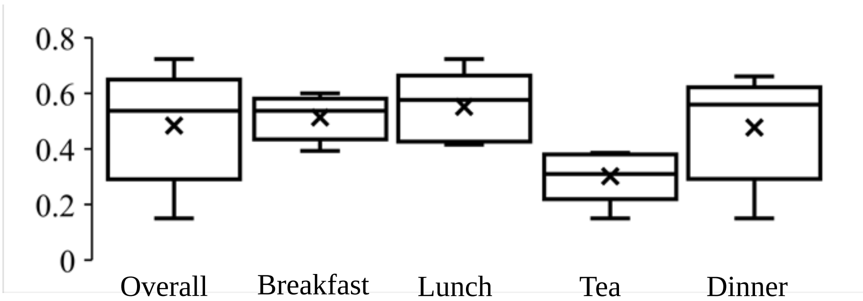
$$v_m = (x_1 - x_2) / x_1; \; v_v = (y_1 - y_2) / y_1 \qquad \ldots (3)$$

3 Results and discussion

Figure 1 shows the attributes of the studied University canteen. The canteen has a seating capacity N_s = 520 seats. It serves fast food items, bakery items, BBQ specialties, Chinese and Western set meals, and beverages. It operates about 12 hours a day and is closed on public holidays. According to the survey results, this canteen served 2,823 (sd=120) users daily: 20%±1.5% (for a 95% confidence interval (CI); sd=2.9%) at breakfast time (0730–1100), 40%±1.8% (for a 95% CI; sd=1.1%) at lunchtime (1100–1430), 25%±1.6% (for a 95% CI; sd=16%) at afternoon tea time (1430–1730) and 15%±1.3% (for a 95% CI; sd=8.7%) at dinner time (1730–2000). On average, it served 5.4 meals per seat daily, with averages of 1.1, 2.1, 1.4 and 0.8 meals at breakfast, lunch, tea and dinner time respectively as shown in Figure 1(a). Figure 1(b) shows the mass of the set meals available in the canteen.



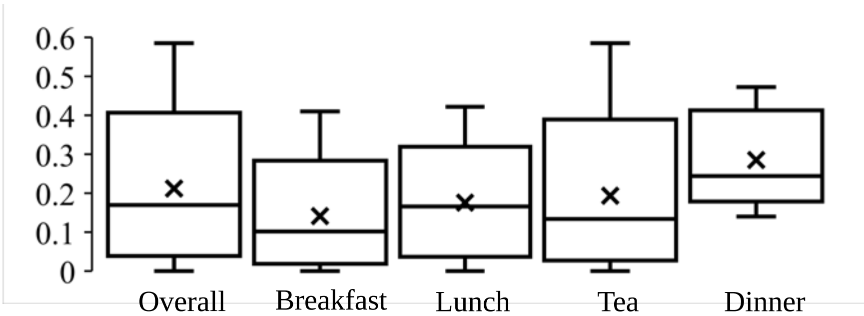
(a) Meals served per seat n_s



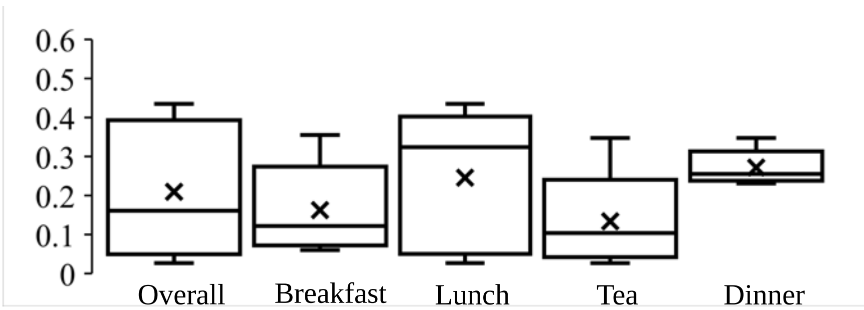
(b) Set meal mass m (kg)

Figure 1. Attributes of a university canteen (520 seats)

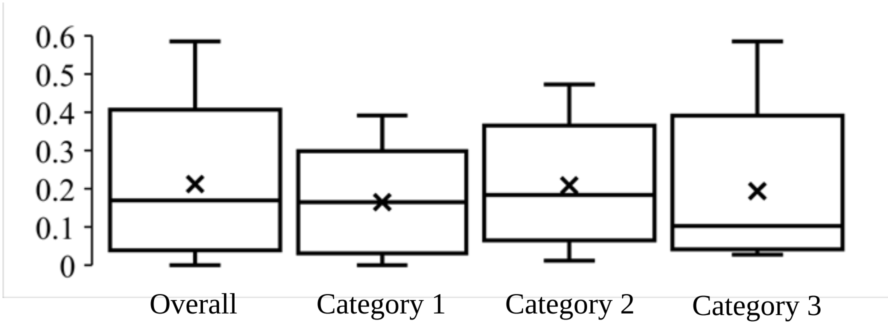
Figure 2 shows the fractional mass food waste w_m and fractional volume food waste w_v during the consumption phase in the canteen. The recorded averages per meal were w_m = 0.13-0.28 (w_m = 0.18 overall) and w_v = 0.15-0.27 (w_v = 0.19 overall).



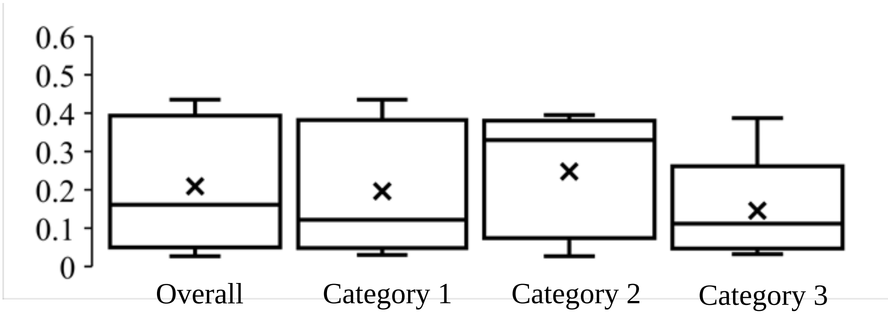
(a) Fractional mass food waste w_m



(b) Fractional volume food waste w_v



(c) Fractional mass food waste w_m



(d) Fractional volume food waste w_v

Figure 2. Fractional quantities of food waste

Food wastes reported by the respondents were classified into 3 categories: Category 1 – the largest portion in a main course, e.g. cereal grains (46%±11% for a 95% CI); Category 2 – sides containing mainly vegetables (36%±11% for a 95% CI); and Category 3 – non-vegetable sides (18%±9% for a 95% CI). Selected foods in the 3 categories are presented in Table 1.

Table 1. Typical food wastes

Category 1	Category 2	Category 3
a1. Rice	b1. Bean curd puffs	c1. Sausage
a2. Toast	b2. Winter melon	c2. Fish fillet
a3. Noodles	b3. Onion	c3. Salted egg
a4. French fries	b4. Cloud ear fungus	c4. Red sausage
a5. Potato	b5. Chestnut	c5. Chicken
	b6. Broccoli	c6. Barbecued pork
	b7. Carrot	c7. Spring roll
	b8. Mushroom	c8. Pork ribs
	b9. Corn	c9. Fish stew
	b10. Tofu	

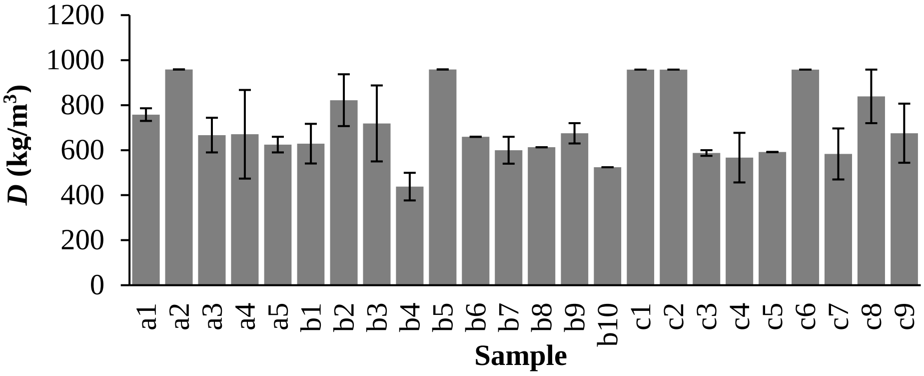
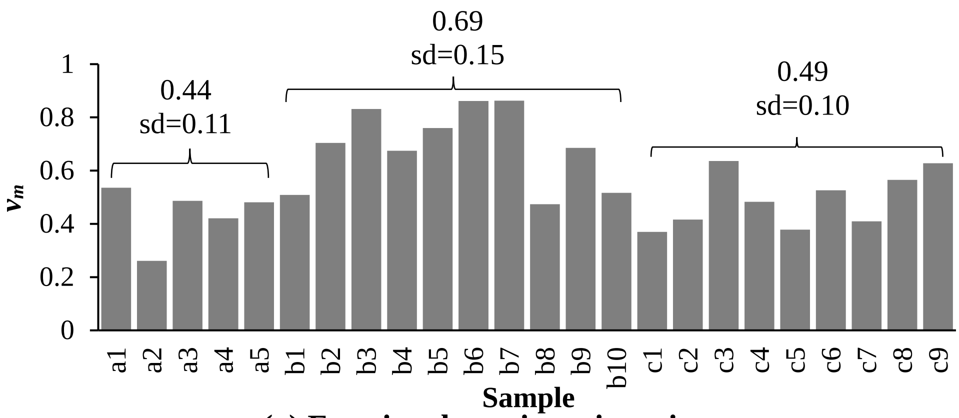
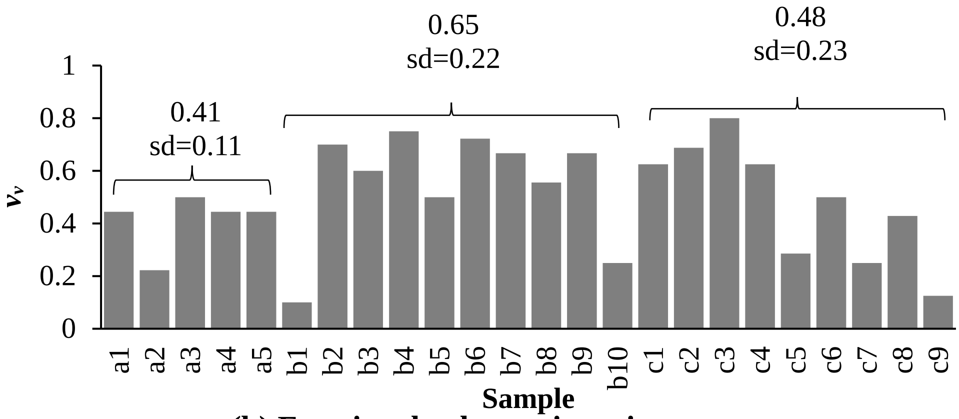


Figure 3. Food waste density *D*



(a) Fractional gravimetric moisture content v_m



(b) Fractional volumetric moisture content v_v

Figure 4. Fractional gravimetric v_m and volumetric v_v moisture contents of food waste samples

Figures 3 and 4 exhibit the food waste density *D* and the fractional moisture contents v_m and v_v for the 24 dehydrated food waste samples respectively. The category averages and standard deviations are also shown in Figure 4. The gravimetric moisture content v_m and volumetric moisture content v_v are appearently correlated (correlation coefficient r=0.48, p=0.02, *t*-test); however, the association between their category averages is insignificant (r=0.95, p=0.2, *t*-test). Although there are significant correlations between samples of Categories 1 and 2 (p<0.05, *t*-test), the samples in Category 3 do not show any correlation with those in Category 1 or 2

(p>0.95, t-test).

The mass and volume of dried food waste, i.e. W_m (g) and V_m (L), during consumption can be estimated by,

$$W_m = N_s \times n_s \times m \times w_m (1 - v_m) \qquad \ldots (4)$$

$$V_m = (N_s \times n_s \times m) / D \times w_v (1 - v_v) \qquad \ldots (5)$$

Based on the average mass values of the meals served and average numbers of customers during breakfast, lunch, afternoon tea and dinner periods from the survey results, it was estimated that a total of 1,400 kg of food was served per day and about 250 kg of it was uneaten and became plate waste. From the dry weight experiment, the average fractional gravimetric and volumetric moisture contents (w_m and w_v) were 0.54 and 0.51 respectively when taking the average composition of cereal grains, vegetables and meats in a given meal into account (D=712 g/L). Hence, the estimated daily mass of dried food waste W_m is 110.88 kg and daily volume of dried food waste V_m is 183 L (0.18 m^3). For a wastewater volume of 50.8% (189 L) generated in the canteen per day, the maximum weight reduction in food waste is 55.6% (139 kg).

The non-residential catering facilities are responsible for 35% (1,299 tonnes per day) of the municipal food waste produced daily (EPD, 2018). In situations where catering facilities already have on-site food waste dewatering systems, increased wastewater load will result in greater drainage discharge. As a rough estimation based on this study, a maximum of 700 tonnes, or 530 m^3, of wastewater could be generated each day if all food waste from the catering facilities is to be dewatered before road transportation. According to the 2017-18 data from the Drainage Services Department, electricity consumption and carbon emissions due to wastewater treatment were 1.13 MJ/ m^3 and 0.22 kg CO_2e/ m^3 respectively (DSD, 2018). Therefore, for treating the maximum quantity of wastewater that can be generated per day, electricity consumption and CO_2e (greenhouse gas) emissions will be 600 MJ and 117 kg respectively. Alternatively, if the wastewater from food waste is transported to the nearest local food waste treatment facility (30 km), CO_2e emissions from road transportation will be 1,302 kg with an emission factor of 0.062 kgCO_2/ tonne-km (McKinnon and Piecyk, 2010).

From the above estimations, it can be seen that an over 10-fold reduction in carbon emissions can be achieved when drainage and treatment of the wastewater from dewatered food waste is done before road transportation. Energy-wise, only 0.85 MJ/ tonne is required for the wastewater treatment while 44 MJ/ tonne (1.46 MJ/ tonne-km) is needed for transporting the wastewater to a waste treatment facility by heavy-duty vehicles (IEA, 2017). The potential reduction in waste volume and weight by dewatering also implies that the transportation costs for delivering existing food waste to treatment facilities can be lowered.

4 Conclusion

This paper analyzed the food wastes generated in a university canteen in order to determine the collectable food waste, its composition and generation patterns, and the probable amount of wastewater produced. Eating habits of 72 customers were also studied through a consumer food waste survey. The results revealed that food wastes were dominated by foods that could have been eaten (i.e. plate waste). As the dry weight experiment demonstrated that there was the potential to reduce up to half of the weight and volume of the studied plate waste, the subsequent reduction in transportation costs would be a monetary incentive for the catering industry. Quantification of food waste in public catering facilities can therefore help to estimate the wastewater flows in drainage systems and potentially reduce carbon emissions, energy consumption and costs coming from food waste transportation. Findings in this paper provide useful insights into not only sustainable food production practices but also wastewater drainage for food waste collection in buildings.

5 Acknowledgement

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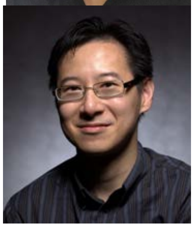
7 Presentation of Authors

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

Mr. K.W. Lai is a graduate student in the Department of Building Services Engineering at The Hong Kong Polytechnic University.

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



Study of the concentration of DEHP plasticizer solving into water by UPVC supply pipes under thermal environment

M.C. Jeffrey Lee (1) Y. J. Yue (1) C. Y. Chen (2) Y.C. Lin (3)
(1) MCJL@nutc.edu.tw National Taichung University Of Science And Technology, Department of Interior Design, #129, Sec.3, Sanmin Rd., Taichung, Taiwan (R.O.C)
(2) cyuchen@mail.cjcu.edu.tw, Chang Jung Christian University (CJCU), #1, Changda Rd., Gueiren District, Tainan City 71101, Taiwan (R.O.C.)
(3) yuchcnlin@ntu.edu.tw, National Taiwan University, Graduate Institute of Environmental Engineering, Taipei #1, Sec. 4, Roosevelt Rd., Taipei, Taiwan (R.O.C)

Abstract
Water quality involved with the human health in the building. Many researchers focused on the water quality control, especially in biological, chemicals, and heavy metals, but few research in hormones toxic solved by plasticizer. The materials of plumbing equipment are considered without harmful compounds for directly drinking water in some countries. It also only allows metal pipes for hot water supply in Taiwan, but no limitation for cool water supply pipes. Most stainless water tanks are installed on the roof and connect with UPVC pipes for gravity water supply, but the water temperature is around 55°C after half day exposure under the strong sunshine. The high water temperature causes the DEHP plasticizer by UPVC pipes solving into water to impact the human health. This study tries to find the concentration of DEHP plasticizer solving into water by UPVC supply pipes under thermal environment. Sample the steady water from the pipe of 1’ long and 1/2” diameter UPVC pipe from 1 to 10 days in different pipes, and detect the concentration of plasticizer in the water by liquid chromatography / mass spectrometer (LC/MS) for each day. The results present the concentration trends for the UPVC pipes increasing to damage human body, and show the health risk exposure for the wrong materials of water supply pipes.

Keywords: thermal environment, UPVC pipes, DEHP, LC/MS

1 Introduction

Building water plumbing system is prone to affect the sanitation and health of users. However, if there are problems or even harmful substances in the equipment of building water supply system, it will have a significant impact on the health of users. Plumbing system is used for supplying water and drainage water. The materials control of pipes on water supply quality has not been regulated in the plasticizer, especially in UPVC pipe. UPVC pipe is adopted by high frequency installation in cold water supply system in the building due to the low cost and easy installation in Taiwan. Most concrete water tanks were setup on the roof because of gravity water supply system, but most concrete water tank were damaged by the high frequency of earthquake and typhoon in Taiwan. Therefore, most concrete water tanks were changed into stainless steel water tanks with flexible materials. Based on our measurement, the water temperature was reached to 55°C inner stainless steel water tank after explored half day sunshine, the temperature is not cold water anymore. When the water with 55°C follows into UPVC pipes, the plasticizer is solved into water to impact the water quality and to damage the human health. Because DEHP is one of plasticizer which has the risk of cancer for endocrine chemicals of human body, it has been listed in the regulation of drinking water. But the materials of pipes have not been listed in the regulation yet in Taiwan.

At present, the usage of plastic pipes with plastic materials in buildings accounts for 54% all over the world, and Polyvinyl chloride (PVC), which is made of vinyl chloride monomer (VCM) [1], accounts for 62% of the market demand. In order to increase the pliability of plastic materials, the common DEHP plasticizer is added to it. After 10 days' exposure under strong sunshine, the concentration of 2.5 mg/L of VCM from the pipes dissolves into heated distilled water of 45°C, which exceeds the drinking water standards regulated by the Environmental Protection Agency (EPA). In view of this, the solution of VCM from UPVC supply pipes into water is closely related to the exposure time and temperature of the materials of the pipes [2]. DEHP is easily dissolved into food, especially fatty foods such as dairy products and meat, drinking water, and blood bags, which is then absorbed by the human body [3], and the materials of the pipes in buildings all have the potential to risk affecting human health [4]. DEHP dissolved into water will affect the human body and cause endocrine disorders, as well as lead to genital hypoplasia in infant boys, precocity in infant girls, and carcinogenesis of the immune system and nervous system, which have all been listed in the regulations of drinking water in many countries and regions [5].

The risks of plasticizers to the health and the environment of human beings have been listed as priority managements. Ten pieces of pipes in commercial packing of high temperature (50°C±10) have been selected as samples for seven days by Taiwan Food and Drug Administration. The polymer structure of PET material does not contain DEHP and its general manufacturing processes do not add or dissolve DEHP [6]. The permissible limit of DEHP in drinking water, as regulated by the WHO, is 8ppb [7], while the maximum permissible limit of the USEPA is 6ppb [8] and the standard of in New Zealand is 9ppb [9]. At present, only hygienic standards for the packing of food containers have been regulated in Taiwan. The permissible limit for the concentration of DEHP dissolving into water by plastics materials is 1.5ppb, while standards for the DEHP concentration in drinking water have not been regulated yet.

Most stainless-steel elevated water towers are installed on roofs in Taiwan, and their pipes are either buried in the walls or are constantly exposed to strong sunshine, which cause maintenance difficulties and long-term exposure under an outdoor environment, as shown in Fig. 1. Unfortunately, only metal pipes are allowed for the hot water supply by the Water Law and Building Technical Regulations in Taiwan, and there are no limitations for cool water supply pipes. The insufficiency of legal regulations has given rise to negligence of the potential risks to the human body.

This study attempted to discover the concentration of plasticizer in water passing through UPVC pipes affected by long-term exposure on the roof under strong sunshine in Taiwan, as shown in Fig. 1. Samples of standing water were collected from UPVC supply pipes with a length of 1’ and a diameter of 1/2” from one to ten days, and the concentration of plasticizer in the water was detected by liquid chromatography/mass spectrometry (LC/MS) for each day in order to discover the trend curve for the concentration of DEHP plasticizer under a thermal environment.

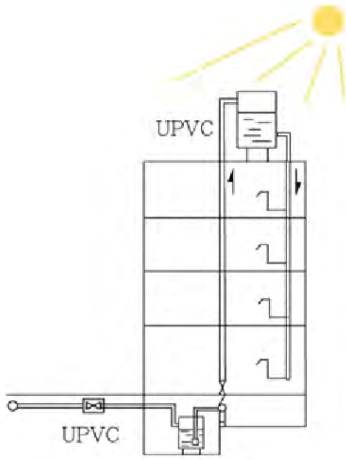


Fig. 1 Elevated stainless water tanks heat the water temperature in cold water pipes

2 Methodology

In order to understand whether UPVC supply pipes will increase the exposure risk of plasticizer to drinking water after long-term exposure under strong sunshine and to analyze the relationship between concentration and time, ten pieces of UPVC supply pipes with a length of one foot and a diameter of 1/2" were placed on the roof of a building, and standing water was kept in them for one to ten days. Then, the concentration of plasticizer in the water samples was detected by LC/MS in order to discover the trend curve for the concentration of plasticizer varying with time under a thermal environment.

"The inspection method of DEHP plasticizer in food" [10], as recommended by the Taiwan Food and Drug Administration, was adopted as the inspection method of drinking water in order to analyze the concentration of nine kinds of DEHP in water. Treatment of the water samples was not carried out. A chromatography column with 3.5μm, 2.1mm×100.0mm was used to absorb and unfreeze the 990μL water samples, and 10μL internal standards phthalates were added to dissolve into the samples to the total sum of 1000μL. The solvent blank, blank, and testing water samples were detected by LC/MS. The concentration range of nine kinds of DEHP metabolites was 2ppb-1000ppb as determined by the (LC/MS instrument. A standard measuring line was made through LC/MS analysis, the main purpose of which was to obtain the precise relationship between the detection signals of the instrument and the concentration. The peak area of the analyte and x were calculated by weighted quadratic regression in order to calibrate the curve, and the range was repeatedly calibrated to confirm linearity. Once R^2 exceeded 0.995, the accuracy of data was calibrated.

All kinds of standard sample solutions (x value) with different concentrations (at least five different concentrations) were prepared, and its signals (y value) were calculated by instruments and the regression-line relationship was displayed between the concentration and signals. Then, the standard measuring line formula y=ax+b was obtained, and the concentrations of nine kinds of DEHP metabolites were calculated by the former formula.

The respective concentration of DEHP in the water samples minus the concentration of the blank samples was the respective concentration (ppb) of DEHP in the samples, as shown in equation (1):

$$PC\ (ppb) = (C - C_0) \qquad \text{Eq.1}$$

,where C: The respective concentration of DEHP (μg/mL) in solution is calculated by the standard curve, C_0: The respective concentration of DEHP in blank solution is calculated by the standard curve

Table 2 Sampling Method

Sampling utensils and materials:	**Analytical instrument:**
Volumetric flask: *50mL brown glass bottles with a Teflon inner pad and lid were used to sample the water.* HPLC system: *0.39g of ammonium acetate was sampled and dissolved into 1000mL of reagent water as mobile phase solution A, and methanol was used as mobile phase solution B.* Internal standard solution: *10μL each of DMP-d4, DEP-d4, DIBP-d4, DBP-d4, BBP-d4, DEHP-d4, DNOP-d4, DINP-d4 and DIDP-d4 were sampled, respectively.*	LC/MS instrument: *A liquid chromatograph (Nexera X2; Shimadzu Corporation, Japan) coupled with a tandem quadrupole mass spectrometer (8045; Shimadzu Corporation, Japan)* Electrospray ion source: *Positive ion electrospray ionization, ESI ＋.* Chromatography column: *Waters XBridge C18, 3.5m, inner diameter 2.1mm × 10 cm.*

Storage and sampling process of water:

Firstly, methanol was used to rinse UPVC supply pipes with a length of one foot and a diameter of 1/2” to make sure that there were no contaminants attached on them, as shown in Fig. 2. Then, HPLC grade methanol was injected into the pipes, upon the condition of pure and clean water, UPVC supply pipes with a length of one foot were placed on the roof under strong sunshine for ten days and a fluid thermometer was used to record the daily temperature changes, as shown in Fig. 3. The water was sampled every day respectively, as shown in Fig. 4. The obtained samples were frozen at -5°C to stabilize the substances in the water, as shown in Fig. 5. The standard measuring lines of nine kinds of plasticizer were made by LC/MS to calculate the concentration (ppb) of plasticizer and discover the changes of time, temperature, and concentration, as shown in Fig. 6.

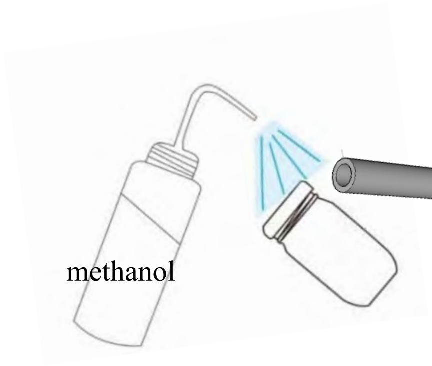


Fig. 2 UPVC supply pipes and sampling glass bottles rinsed with methanol

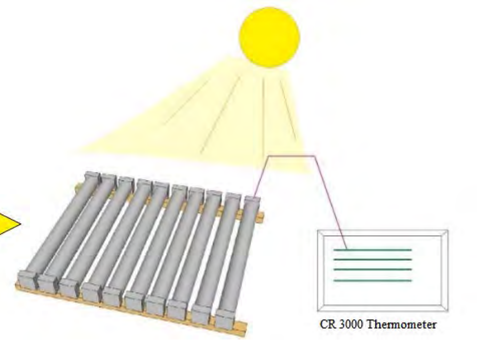


Fig. 3 A fluid thermometer was used to detect daily temperature

Fig. 4 Sample the water quality every day for 10 days

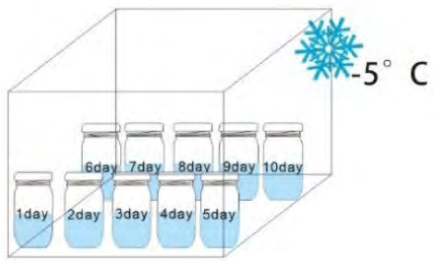


Fig.5 The water samples were frozen in the freezer at -5°C to stabilize the stability of substances in water

Fig. 6 The concentration (ppb) of plasticizer was tested by liquid chromatography/mass spectrometry (LC/MS) to discover the changes of time, temperature, and concentration

3 Results & Discussion

UPVC supply pipes with a length of 1’ and a diameter of 1/2” were set as the experimental instruments and were used to obtain water samples for 10 days, respectively. Firstly, methanol was used to rinse UPVC supply pipes and sampling glass bottles to ensure there were no interfering materials attached to the pipes and sampling glass bottles, as shown in Fig. 7. After that, the pipes were filled with pure water without any substances, in order to ensure the accuracy of experiments.

Fig. 7 Rinsing the UPVC supply pipes and sampling glass bottles

Ten pieces of pipe were respectively filled with pure water and placed on a roof under strong sunshine for ten days, as shown in Fig. 8. Then, the water in the UPVC supply pipes was sampled every day to analyze the concentration of plasticizer dissolving into the water, and a CR3000 fluid thermometer connected behind the pipes was used to detect the water temperature and concentration reaction, as shown in Fig. 9.

Fig. 8 Ten pieces of pipe were placed on the roof under strong sunshine

Fig. 9 A fluid thermometer was connected behind the pipes to record the temperature

The water in the pipes, which had been exposed to strong sunshine for one day, was collected and poured into 50mL brown glass bottles with a Teflon inner pad and lid, as shown in Fig. 10. The pipes were steadily shaken to make sure that the liquid solution was mixed homogeneously before being poured into the glass bottles. At last, the samples were placed at a temperature of -5°C to stabilize the substances in the water, as shown in Fig. 11.

Fig. 10 Homogeneously pouring the liquid solution into glass bottles

Fig. 11 Storing the glass bottles at -5°C to stabilize the substances in water

The water samples which were obtained by unfreezing the sampled water after 10 days of exposure under strong sunshine, and the pure water which was originally poured into pipes, were used as bank samples. An analytical column (3.5μm, 2.1mm×100.0mm i.d.) (XBridge; Waters, Wexford, Ireland) was used to obtain 990μL water samples, as shown in Fig. 12, to which 10μL of internal standards phthalates were added to create 1000μL with standards and water, as shown in Fig. 13. An HPLC system was used as mobile phase solution A and methanol was used as mobile phase solution B, as shown in Fig. 14. Liquid chromatography/mass spectrometry (LC/MS) chromatographic separation coupled with tandem quadrupole mass spectrometry owns positive ions (8045; Shimadzu Corporation, Japan), as shown in Fig. 15.

Fig. 12 An analytical column was used to unfreeze 9900μL of water in the sampling bottles

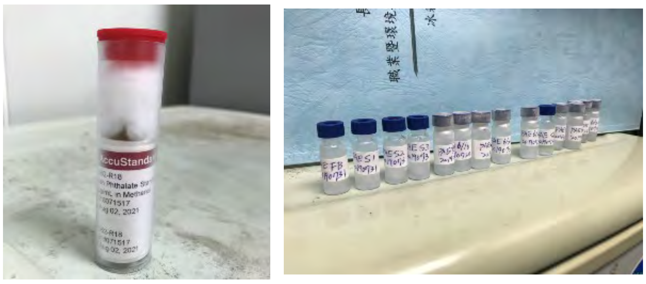


Fig. 13 An analytical column was used to dissolve the 10μL standard samples and reach 1000μL

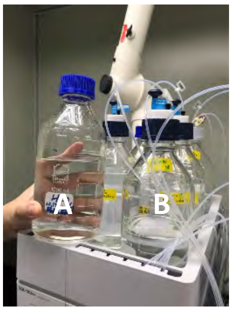


Fig. 14 An HPLC system was used as mobile phase solution A, and methanol was used as mobile phase solution B

Fig. 15 LC/MS chromatographic separation was carried out

The standard curve was obtained by LC MS/MS analysis, the standard sampling solution (x value) was obtained by the formula y=ax+b, and the symbols (y value) were detected by an instrument. There is a linear relationship displayed between concentration and signal. During the inspection process of the blank samples, the concentration range of nine kinds of DEHP was 2 ppb-1000ppb according to the LC/MS instrument. Each batch included the curve trend of the solvent blank and blank samples, as shown in Fig.16.

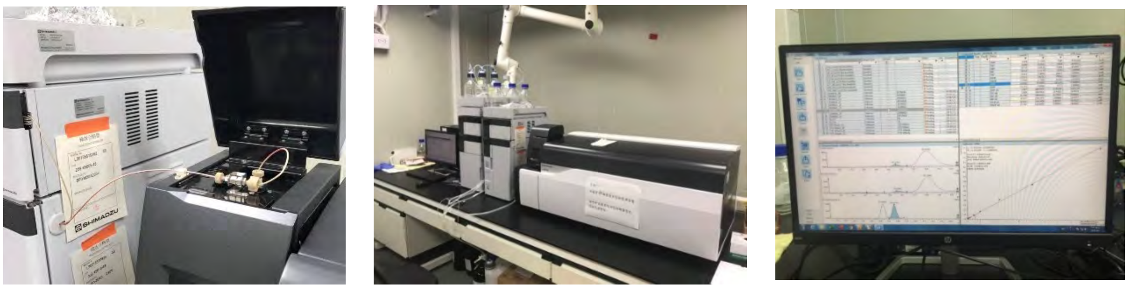


Fig. 16 The concentration of DEHP and curve trend of the nine kinds of DEHP

During the experiment, the water in the UPVC supply pipes after ten days' exposure to strong sunshine was respectively sampled every day to analyze the concentration of nine kinds of plasticizer by liquid chromatography/mass spectrometry (LC/MS). It could be seen from the experiment that the concentration of DEHP and DINP plasticizer began to dissolve into the water, and the concentration of DINP was higher than that of DEHP, as shown in Table 1.

Table 1 The concentration of substances dissolved after 10 days' exposure to strong sunshine in UPVC supply pipes

Sample Name / Dates	DMP Conc (ppb	DEP Conc (ppb)	DIBP Conc (ppb)	BBP Conc (ppb)	DBP Conc (ppb)	DEHP Conc (ppb)	DNOP Conc (ppb)	DINP Conc (ppb)	DIDP Conc (ppb)
1	ND	ND	ND	ND	ND	ND	ND	ND	ND
2	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	ND	ND	ND	ND	ND	ND	ND	ND	ND
4	ND	ND	ND	ND	ND	ND	ND	22.96	ND
5	ND	ND	ND	ND	ND	ND	ND	34.78	ND
6	ND	ND	ND	ND	ND	1.28	ND	36.43	ND
7	ND	ND	ND	ND	ND	4.47	ND	41.71	ND
8	ND	ND	ND	ND	ND	6.74	ND	46.11	ND
9	ND	ND	ND	ND	ND	8.28	ND	53.46	ND
10	ND	ND	ND	ND	ND	9.67	ND	59.04	ND

Quantitative analysis was carried out to analyze the concentration of nine kinds of DEHP dissolving into water in the UPVC supply water pipes. The instrument's detectable concentration range was 2 ppb-1000ppb. The different signal intensity of the nine kinds of DEHP by the LC/MS instrument differed with respect to the different standard curves. The standard curves were obtained according to DEHP and DINP of Table 1 that were dissolved, as shown in Fig. 17 and Fig. 18. A linear relationship was displayed between the signal value of the instrument and the concentration of DEHP and DINP. The standard sampling solution (x value), the signal detected by the instrument (y value), and the concentration (ppb) of the involved DEHP and DINP in each water sample were calculated by the Regression equation, as shown in Fig. 19 and Fig. 20.

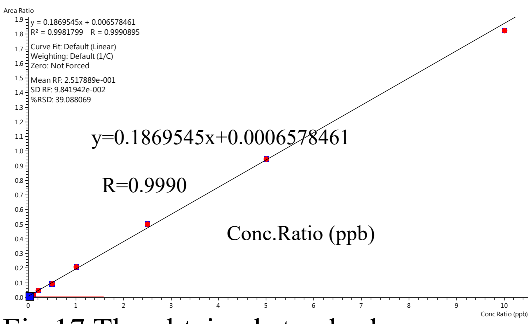


Fig.17 The obtained standard curve according to DEHP

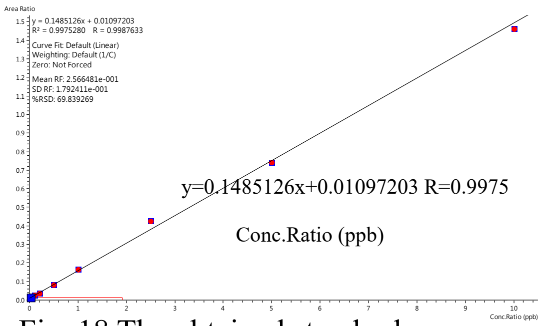


Fig. 18 The obtained standard curve according to DINP

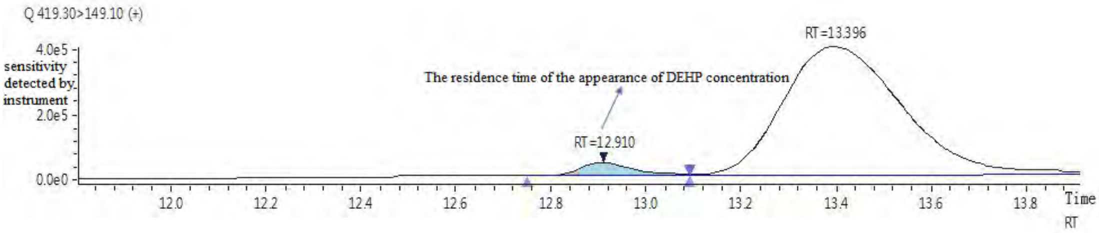


Fig. 19 DEHP chromatography detected by LC/MS

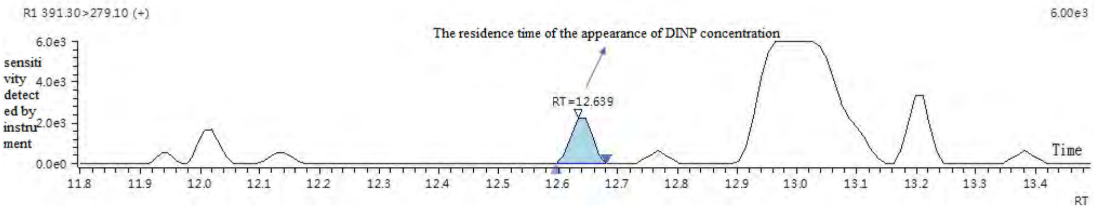


Fig. 20 DINP chromatography detected by LC/MS

The changes of time, temperature, and concentration were discovered according to the dissolved substances in the water, as shown in Fig. 21 and Fig. 22. The concentration of DEHP and DINP plasticizer began to dissolve into the water in the UPVC supply pipes after exposure to strong sunshine and an air temperature rising up to 30℃, the equal temperature including radiant temperature should be around 55℃. The data indicated that exposure to temperature and time were correlated with the increase of the concentration of DEHP and DINP. It could be seen that the concentration of DEHP and DINP dissolving into water increased with the increase of temperature after fourth day's exposure to strong sunshine, and the concentration in DEHP is higher than 10ppb and DINP is higher than 60ppb. The concentration is more than the safe index for the WHO [7], USEPA [8], and New Zealand [9] to impact the human health.

Fig. 21 The influence of exposure under strong sunshine on DEHP dissolution

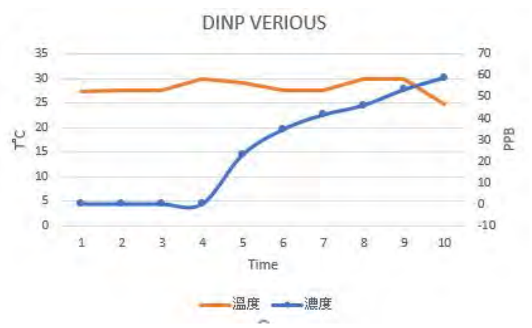


Fig. 22 The influence of exposure under strong sunshine on DINP dissolution

4 Conclusion

According to the test of sunshine exposure 10 days, the deterioration of UPVC water supply pipes was insufficient to reach the expected concentration of plasticizer when dissolving into water. However, the results indicated that the concentration of DINP dissolving into the water in the UPVC water supply pipes was higher than that of DEHP, and that the exposure temperature was correlated with the concentration. Perhaps due to the food safety incident based on plasticizer exposure in Taiwan in 2011[11], DEHP has been gradually replaced by DINP in the manufacture of various kinds of plastic products. Future research should target the differences between the involved substances in older pipes and new pipes. In addition, the acceleration of the deterioration of pipes with different diameters and use of temperature controlled ovens should be discussed to provide the best future direction

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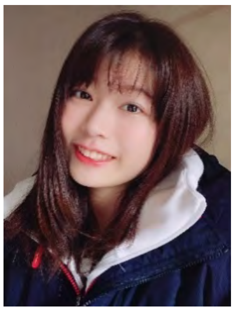
6. Presentation of Authors

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.

YU-JIA YUE is the graduate student at National Taichung University of Science and Technology, Department of Interior Design.



How much water does this building need?

David M Steblina

(1) david.steblina@wge.com.au

1) Australian Discipline Leader- Hydraulics (WGE now part of Stantec). Director of Hydraulic Consultants Australasia (HCAA)

Abstract

In the last 6 years a boom in residential apartment projects being built chiefly in Sydney, Melbourne and Brisbane has led to a re-evaluation of how we cater for the design on multifaceted commercial/residential/hotel complexes.

The AS/NZS 3500 suite of standards nominated in the National Construction Code (NCC) Volume 111 are limited in their breadth to properly support this developing Industry. It is virtually impossible to rely entirely on these source documents to confidently design an economical, efficient and compliant Hot Water (HW) and Cold Water (CW) reticulation system.

Engineers are forced to consider a range outsourced material to support a complex design scenario as the standards are silent in all areas apart from large residential (housing) subdivisions. When an engineer uses logic to replace the tabled flow rates with restricted flow tapware their design solutions inadvertently sit outside the DTS provisions of the Standard. Subsequently, the engineer is at risk of providing a design solution that does not comply with AS/NZS3500.1, even though the resultant methodology is fit for the intended purpose.

This paper will explore various design opportunities available for a multi-storey residential/hotel development and examine pipe sizing outcomes from the DTS provisions v's other published and source data.

The outcomes provided in this paper should open debate about how we move forward as an Industry to provide a more realistic design guideline.

Keywords

Fixture Loading Units, Peak Flows

1 Introduction

There have been several papers which discuss the problems with the current practices of sizing Hot Water (HW) and Cold Water (CW) reticulation systems for residential buildings. This paper will not explore methods adopted by other countries but will focus on the DTS provisions of AS/NZS 3500.1 and other available data to Australian and New Zealand designers.

In Australia, the National Construction Code (NCC) Volume 111, mandates that to meet the performance requirements, the design must meet the Deemed-to-Satisfy (DTS) objective or have a performance solution that must be equivalent to the DTS provisions.

As the reference documents nominated in the NCC V3 for water pipework sizing limits the engineer to AS/NZS3500.1 our direction is focused as to the relevancy of the sizing tables given the advancement of technology and change of household usage patterns.

There are specific deficiencies in the current AS/NZS Standards for sizing HW and CW reticulation systems as the guidelines and reference tables provide "holistic" data in the form of Loading Units (LU's) or Litres per Second (L/s) for combined hot and cold flows to fixtures. These tables limit the engineer to confidently design an incoming supply that is adequate to cater for a single or group of residential dwellings only. This is because Table 3.2.3 AS/NZS 3500.1 directs the engineer to the Probable Simultaneous Demand (PSD) for up to 100 multiple dwellings. The inference is that the PSD is for combined HW and CW flows with no commentary on an acceptable method to isolate HW and CW reticulation systems.

Given this, the Standard's deficiencies exist as there is no clear direction on how to size complex hot and cold-water distribution systems that include a separate centralized HW plant and independent CW pipework.

It has been discussed that any building designed with a centralized hot water plant cannot therefore by definition sit within the DTS provisions of the standard other than ensuring the reticulation meets Clause 3.4 "Velocity Requirements". [1]

In order to have a reasonable debate about deficiencies of the Standard and the discretionary resource material available for engineers to confidently design a complex high-rise building. It is necessary to review a case study of such a project using varying design guides. With this information, we can interrogate the findings against 'Live" data available and form a view on how our Industry moves forward.

[1] The topic of velocity requirements as presented in AS/NZS 3500.1 requires further information. It appears this clause inadequately covers the dynamics of conveying water at differing temperatures and pressures.

2 Case Study- 56 storey hotel/residential tower

The discussion will focus on an actual project that is currently under construction in Sydney's western suburbs.

This 56 storey building consists of:

- 4 levels of retail commercial,
- 14 floors of Hotel suites and
- 36 floors of 1,2 and 3 bed apartments.

This commercial make-up is now very much on-trend as full residential towers are coming "off the boil" due to overheated markets. It is very typical of the type of buildings engineers in Australia and New Zealand are required to confidently design an efficient and compliant HW and CW reticulation system within the limited guidelines of the Standards available under NCC V3.

Figure 1- Artistic representation of Case study

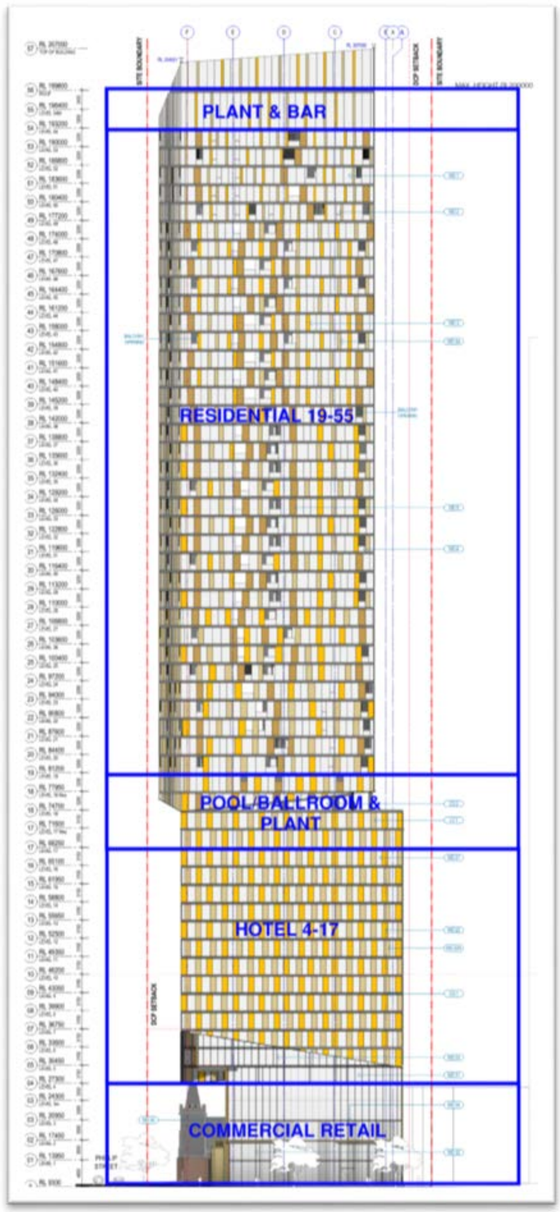


Figure 2- Floor level breakdown

The objective is to compare a compliant AS/NZS3500.1 designed system v's following:

a) what was originally designed for tender,
b) Barrie's book
c) an alternative option using Peak Flows (PF's) and,
d) extrapolation from actual "live" data

The tabled results in the summary of this paper should provide data to instigate debate on the way our industry moves forward.

3 As Tendered Documents- Case Study

Figure 3 below represents the tendered schematic of the CW distribution system. The tower (shown in 3 parts) clearly shows the distinct zones agreed within the design phase being:

- Mid-level plantroom- includes domestic CW storage tank and HW plant to serve level 18 and below (Hotel)
- Hi Level plantroom- includes CW storage tank and HW plant to serve level 57 to Level 19 (Residential)

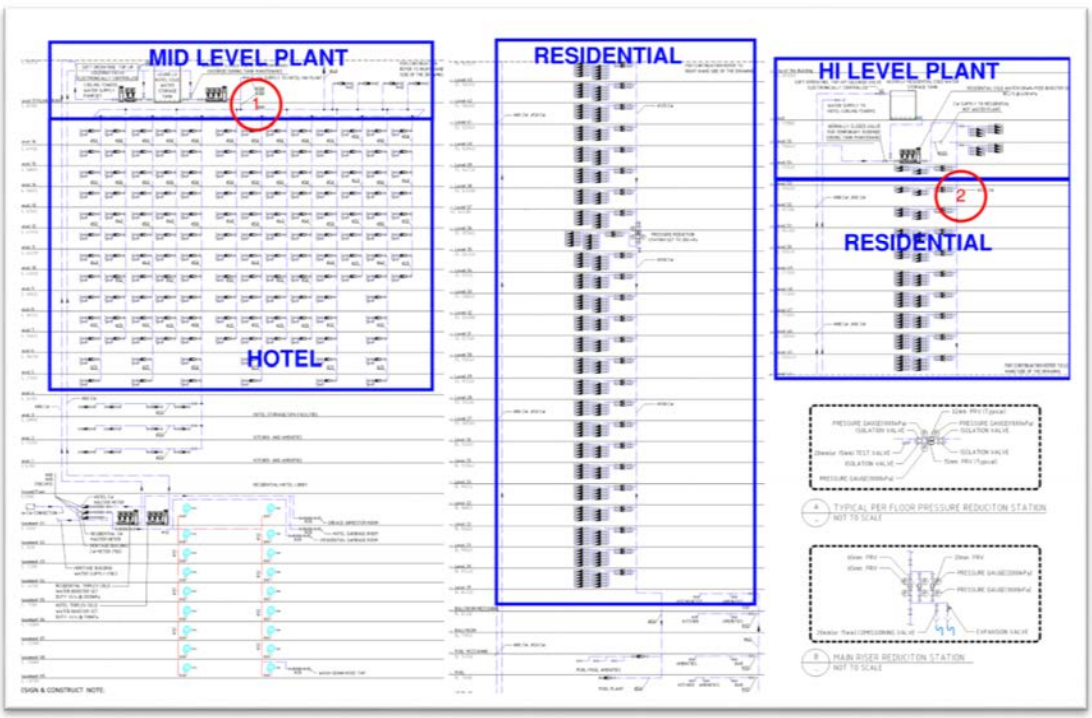


Figure 3- Actual diagrammatic of "live" project

In this report, we have focused on 2 specific pipe sizes, which should provide adequate variance for discussion.

1. Pipe Size No: 1 is the main CW supply serving the 250 Hotel suites.
2. Pipe Size No: 2 is the main CW supply serving the 325 Residential apartments

The tendered design results provided by the project engineer were:

AREA	Design Options	Flow rate (l/sec)	Pipe size (copper)	Velocity (m/sec)
Residential	As Tendered design	14.6	125	1.21
Hotel	As Tendered design	12.5	100	1.64

Figure 4- Tendered design pipe size and flow rate results for main CW feed

4 AS/NZS 3500.1- Case Study

This design was created with an in-house modelling program which selects data from AS/NZS 3500.1 tables and creates a schematics model.

In this Standard, there are two design options available to the engineer when assessing pipe sizes for a network.

4.1 Option 1- PSD

Table 3.2.3 suggests a Probable Simultaneous Demand (PSD) for a given number of dwellings. The Standard is not specific as to whether this table refers to HW or CW pipe sizing. The accepted industry norm is that the flow rates refer to a total HW and CW demand per dwelling.

TABLE 3.2.3

PROBABLE SIMULTANEOUS DEMAND (PSD) FOR DWELLINGS

No. of units or dwellings	Flow rate L/s	No. of units or dwellings	Flow rate L/s	No. of units or dwellings	Flow rate L/s
1	0.48	35	3.74	68	5.79
2	0.70	36	3.81	69	5.85
3	0.88	37	3.88	70	5.91
4	1.03	38	3.95	71	5.96
5	1.17	39	4.01	72	6.02
6	1.30	40	4.08	73	6.08
7	1.41	41	4.14	74	6.13
8	1.53	42	4.21	75	6.19
9	1.64	43	4.27	76	6.25
10	1.74	44	4.34	77	6.30
11	1.84	45	4.40	78	6.36
12	1.94	46	4.47	79	6.41

Figure 5- Table 3.2.3- Suitable for sizing clusters of dwellings

We have found the limitations to provide an engineered design, relate to the variables associated with the number of fixtures and bathrooms that exist within a dwelling. The flow rates provided in the table above, do not enable the engineer to discriminate between small and large dwellings. It assumes all are identical and occupant numbers are consistent. Further there is no advice to provide discretional adjustments when considering aged care facilities, nursing homes and multi-faceted hotel/residential living.

Our expectation is that a design reflecting values from table 3.2.3 (Fig. 5) would be extremely conservative to accommodate these ambiguities.

4.2 Option 2- PSF

The data we are using for this discussion comes from Table 3.2.4 (Fig. 8) and would hopefully reflect a more accurate representation of expected PSD as we have calculated the actual number of loading units based on the actual number of fixtures for this development (rather than assuming 31 FLU’s per dwelling).

The FLU count used now accurately reflects the 1, 2 and 3 bed apartments and would exclude the Hose Cocks (8 FLU's) and Mains pressure HWU's (8 FLU's).

Calculated Total FLU's:

- Residential Tower – 6426 FLU's
- Hotel Tower – 2796 FLU's

TABLE 3.2.1

FLOW RATES AND LOADING UNITS

Fixture/appliance	Flow rate L/s	Flow rate L/min	Loading units
Water closet cistern	0.10	6	2
Bath	0.30	18	8
Basin (standard outlet)	0.10	6	1
Spray tap	0.03	1.8	0.5
Shower	0.10	6	2
Sink (standard tap)	0.12	7	3
Sink (aerated tap)	0.10	6	2
Laundry trough	0.12	7	3
Washing machine/dishwasher	0.20	12	3
Mains pressure water heater	0.20	12	8
Hose tap (20 nom. size)	0.30	18	8
Hose tap (15 nom. size)	0.20	12	4

Figure 6- Table 3.2.1 loading units for a single dwelling

Table 3.2.4 accommodates total FLU's up to a total of 60. As our project exceeds this limitation, the engineer is required to extrapolate using the formula provided in the Code and the data in Table 3.2.4.

2 Determination of PSD for dwellings exceeding the scope of this Table may be estimated using the following equation:

$$Q = 0.03\,n + 0.4554\sqrt{n}$$

where

Q = flow rate, in litres per second

n = number of dwellings

Figure 7- formula used for extrapolation

$$PSFR = 0.03 \times \left(\frac{FLU}{31}\right) + 0.4554 \times \sqrt{\frac{FLU}{31}}$$

Figure 8- Final formula used after substituting "n" with a more realistic FLU

The engineer needs to consider the results will generate a flow rate that accommodates a HW and CW PSD. However, it is commonly used to size the CW distribution network as there is no interpolation provided to discriminate between the loads.

The results are therefore skewed heavily to provide an extremely conservative CW distribution size.

2018 20

31 Loading units used for formula extrapolation

TABLE 3.2.4

PROBABLE SIMULTANEOUS FLOW RATES (PSFRs)

Loading units	PSFR L/s	Loading units	PSFR L/s	Loading units	PSFR L/s
1	0.09	21	0.39	41	0.55
2	0.12	22	0.40	42	0.56
3	0.14	23	0.41	43	0.57
4	0.16	24	0.42	44	0.58
5	0.18	25	0.43	45	0.58
6	0.20	26	0.43	46	0.59
7	0.22	27	0.44	47	0.60
8	0.24	28	0.45	48	0.60
9	0.25	29	0.46	49	0.61
10	0.26	30	0.47	50	0.62
11	0.28	31	0.48	51	0.62
12	0.29	32	0.49	52	0.63
13	0.30	33	0.49	53	0.64
14	0.31	34	0.50	54	0.64

Figure 9- Table 3.2.4 PSD FLU's to 60

The results using the extrapolated formula accommodating rooms with differing number of fixture units on the main CW pipe sizes feeding the Hotel and Residential components are as per below:

AREA	Design Options	Flow rate (l/sec)	Pipe size (D-copper)	Velocity (m/sec)
Residential	AS/NZS3500.1	12.78	150	0.74
Hotel	AS/NZS3500.1	6.88	100	0.91

Figure 10- AS/NZS3500.1 results

5 Barrie's Book-Case Study

This design was created by using an Industry accepted guideline known as "Barrie's Book".

To provide consistency with our comparisons, the total FLU count of the actual number of fixtures in the residential apartments and hotel suites was used from NZS 3500.1 (Fig 6) .

The direct correlation of 6426 and 2796 FLU's into Table 48 of Barrie's Book, led to a PSD as indicated below:

AREA	Design Options	Flow rate (l/sec)	Pipe size (D-copper)	Velocity (m/sec)
Residential	Barries Book	17.65	150	1.02
Hotel	Barries Book	8.77	100	1.16

Figure 11- results from Barrie's book using Table 48

6 Alternative Design Option-Case Study

If it is accepted that the industry accepted standards are broadly based on "subdivision style" dwellings, an opportunity exists into the study of what is an appropriate design philosophy for high rise complex buildings.

There are two main "design performance" areas that largely impact on an engineered design. Taking consideration of these factors would greatly affect the pipe sizing for a HW and CW reticulation system.

6.1 Peak flow- The focus of a properly engineered system is to ensure that the calculated peak flow periods are accommodated with both correct pipe sizing and hot water delivery. Regardless of the PSD assumed, hotel operators and body corporates would not tolerate an installation that does not provide HW and CW delivery as and when required.

As more available real data becomes available to our industry, the peak flow period can be better understood. The industry standard appears to be between 1-2 hours morning and evening.

To further create a realistic demand outcome, we have assumed the occupancy ratio of the residential and hotel portions as being:

Hotel		
Occupancy:	1Bed	2Bed
	1.2	2.2

Apartment			
Occupancy:	1Bed	2Bed	3Bed
	1.5	2.5	3.0

The challenge is to deduce what percentage of residents and guests are using fixtures at any one time within that peak period.

For the purpose of this discussion, we have assumed the following:

- Hotel – 30% of guests showering at any one time
- Residential – 20% of residents showring at any one time

6.2 Peak flow- HW and CW only pipe sizes- by understanding the peak flow delivery based on time frame and demand percentage, we can be better placed to engineer the correct pipework sizes with some degree of certainty.

If we accept the largest demand during peak period on average would be the shower fixture, the HW and CW flow rates required for delivery would be:

Hotel		
Occupancy:	1Bed	2Bed
	1.2	2.2
Hotel Showers		
Shower Diversity Factor	30 %	
Total Hotel Showers	258	
Diversified Shower Total	77.4	
Shower Flow Rate	9.0 L/Min	
Total Shower Flow at Peak	11.61	L/Sec
Ratio to achieve 38 degrees		
Hot	30	%
Cold	70	%
Total Showers Cold Water Flow at Peak	8.127	L/Sec

Apartment			
Occupancy:	1Bed	2Bed	3Bed
	1.5	2.5	3.0
Residential Showers			
Shower Diversity Factor	20 %		
Total Hotel Showers	502		
Diversified Shower Total	100.4		
Shower Flow Rate	9.0 L/Min		
Total Shower Flow at Peak	15.06 L/Sec		
Ratio to achieve 38 degrees			
Hot	30	%	
Cold	70	%	
Total Showers Cold Water Flow at Peak	10.542	L/Sec	

Figure 12- Tables indicating maximum flow rate at peak times using 20-30% variables

7 LIVE DATA

Until recently we have not had real live data available to our industry. With an increased awareness of water conservation and pressure directed to the Water Authorities to provide a transparent user pays system. Metering of water supplies to apartments and high water usage plant and equipment (cooling towers) is being integrated into design standards.

Resourcing this metered data for the purpose of analyzing peak flows and total usage without impacting on the privacy of individual occupants has proven tricky.

We have however received formal approval from certain Body Corporates to install private monitoring meters on the CW incoming supply. Results of this monitored data are available on the HCAA's website link www.waterdemand.com.au. The details of the property are limited to the rise in storey's and the number of apartments. Although further criteria i.e. number of rooms per apartments would be valuable, by extrapolating this live data, we can begin a legitimate discussion about industry accepted practice and alternative options.

Summary of a 13 Story Apartment Block with 146 Apartments - Tested for 1 month

	Flow	Pipe Size @ <1.5m's	% of PSD
AS/NZS 3500.1 PSD	**10.4 L's**	**100mm**	**100%**
ASPE	**4.73 L's**		**45%**
DIN	**2.61 L's**		**25%**
Monitored Cold Peak	2.52 L's	50mm	24%
Monitored Cold Average	0.32 L's	25mm	3%
Monitored Cold Peak Average	1.74 L's	50mm	17%
95% of CW Flows recorded were <10% of the PSD			
Monitored Hot Peak	2.43 L's	50mm	23%
Monitored Hot Average	0.68 L's	32mm	6%
Monitored Hot Peak Average	1.43 L's	40mm	14%
97% of HW Flows recorded were <10% of the PSD			

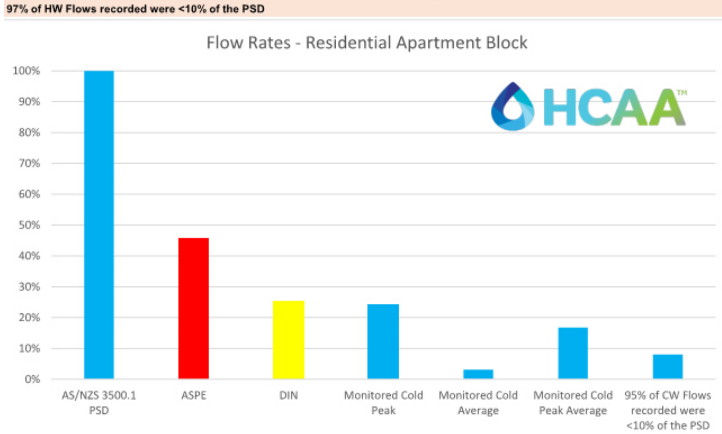


Figure 13- live data usage when compared to Industry practice methodologies.

The table above clearly illustrates real time usage (only over one month at this stage) and designed PSD for a standard residential tower. Interestingly, 95% of recorded flows were less than 10% of the AS/NZS3500.1 PSD value.

8 SUMMARY

By summarizing the sizing outcomes in a simplified table, we can visualize the discrepancies between the accepted sizing principals and actual usage patterns.

Residential Tower				
Design Options	Flow rate (l/sec)	Pipe size (D-copper)	Velocity (m/sec)	Reduced pipe size (Max: 1.6m/sec)
As Tendered design	14.6	125	1.21	
AS /NZS 3500.1	12.78	150	0.74	100
Barries Book	17.65	150	1.02	125
Alternative Design	10.5	100	1.38	
Extrapolated "live" data	2.30	50	1.25	N/A

Figure 14- scheduled results for CW delivery for the residential tower

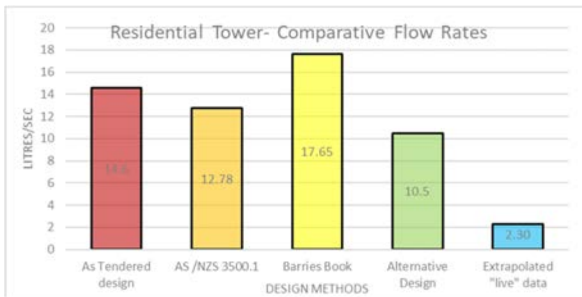


Figure 15-graphic results for CW delivery of the residential tower

The results above for the accepted sizing methods although not too dissimilar for this tower, do show that pipe sizing from 150mm to 100mm could be considered by the engineer. By using more robust live data we could consider pipe sizing between 50mm to 100mm. This of course translates to saving in the construction phase but more importantly, significant environmental saving in the manufacture of materials.

Hotel Tower				
Design Options	Flow rate (l/sec)	Pipe size (D-copper)	Velocity (m/sec)	Reduced pipe size (Max: 1.6m/sec)
As Tendered design	12.5	100	1.64	
AS /NZS 3500.1	6.88	100	0.91	80
Barries Book	8.77	100	1.16	100
Alternative Design	8.12	100	1.1	
Extrapolated "live" data	1.24	40	1.25	N/A

Figure 16-scheduled results for CW delivery for the hotel tower

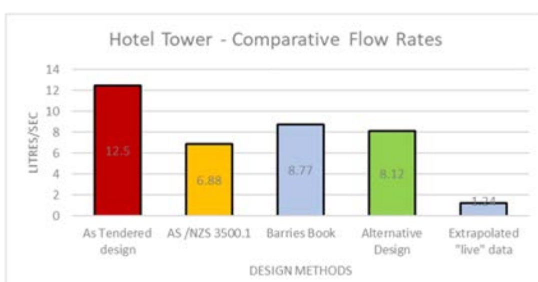


Figure 17- graphic results for CW delivery of the hotel tower

Comparing the extrapolated results of the CW supply for the hotel tower against industry practice or the Alternative design method would be skewed, without the engineer considering that peak flow and PSD operate at differing intensities for hotel occupants.

Of interesting note, the AS/NZS3500.1 PSD value for the hotel portion is considerably lower than the Alternative design option of calculating peak flows.

Based on the hotel results above, the AS/NZS3500.1 design tables would provide a shortfall in the peak period when compared to the Alternative design results. Without coordinated industry assistance we would be unable to confidently confirm that the factor of 30% users at any one time is an overkill or simply a good design measure to provide a conservative buffer.

The data presented provides enough evidence to open discussion regarding our pipe sizing procedures. What is clear is that in most cases, the DTS solutions are extremely conservative in their outputs.

With mindful debate and appropriate industry and Government support, a more comprehensive design table could be adopted by Australian and New Zealand industry.

9 Acknowledgements

- AS/NZS3500.1
- The Institute of Plumbing Australia- Selection & Sizing of copper tubes for Water Piping Systems "Barrie's Book"
- HCAA- Hydraulic Consultants Association Australasia
- NCC Volume 3
- Oliver Vile, Dominika Sala, Thomas Pollifrone- Wood and Grieve Engineers

10 Abbreviations

- HW- Hot Water and associated systems
- CW- Cold Water and associated systems
- HCAA- Hydraulic Consultants Association Australasia
- FLU- Fixture Unit Load
- PSD- Probable Simultaneous Load
- DTS- Deemed to Satisfy
- NCC- National Construction Code
- PSF- Probable Simultaneous Flow

11 Presentation of Author

David Steblina is a Hydraulic Principal at Wood and Grieve Engineers now part of Stantec and has been involved in the Hydraulic Industry for 30 years. He is a Director of the Hydraulic Consultants Association Australia (HCAA), and as the Australian Discipline Leader for his firm he is responsible for managing the hydraulic processes and procedures used in WGE.

Assessing overestimation of water demand in different types of non-residential buildings in the UK

S. Mohammed (1), L.B. Jack (2), S. Patidar (3), and D.A. Kelly (4)

(1) sam77@hw.ac.uk
(2) L.B.Jack@hw.ac.uk
(3) S.Patidar@hw.ac.uk
(4) D.A.Kelly@hw.ac.uk

(1, 3, 4) School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, UK.
(2) Heriot-Watt University, Putrajaya, Malaysia.

Abstract:

Water demand in buildings has reduced significantly over recent years as a result of the use of more water-efficient appliances and a heightened awareness of the need to conserve water. This has, in part, led to oversizing of water supply networks; a phenomenon that has given cause for concern from those responsible for the design of building plumbing systems. In spite of it being possible to define diurnal water use patterns as a specific feature of most non-residential applications, water demand is known to be different for different types of building and may be further influenced by factors such as occupancy and usage. Assessing water usage patterns hence becomes essential to develop new design approaches to provide a better estimate of water demand. It is therefore important to investigate water demand patterns in different types of non-residential buildings and determine whether or not current design methods in the UK remain appropriate.

This paper addresses water demand patterns in three different types of building, namely: mixed use, office and student accommodation. It investigates the oversizing problem by presenting a comparison of recommended design flow rates and monitored water demand. The paper also discusses the challenges of appropriate representation of student halls of residence.

The results clearly show that current design methods result in an overestimation and indicate the extent of oversizing for different types of non-residential buildings. Oversizing rates of 198% to 798% were found, and confirm that using the loading unit (LU) technique in current design codes is no longer an appropriate tool to estimate design flow. This outcome underscores the need to develop a new approach to support a better estimation of water demand.

Keywords

Water supply system, non-residential buildings, oversizing problem.

1 Introduction and background

Water is vital for life and is a critical resource for wellbeing. A growing global population, together with the impacts of climate change, have raised awareness across society in general and also within government for the need to have a strategy to reduce consumption. Long-term plans have been initiated by the UK government to increase supply whilst reducing demand (DEFRA, 2018). Additionally, both national and regional water labelling is in place to encourage people to use more efficient appliances such as low-flow taps and low and dual flush WCs. Replacing traditional products with water efficient models has already resulted in a significant reduction in water consumption (Kelly, 2015). In addition, working habits have changed, with working hours becoming more flexible. The difference in male:female ratio and in behavioural change amongst water users has also altered the overall demand (Pieterse-Quirijns *et al.*, 2013).

Despite a considerable reduction in water demand in buildings, there has been little, if any, corresponding change in system sizing approaches in the UK, and no significant updating of the design equations to adjust pipes and systems to a more appropriate scale and avoid oversizing.

In the UK, there are different design guides used to estimate water demand in buildings. In response to concerns that the traditional loading unit method results in over-estimation of the design flow, a study was undertaken by the LUNA Group (Loading Unit Normalisation Assessment) and provided recommendations for developing a new design approach, with greater accuracy, for residential buildings (Jack, 2017). However, there has been little research into the water demand arising from non-residential buildings and there is no evidence that the existing recommended design guides are able to address the oversizing problem. This paper summarises data collected from three case study buildings located at Heriot-Watt University in the UK. It provides critical information about water demand estimation in different types of non-residential building and investigates the extent of the oversizing problem.

1.1 The need for water conservation

Providing sufficient drinking water for populations globally has become a matter for some concern, even in seemingly water-rich countries such as the UK. There are many factors as to why fresh water has become more scarce a resource year upon year. These include: climate change, shifting demographics, increasing rates of ground water extraction, and increased chemical and organic pollution in water resources (Butler and Memon, 2006). The pressure on our water resources is also rising because of the need to retain sufficient water in our lakes, watercourses and wetlands to support the natural environment. In the UK, there are some areas that are over-abstracted or over licensed. In addition, water has to be used in an environmentally sustainable way in order to optimise its social and economic benefit. In some parts of the country, the amount of water taken from the environment causes damage to our ecosystems (Environment Agency, 2008). The Water Industry National Environment Programme notes that over 700 million litres per day of abstracted volume needs to be cut by water companies to address environmental problems and mitigate damage to ecosystems (DEFRA, 2018). These pressures are likely to be exacerbated in the future due to climate change impacts.

Reducing the amount of water consumed could make a considerable difference to water availability whilst also supporting the natural environment. The Water Resources Long-term Planning Framework states that a twin-track approach of reducing demand and increasing supply is needed to secure the resilience of water supplies over the next 50 years as preparation for a drier future (Water UK, 2016).

As a result of undertaking water conservation planning, water usage has changed across recent decades. Figure 1 shows the per capita water consumption in the UK between 1999 and 2017. It can be seen that there was an obvious reduction in water consumption from 150 to 140 litres per person per day (l/p/d) between 2005 to 2012. Minimum water efficiency standards were introduced into the building regulations in 2010 which required that all new homes were designed so that their calculated water use was no more than 125 l/p/d (DCLG, 2014b). Subsequently, a proposed water standard set a new threshold of 110 l/p/d (DCLG, 2014a) with the intention that this may be achieved at little additional cost (DEFRA, 2018).

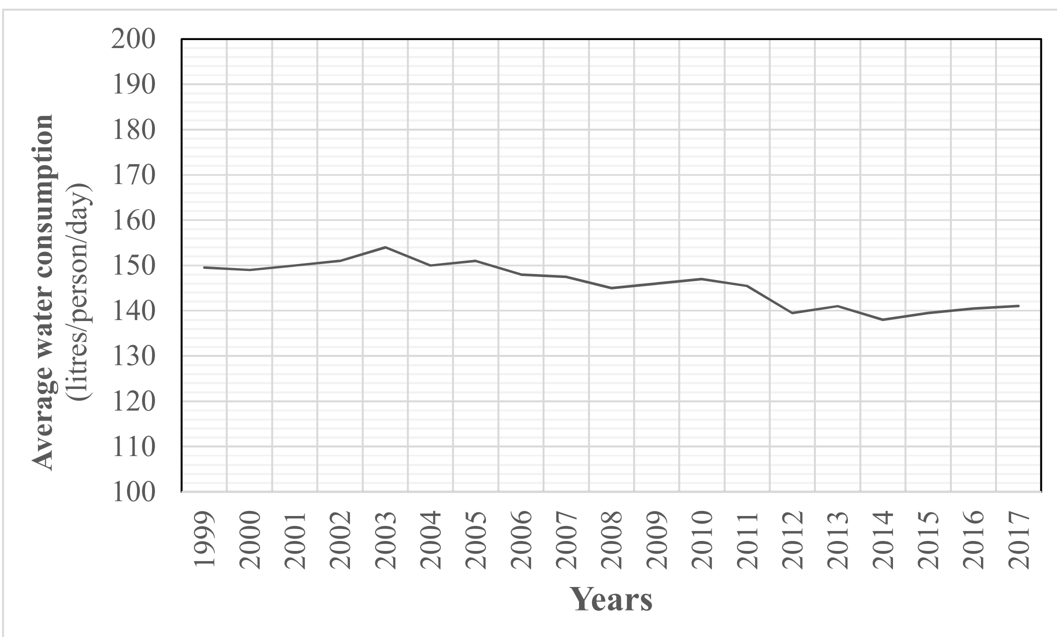


Figure 1 Per capita water consumption in the UK between 1999 and 2018 (DEFRA, 2018)

1.2 Oversizing problem

It is essential for each building to have a water supply system that provides an adequate quantity of water at all end use points at all times. Flow rates, therefore, should be designed to an acceptable level of confidence considering energy efficiency, health consequences and sustainability. Despite considerable efforts by water companies to provide high quality water, it is recognised that quality may deteriorate in water distribution systems because of any oversizing problems (Blokker, 2010) This also encourages the growth of Legionella which is acknowledged as a global problem, particularly in non-residential buildings. Furthermore, oversized systems are usually much less energy efficient and therefore cost more in terms of operation. The oversizing of water systems not only affects the cost of pipes but also leads to oversizing of storage tanks, booster pumps, and water heating devices, wasting both money and energy (Blokker, 2010; Pieterse-Quirijns *et al.*, 2013, 2014; Omaghomi and Buchberger, 2014). The British Standards Institution BS 8558 (2015) guidance also highlights concern related to overestimation of peak demand and states that this can result in larger than necessary pipe sizes, and related adverse effects.

1.3 Water demand estimation

It is important to provide adequate amounts of water to different sectors such as agriculture, industry, and the built environment, and to manage available water resources in the most efficient and equitable way. Information about water demand is also required to design water and wastewater infrastructure such as pipelines, treatment plants and storage. Water engineers hence need to know the water requirements of all types of users, as inaccurate demand estimates result in either underestimation which leads to inefficient use and inadequate service provision, or overestimation which leads to under-performance of systems with possible negative health consequences (Ilemobade, Van Zyl and Van Zyl, 2010). In addition, reliable water demand forecasting is essential to provide the basis for tactical, operational and strategic decision-making for potable water utilities organisations. For example, water companies need to know what the day-to-day water demand will be in order to operate their treatment plants properly to meet demand. They also need to predict the water demand for the next 20–30 years in order to plan treatment plant expansions and/or identify and develop new water sources (Donkor, Mazzuchi, Soyer and Roberson, 2014).

The first step in designing a water pipe network in any building is the estimation of the likely simultaneous peak water demand. In most of the design guides used for this purpose, flow rate is estimated, then designers assign reasonable values of design parameters and analyse the system to check whether the requirements of the users are met. (The Institute of Plumbing, 2002; BS EN 806-3, 2006; BS 6700:2006+A1:, 2009; BS 8558, 2015).

2 Case studies

In order to understand the water demand patterns in different types of non-residential buildings, flow rates were monitored and recorded in three different buildings at Heriot-Watt University in Edinburgh. The selection of buildings was based on size and usage parameters. The first building, the 'Estates' building, is a two-storey office building (Figure 2). The flowmeter was installed on the outlet pipe of the storage tank which supplies the building through gravity-feed. During flow measurement, the building was used by a maximum of about 50 persons.

Figure 2 Estates building

The second building monitored was the Hugh Nisbet building which is a three-storey mixed-use building. The building includes offices, a shopping area, canteen and coffee shop (Figure 3). Water is distributed to the building from two storage tanks. The building was used by about 1,150 persons during two weeks of flow measurement.

Figure 3 Hugh Nisbet building

The third building reviewed was the Christina Miller Hall; a five-storey student accommodation block (Figure 4). Here, water is pumped from a storage tank to the building using a set of booster pumps. The building was designed to be occupied by 133 students. It will be appreciated that water usage patterns in student accommodation may be different to other types of non-residential buildings such as those accommodating offices or shops. BS 6465-1:2006+A1, (2009) classifies this type of building under (bedrooms in hotels, hostels, and similar accommodation) category.

Figure 4 Christina Miller Hall

Information about the buildings, users, distribution pipe lines and sanitary appliances was collected in collaboration with technical staff. The number and type of appliances in each building are summarised in Table 1.

Table 1 Number and types of appliances in each building

Appliance	Estates building	Hugh Nisbet building	Christina Miller hall
WC	9	45	132
Wash hand basin	8	72	132
Urinal	2	18	
Kitchen sink	5	19	30
Shower	1		132
Cleaners sink	1	5	8
Washing machine			8
Dishwasher	1	6	
Total	**27**	**165**	**442**

3 Design flow rate estimation

Most UK design guides have changed over the years and different guides are available for designing water supply networks in buildings. The latest British Standard is BS 8558, published in 2015. This recommends the use of BS EN 806-3 to estimate design flow rates in residential buildings, and what is referred to as the ‘traditional’ method for all other applications (non-residential buildings).

BS 8558 explains that care is required when assessing the combined demand of cold and hot water supplies in order to reduce the effect of oversizing. For sanitary appliances fed with both cold and hot water, the traditional loading unit model assumes that the system demand imposed by the appliance is met fully by each separate supply, which is logical when separate cold and hot water taps are fitted to an appliance. BS 8558 states that this assumption is not valid when mixer taps or valves are used and it confirms that individual loading units relevant to the cold and hot water supplies ought not to be added together for sizing any combined cold and hot water demand.

BS EN 806-3, which is recommended for use for residential buildings, is the harmonised version of the UK and European Union guidance, the first part being published in 2000 and the fifth and final part in 2012. It introduced a new water demand estimation by assuming one loading unit to be equivalent to 0.1 l/s draw-off which results in a reduction in predicted water demand. In recent work by (Tindall and Pendle, 2017), who assessed the application of different guides to estimate design flow rates, results illustrate that BS EN 806-3 best predicts water demand for residential buildings (in comparison to BS6700 and the CIPHE Design Guide).

BS 6700 was published in three iterations between 1987 and 2006 and it was withdrawn in 2012. However, while BS 6700 used the same group of LUs and conversion chart as used in BS 8558, BS 6700 disregarded the difference in water demand resulting from the use of combined taps and mixers. Thus, when used in this study, the relevant LUs for hot and cold water supplies for BS6700 were added together for each appliance with the exception of the WC, urinal, washing machine and dishwasher; all of which use only cold water. It can hence be seen that BS 6700 results in the highest design flow rates.

The Plumbing Engineering Services Design Guide was published by the Chartered Institute of Plumbing and Heating Engineering (CIPHE), previously the Institute of Plumbing (IoP), and provides more detailed industry guidance for estimation of design flow rates. This guide uses LU values developed from the same probabilistic method, but enables more detailed LU information by considering period and frequency of use of each appliance. The latest version, published in 2002, provides a range of LU values including three classifications of use: Low, Medium, and High. The three groups are applied to reduce the effect of variations in capacity, flow rate, period and frequency of use of the appliances. This also helps designers make a professional judgement about the best LU value for use for different building types.

In this work, we have opted to use conventional sizing methods for all three buildings and additionally, have applied BS EN 806-3 to the Christina Millar building in order to assess its performance when applied to student accommodation. Although this latter application is not necessarily in-keeping with pre-defined guidance, it can be seen that the demand profile for halls of residence differs from other non-residential settings and is, in fact, more in line with domestic consumption patterns. BS 6700, although technically withdrawn, has also been used to show its performance in non-residential buildings and to emphasise the difference introduced by combining LUs for cold and hot water supplies to all types of sanitary appliances.

Figure 5 illustrates the flow rates estimated by each of the design guides (BS 6700, BS 8558, BS EN 806-3 and the CIPHE Design Guide [Medium]), for each of the case study buildings discussed above. In the Christina Miller hall when applying the CIPHE Design Guide, [Low] loading units were used for the appliances in the individual rooms and [Medium] in the shared kitchens.

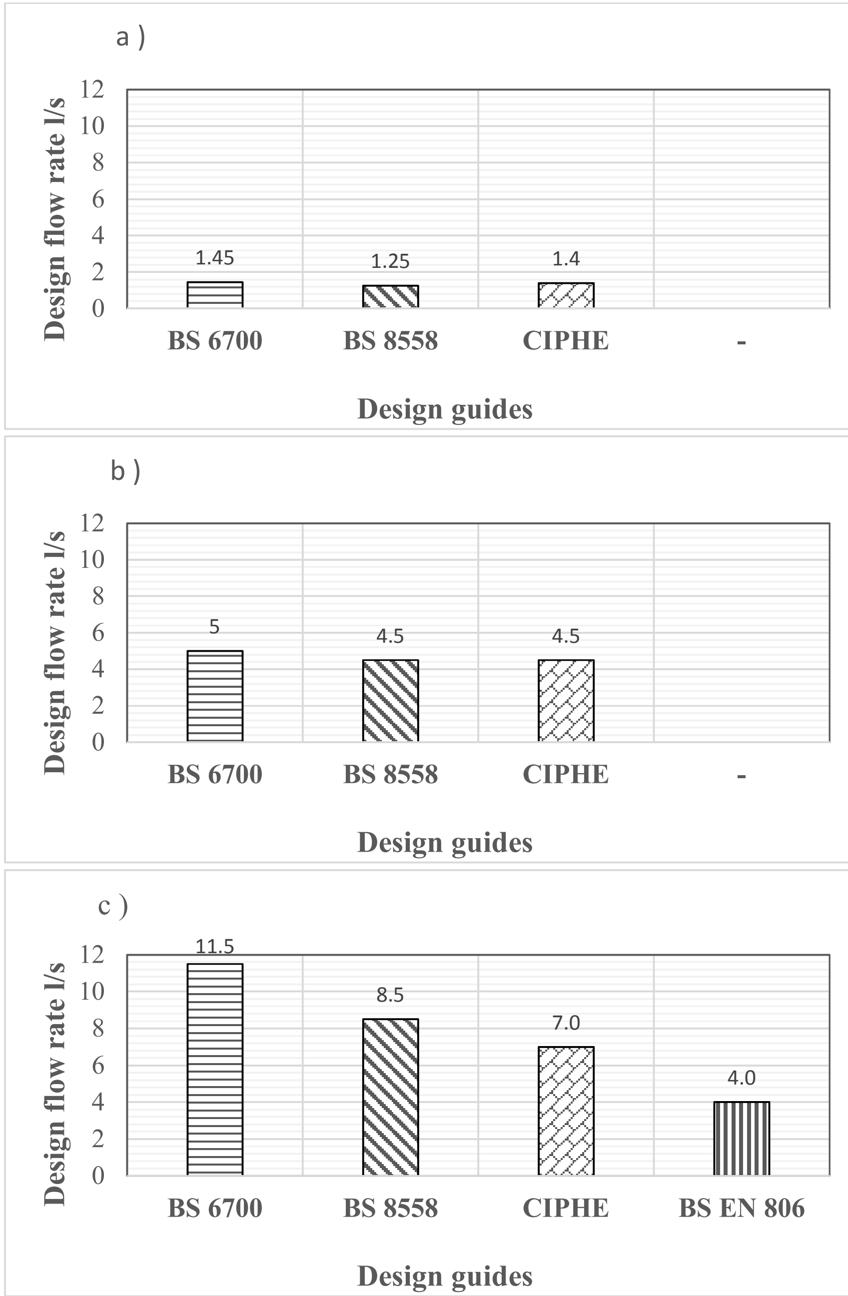


Figure 5 Estimated design flow rate using different guidance for a) the Estates building, b) the Hugh Nisbet building, and c) Christina Miller hall

4 Flow rate measurement

Recording in-situ flow measurements in different types of non-residential buildings is crucial to be able to assess the validity of current design guides and establish the extent of oversizing. It is also important to measure diurnal water demand on a per second basis to capture simultaneous usage of various appliances. Water flow in the main supply pipes within the case study buildings was measured using an ultrasonic flowmeter (a Portaflow

P330), as shown in Figure 6. This flowmeter is a non-intrusive device which is designed to work with clamp-on transducers to enable the flow of a liquid within a closed pipe to be measured without the need for any mechanical parts to be inserted through the pipe wall or protrude into the flow. The transducers and adjustable guide rails were secured in-situ after entering all pipe properties into the device ie. material, diameter, thickness so as to enable accurate calibration.

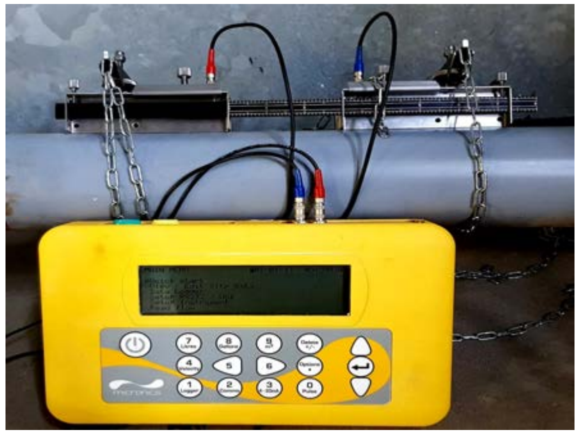


Figure 6 Ultrasonic flowmeter in place during monitoring

Each of the water systems in the selected case-study buildings contained large storage tanks located within the roof space that receive water from a main pipe and that feed the building either by gravity or using a booster pump set. Each flowmeter was installed on the main pipe between the storage tank and the booster pumps in the plant room, or was installed on the outlet pipe of the storage tanks in gravity-fed buildings. Flow rates were recorded every 5 seconds for a duration of around two weeks. It is worth mentioning that we believe that this is the first time in the UK that water demand has been measured at such high resolution (5 seconds) in non-residential buildings.

Like most design guidance, British Standards use a 99th percentile level of confidence. Thus, Cumulative Distribution Functions (CDF) were generated for this level of reliability from the data gathered in order to yield an appropriate comparison with flow rates obtained from design guides. Figure 7 shows the observed flow rates (Q') for each of the case study buildings. The maximum flow rate (Q'_{max}) was found to be 0.689 l/s for the Estates building, 1.62 l/s for the Hugh Nisbet building, and 1.77 l/s for the Christina Miller hall. The 99th percentiles of observed flow rates ($Q'_{0.99}$) were found to be 0.42 l/s for the Estates building, 1.11 l/s for the Hugh Nisbet building, and 1.28 l/s for the Christina Miller hall.

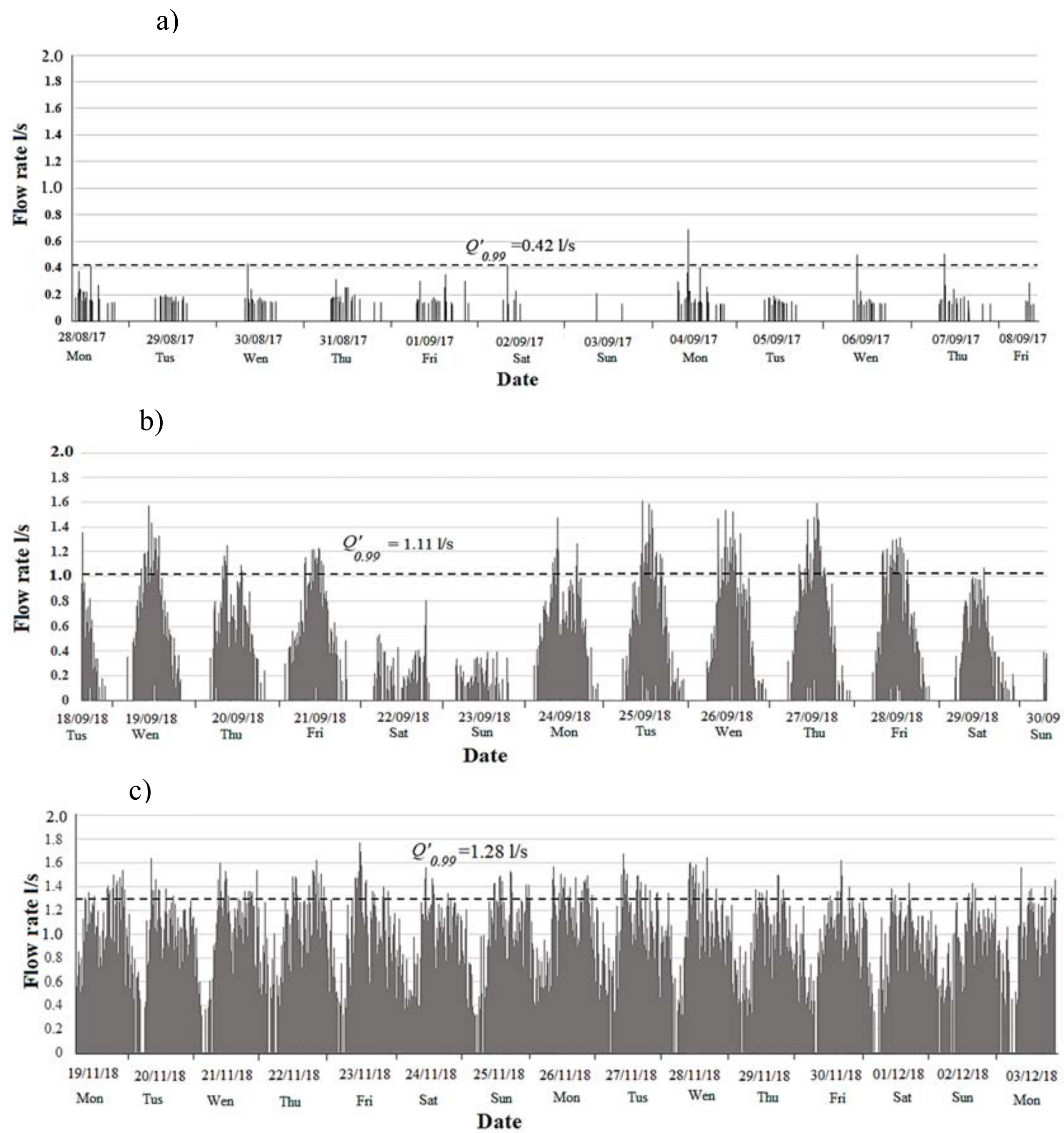


Figure 7 Observed flow rates in a) the Estates building, b) the Hugh Nisbet building and c) Christina Miller hall

5 Results and discussion

The comparison between flow rates obtained from design guides and the measured flows (99^{th} percentile) is shown in Figure 8. Firstly, the results show comparability between design flow rates for both the Estates building and the High Nesbitt building, with all over-estimating. Secondly, the results show that despite the enhanced level of flexibility included in the CIPHE Design Guide, this has not resulted in a significant reduction in design flow rate across the piece. Despite taking into account peak times for water demand and frequency of use as recommended in the guidance, this yielded almost the same design flow rates as other guides for the Estates and Hugh Nisbet buildings. Thirdly, BS 8558 resulted in a slightly smaller flow rate than that calculated from BS 6700 and the CIPHE Design Guide for the Estates building. This lower estimation by BS 8558 resulted from excluding urinals in the calculation of LU and not applying the relevant LU separately to the hot and cold water supply for kitchen sinks. Finally, the design flow rates obtained from BS 6700 resulted in a significant over-estimation in all buildings. This is because it disregards the reduction in flow rate for appliances fitted with mixer devices. Notably, it can be seen that BSEN806, when applied to the student halls of residence, still over-estimates the flow.

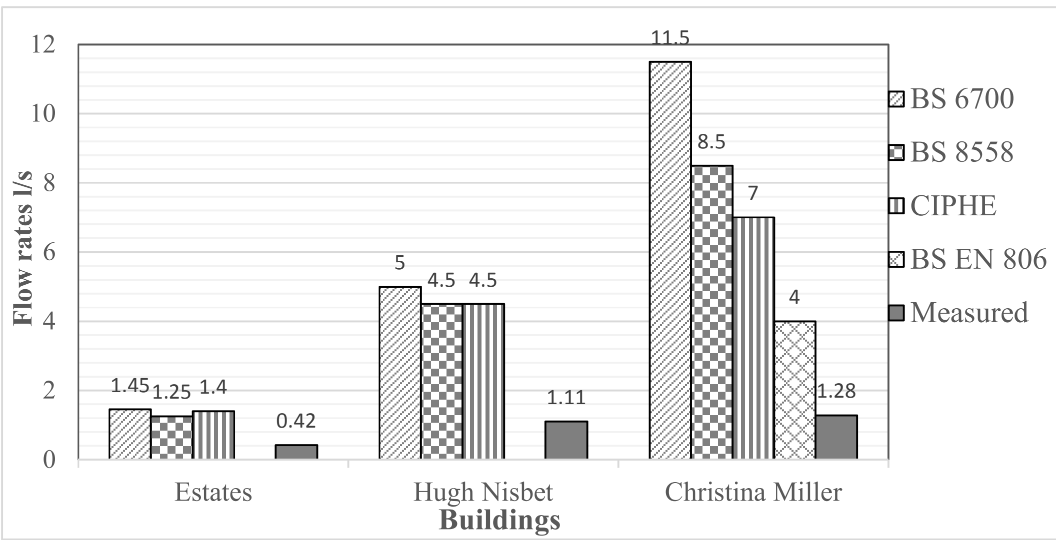


Figure 8 Comparison between design and measured flow rates

It can be seen that significant differences emerge dependent upon the selected design method. This is because each approach has different LUs and LU-to-flowrate conversion charts. In-keeping with previous studies, and as expected, all design methods produced significantly greater design flow values than those measured in each of the case study buildings. The extent of overestimation of water demand is shown in Figure 9. The lowest values of overestimation were found to be 198%, 305%, and 213% for the Estates building, the Hugh Nisbet building and the Christina Miller hall respectively.

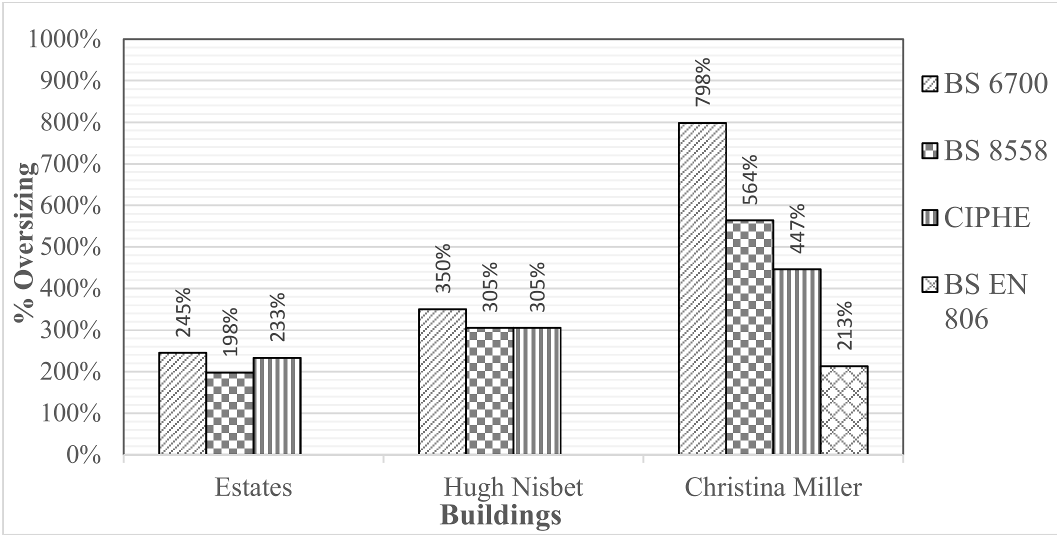


Figure 9 Percentage of oversizing based on measured flow rates

6 Conclusion

Design flow rates were calculated for three non-residential buildings using different design guides available in the UK. In order to provide a comparison and to assess the validity of current design guides, flow rates were measured in each of three buildings at a frequency of every 5 seconds for two weeks. Results clearly show the degree of over-estimation. In addition, despite the fact that the CIPHE Design Guide provides a range of flexible options for the selection of appliances (including different LUs for separate taps and mixers in washbasins, and provides three classifications of demand (low, medium and high), it's use still resulted in the prediction of high flow rates. It was also found that the application, to the student halls of residence, of the standard normally assumed to give the lowest demand prediction, BS EN 806-3, still resulted in a significant overestimation by 213% when compared to measured flow rate.

This study clearly shows that the design flow rates obtained from current design guides used in the UK result in a significant overestimation for different types and sizes of buildings. Although the latest British Standard (BS 8558:2015) recommends the use of BS EN 806-3 for residential buildings and the "traditional" method for non-residential buildings, none of these fully address the oversizing problem. The results indicate that it is not possible to accurately estimate water demand using the current design guides and highlights the need to develop a new approach for better estimation of water demand in non-residential buildings.

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8 Presentation of Authors

Sarwar is a PhD student at the School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University in the UK. His research interests include design of water supply systems, stochastic modelling for water demand and analysis of performance of water supply systems in buildings.

Professor Lynne Jack is Director of Research at Heriot-Watt University's Malaysia campus. Her research focuses on modelling the flow characteristics in vertical drainage stacks and in building roof drainage systems, as well as on predicting simultaneous design flow for water distribution networks in buildings. Lynne was recently appointed President of the Chartered Institution of Buildings Services Engineers; becoming the Institution's first female President in May 2019.

Dr Sandhya Patidar is Associate Professor in Statistical modelling at Heriot-Watt University with expertise in multi-disciplinary applications of mathematical/statistical modelling techniques in the area of climate change, extreme events, water, flood risk, built environment and energy. She developed several novel models exploring techniques involving Hidden-Markov Modelling, Stochastic Processes, Time series modelling, Uncertainty and

Data Analysis, Machine learning, Artificial Intelligence, Complex Networks, Non-Linear Dynamical System, Bifurcation Analysis, and Chaos.

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.

Modeling design flow rates for cascade water supply systems in super high-rise residential buildings

Y. Zhou (1), Eric W.M. Lee (2), L.T. Wong (3), K.W. Mui (4)
1. yzhou352@cityu.edu.hk
2. ericlee@cityu.edu.hk
3. beltw@polyu.edu.hk
4. behorace@polyu.edu.hk

(1), (2) Department of Architecture and Civil Engineering, City University of Hong Kong, Hong Kong, China

(3), (4) Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

Abstract

Super high-rise buildings are common nowadays around the world, especially in cities with high population density and limited development area, e.g. Hong Kong. In order to pump water to the high level of super high-rise buildings, cascade water supply system is usually used. However, systematic studies about cascade water supply system design are still limited in the literature. This study proposes mathematical models and uses Monte Carlo simulations to evaluate the design flow rate of a typical cascade water supply system that fed various appliances including showerheads, wash basins, kitchen sinks and washing machines in a super high-rise residential building in Hong Kong. Graphs that showed the correlations between the inflow rate in the up-feed pipe and tank storage volume were obtained. In practical application, while tank storage volume was confirmed, the design flow rate of the cascade water supply system can be determined from these graphs. The proposed mathematical models can also be applied to evaluate the design flow rate of cascade water supply systems in other types of super high-rise buildings (e.g. office, commercial buildings) as well as with the changes of water demand pattern in the models.

Keywords

Cascade water supply system; design flow rate; Monte Carlo simulation; super high-rise buildings.

1 Introduction

Super high-rise buildings are popular nowadays in developed cities or regions where development areas are limited. This raises the concern of water supply system design inside super high-rise buildings. Even though some practices of water supply systems in super high-rise buildings can be found around the world, which are designed based on practical experiences or requirements of existing codes/ordinances, there is still no systematic investigation of water supply system design as well as no standard/handbook specifically for guiding the design of water supply systems in super high-rise buildings. Besides, overestimation of design flow rate by current standards/guidelines has been revealed by several studies [1-3]. The application of current standards/guidelines on super high-rise buildings needs to be justified. Therefore, it is necessary to systematically evaluate the design flow rate in super high-rise buildings.

Cascade water supply system is commonly used in super high-rise buildings, as shown in Figure 1. This system divides the super high-rise buildings into several zones, with a water tank on the top of each zone feeding demand points below it, which is similar to traditional roof tank water supply system [4]. However, the intermediate tanks (e.g. Tank 1 and Tank 2 in Figure 1) in the cascade water supply system also supply water to the adjacent tank on the upper zone by a transfer pump. This study investigates the design flow rate for a typical cascade water supply system that fed various appliances including showerheads, wash basins, kitchen sinks and washing machines in a super high-rise residential building in Hong Kong.

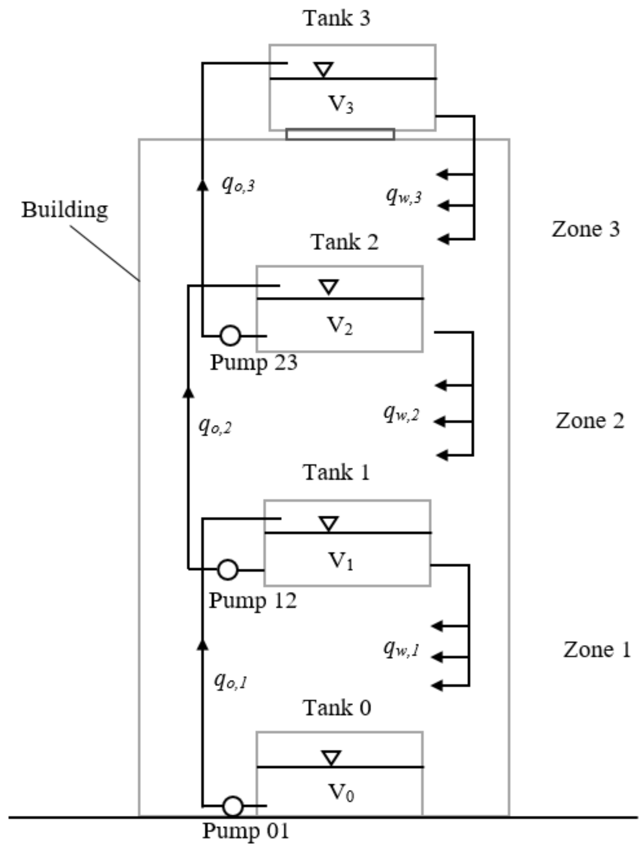


Figure 1 - A cascade water supply system in a super high-rise building

2 Water demand pattern in high-rise buildings in Hong Kong

The simulation accuracy of water demand by Monte Carlo method is highly dependent on the input parameter values (i.e. occupant load, water demand pattern) that derived from field survey. The occupant load and water demand pattern in high-rise buildings were studied by Wong and Mui via two interview surveys in residential households in Hong Kong [5,6].

The surveys reported that the average number of occupant per household is 4.2 [5,6]. The hourly demand patterns for all appliance types in an apartment are exhibited in Figure 2. In these figures, demand peaks can be seen at night for all appliance types, while morning peaks are not obvious for some appliance types, e.g., showerhead.

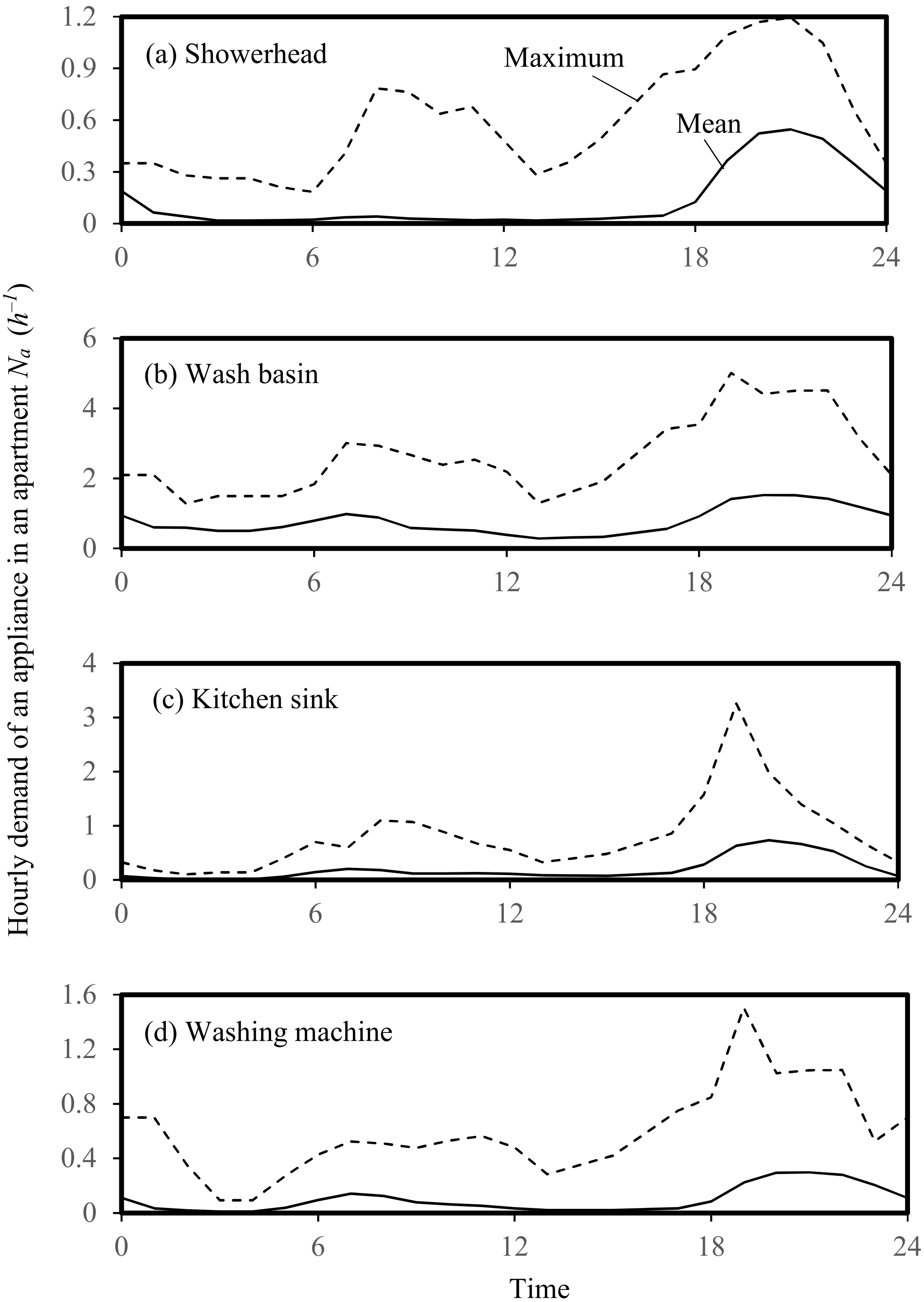


Figure 2 - Hourly demand of each type of appliances in an apartment: (a) showerhead; (b) wash basin; (c) kitchen sink; (d) washing machine

3 Methodology

Monte Carlo simulations of the design flow rate for a cascade water supply system in super high-rise residential building that fed various appliances including showerheads, wash basins, kitchen sinks and washing machines were performed. As shown in Figure 1, it was assumed that the vertical height of each zone was around 50 m and the number of appliances for each appliance type in each zone was 600 in this study. The design flow rate in each zone was simulated sequentially from the uppermost zone to the lowest zone, as shown in Figure 1, e.g. q_{23} in Zone 3 was simulated first, and q_{01} in Zone 1 was simulated lastly. The Monte Carlo simulations were carried out in two steps: The first step was to simulate the simultaneous water demands generated by all appliance types in the time series; the second step was to integrate the water demand time series, with tank volume considered, to determine the design flow rate. For the simulation of the simultaneous water demands by all appliance types, a water demand time series was simulated for each appliance type first, and a total water demand time series was then generated by aggregating the individual water demand time series data points.

3.1 Models of design flow rate

Mass balance equations were proposed at each tank of the cascade water supply system as shown in Figure 1, to decide the inflow rate of the up-feed pipes, as Equations (1) to (3), where $q_{w,3}$ (L.s^{-1}), $q_{w,2}$ (L.s^{-1}) and $q_{w,1}$ (L.s^{-1}) are time-variant water demands in Zone 3, Zone 2 and Zone 1 respectively; $q_{o,3}$ (L.s^{-1}), $q_{o,2}$ (L.s^{-1}) and $q_{o,1}$ (L.s^{-1}) are inflow rates of up-feed pipes to Tank 3, Tank 2 and Tank 1 respectively; $\tau_{\infty,3}$, $\tau_{\infty,2}$, $\tau_{\infty,1}$ are demand time periods in Zone 3, Zone 2 and Zone 1 respectively; V_3 (L), V_2 (L), V_1 (L) are the tank storage volumes for Tank 3, Tank 2 and Tank 1 respectively.

$$\int_{\tau_{\infty,3}} q_{w,3} d_t \le q_{o,3}\tau_{\infty,3} + V_3 \tag{1}$$

$$\int_{\tau_{\infty,2}} q_{w,2} d_t + q_{o,3}\tau_{\infty,2} \le q_{o,2}\tau_{\infty,2} + V_2 \tag{2}$$

$$\int_{\tau_{\infty,1}} q_{w,1} d_t + q_{o,2}\tau_{\infty,1} \le q_{o,1}\tau_{\infty,1} + V_1 \tag{3}$$

Assuming the time-variant water demands and the demand time periods in the three zones are the same in this study, namely,

$$q_{w,3} = q_{w,2} = q_{w,1} = q_w \tag{4}$$

$$\tau_{\infty,3} = \tau_{\infty,2} = \tau_{\infty,1} = \tau_\infty \tag{5}$$

Therefore, Equations (1) to (3) can be rewritten as,

$$\int_{\tau_\infty} q_w d_t \le q_{o,3}\tau_\infty + V_3 \tag{6}$$

$$\int_{\tau_\infty} q_w d_t + q_{o,3}\tau_\infty \le q_{o,2}\tau_\infty + V_2 \tag{7}$$

$$\int_{\tau_\infty} q_w d_t + q_{o,2}\tau_\infty \le q_{o,1}\tau_\infty + V_1 \tag{8}$$

For Equations (6) to (8), there are solution pairs (V_3, $q_{o,3}$), (V_2, $q_{o,2}$) and (V_1, $q_{o,1}$) respectively at any time period within the time period of demand.

The values of input parameters for the Monte Carlo simulation are summarized in Table 1.

Table 1 - Values of input parameters

Appliance	Parameter	Value		Reference
showerhead	Flow rate (L/s)	Max	0.20	[7]
		Min	0.10	[7]
		Mean	0.16	[7]
	Discharge time (s)	Max	359	[7]
		Min	240	[7]
		Mean	310.2	[7]
Washbasin	Flow rate (L/s)	Max	0.23	[5]
		Min	0.03	[8]
		AM[1]	0.13	[9]
	Discharge time (s)	GM[2]	23.2	[9]
Kitchen sink	Flow rate (L/s)	Max	0.26	[5]
		Min	0.03	[8]
		AM[1]	0.15	[9]
	Discharge time (s)	GM[2]	257	[9]
Washing machine	Flow rate (L/s)	AM[1]	0.2	[9]
	Discharge time (s)	GM[2]	150	[9]

Note: [1]AM: arithmetic mean; [2]GM: geometric mean

4 Results and discussion

4.1 Simulated water demand time series

Figures 3 show the simulation results of the time series of total demand flow rates $q_w(t)$ for all types of appliances in terms of maximum and minimum daily volumetric consumption, on the condition that the water supply system is in use for 100 years. The use of “100 years” was based on the findings that there was no significant difference in the simulation results with an increase in years of operation after 100. Some design guides suggest a 1% failure rate for the design demand flow rate [10]; therefore, 1 out of 100 years was taken as a reference calculation in this study. The time step of the daily demand time series is 1 s.

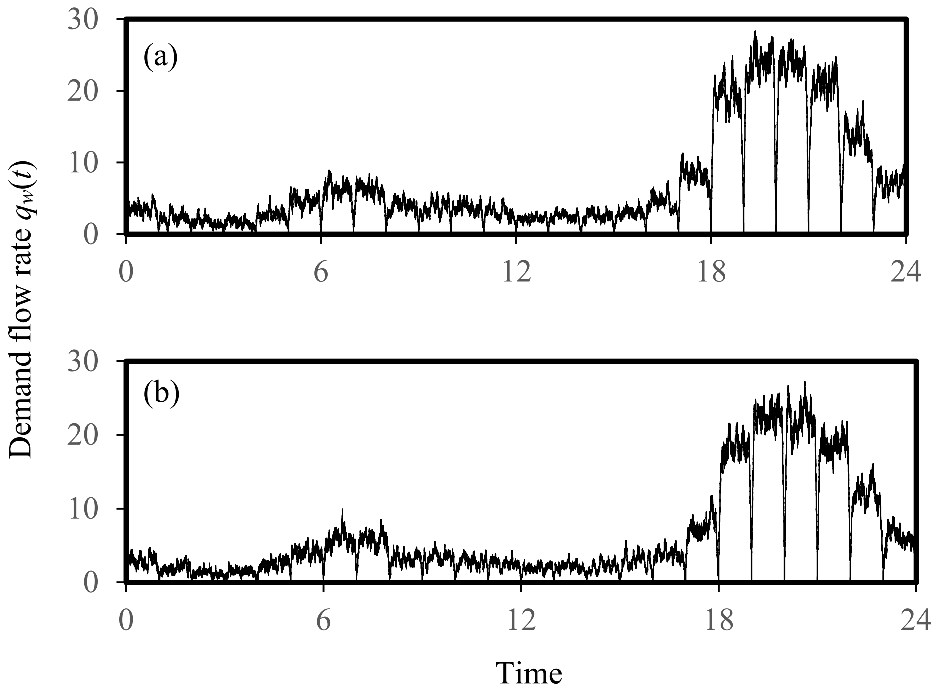


Figure 3 - Total demand flow rates: (a) maximum daily consumption (590.0 m^3d^{-1}); (b) minimum daily consumption (534.8 m^3d^{-1})

The daily water consumptions were acquired by summing the demand flow rates across the time series showing in Figure 3. Results in Figure 3 indicated that the simulated daily consumption range was from 534.8 m^3d^{-1} to 590.0 m^3d^{-1}, with an average of 562.4 m^3d^{-1}.

4.2 Simulated design flow rates for cascade water supply systems

Figures 4 demonstrates the solution pairs (V_3, $q_{o,3}$) for Equation (6) regarding integration time periods τ_o=10, 60 and 300s for the demand flow rates in time series shown in Figures 3. Since the simulated solution pairs with an integration time period τ_o= 1s for the WC demand in a previous study showed no significant difference from those with τ_o= 10s (Wong et al. 2014a), τ_o= 10s was chosen as the minimum integration time period in this study. As demonstrated in Figure 4, a great discrepancy occurred when with a rough integration time period τ_o (e.g. 300s), i.e. the simulated inflow rate with τ_o= 300s was greatly lower than that with τ_o= 10s or 60s, however, while no significant difference was found between the solutions for large storage volumes. With the specific value of tank volume V_3, inflow rate $q_{o,3}$ can be determined from the Figure 4.

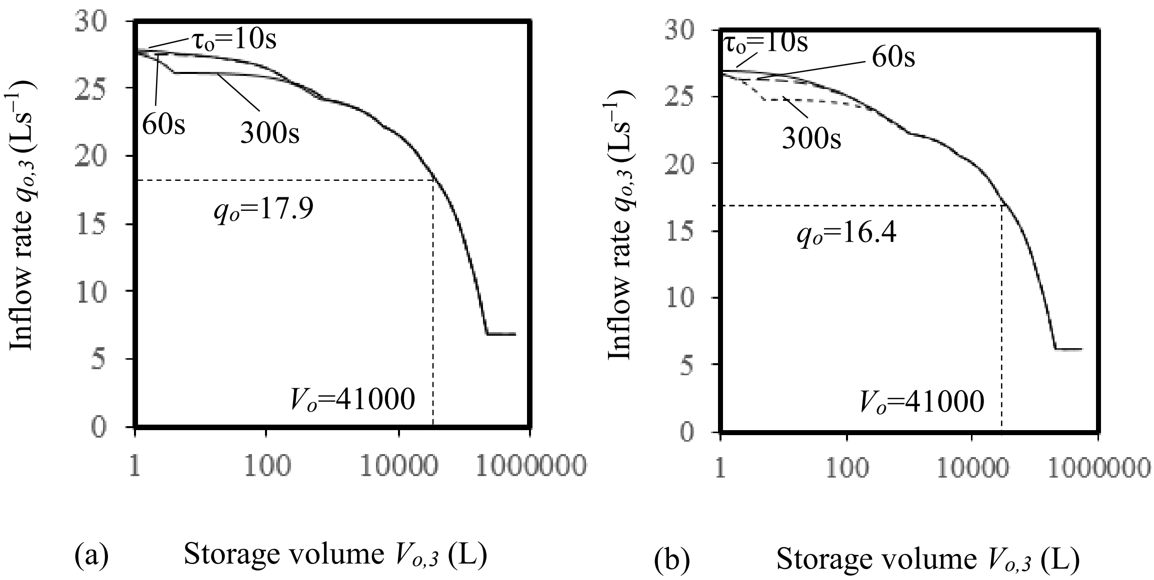


Figure 4 - Solutions of inflow rate and storage volume at Zone 3: (a) for the maximum demand time series in Figure 4(a); (b) for the minimum demand time series in Figure 4(b)

As shown by Equation (7), inflow rate $q_{o,2}$ is influenced by the demand flow rate at Zone 2, the volume of Tank 2 and the inflow rate $q_{o,3}$ to Tank 3. The solution pairs ($q_{o,2}$, V_2) for Equation (7) regarding integration time periods τ_o=10 under different values of V_3 ($q_{o,3}$) are plotted in Figure 5.

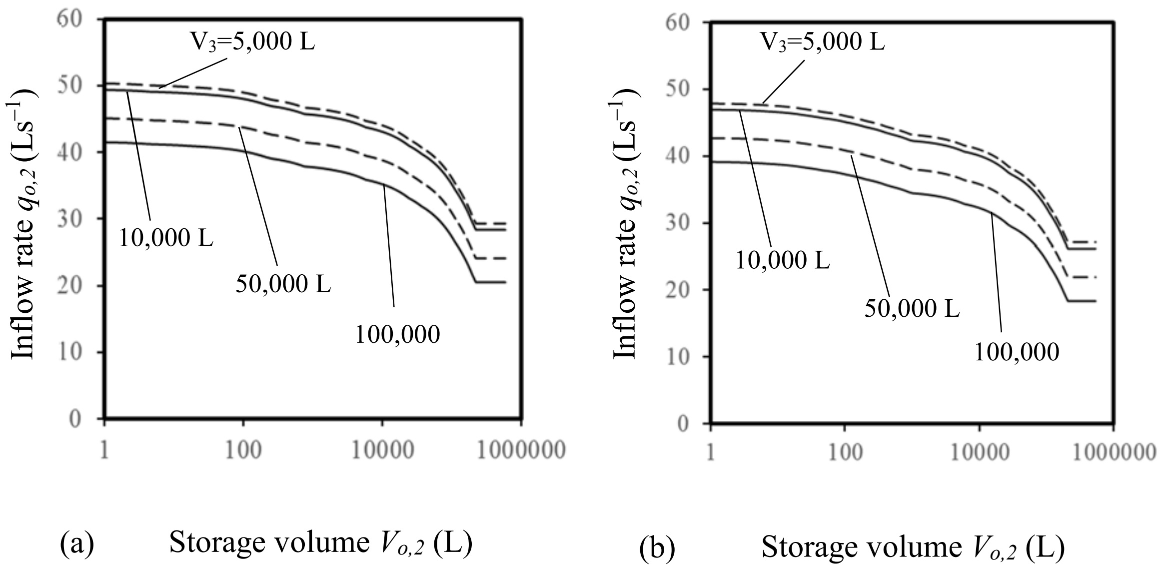
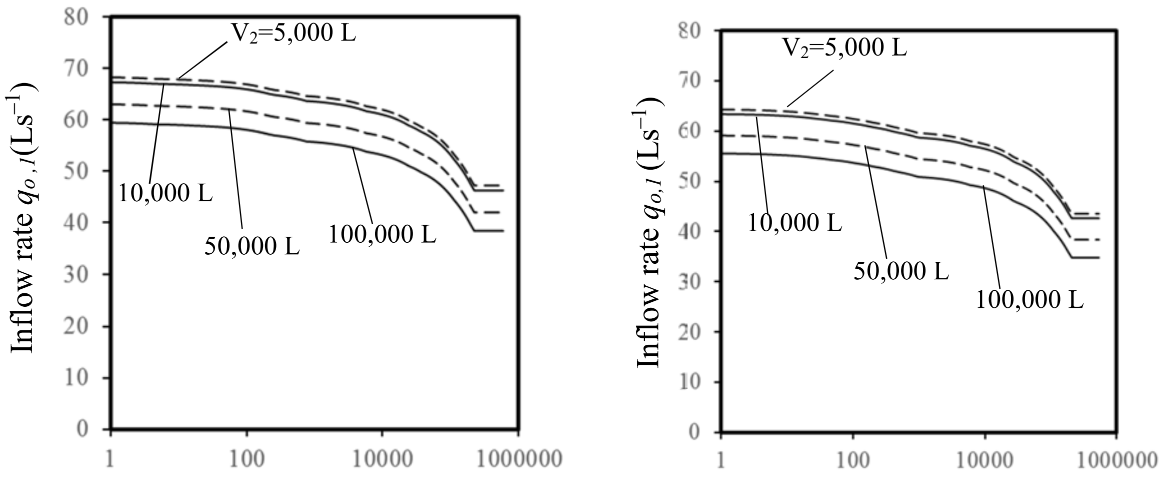


Figure 5 - Solutions of inflow rate and storage volume at Zone 2: (a) for the maximum demand time series in Figure 4(a); (b) for the minimum demand time series in Figure 4(b)

For Hong Kong practice, the total volume of water tanks (including sump and roof tanks, and the proportion of capacity of sump tank to roof tank is 1:3) shall be on the basis of 135 L for each of the first 10 flats and 90 L thereafter for each additional flat [11]. Each zone of the cascade water supply system can be taken as a roof tank water supply system, and assuming the 600 simulated appliances of each type are installed in 600 flats in that zone. Then the tank volume V_3 should be 41000 L (≈ 40838L ($=3/4(135\times10+90\times590)$)). With V_3 = 41000 L, the solution pairs ($q_{o,1}$, V_1) for Equation (8) regarding integration time periods τ_o=10 under different values of V_2 ($q_{o,2}$) are plotted in Figure 6.



(a) Storage volume $V_{o,1}$ (L) (b) Storage volume $V_{o,1}$ (L)

Figure 6 - Solutions of inflow rate and storage volume at Zone 1: (a) for the maximum demand time series in Figure 4(a); (b) for the minimum demand time series in Figure 4(b)

In practical application, the tank size is determined based on the balance of water demand, fire safety requirements and space available in the plant room. As shown in Figures 4-6, since tank storage volume is known, the inflow rate in each zone of the cascade water supply system can be obtained from these graphs. With different water demand pattern in each zone of cascade water supply systems, different correlation graphs of inflow rate and tank storage volume can be obtained using the models proposed in this study. These correlation graphs can be a reference for determining the design flow rates of cascade water supply systems.

5 Conclusion

Super high-rise buildings are popular nowadays around the world, especially in cities with high population density and limited development area, like Hong Kong. The booming of super high-rise buildings arises the concern of water supply system design inside it, and cascade water supply system is commonly used in super high-rise buildings nowadays. However, systematic studies about the design of cascade water supply system are still limited in literature, and currently there are no standards/handbooks that specifically for guiding the design of cascade water supply systems in super high-rise buildings. This study proposed mathematical models and used Monte Carlo simulations to evaluate the design flow rate for a typical cascade water supply system that fed various appliances including showerheads, wash basins, kitchen sinks and washing machines in a super high-rise residential building in Hong Kong. Water demand pattern was obtained first by the Monte Carlo simulations with input data from field surveys. Corresponding to the water demand pattern, graphs about the correlations between the inflow rate in the up-feed pipe and tank storage volume were acquired. In practical application, while the tank storage volume was confirmed, the design flow rate of cascade water supply systems can be determined from these graphs. For the future application with different demand patterns, the correlations between inflow rate and tank storage volume can be obtained based on the Monte Carlo model proposed in this study, and further design flow rate of cascade water supply system can be determined.

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7 Presentations of Authors

Dr. Y. Zhou is a PhD graduate from the Department of Building Services Engineering, The Hong Kong Polytechnic University. Now he is a senior research associate at the Department of Architecture and Civil Engineering, City University of Hong Kong.

Dr. Eric W.M. Lee is an associate professor at the Department of Architecture and Civil Engineering, City University of Hong Kong.

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.

Performance metrics for cold water pipework sizing in the National Construction Code

A. Zeller (1), B. Ashe (2)

(1) alex.zeller@abcb.gov.au

(2) brian.ashe@abcb.gov.au

(1) Project Officer, Australian Building Codes Board, Australia

(2) Director, Australian Building Codes Board, Australia

Abstract

The Australian Building Codes Board (ABCB) is proposing to quantify the Performance Requirement for the sizing of pipework in cold water systems in the next iteration of the National Construction Code (NCC). This is intended to allow practitioners to determine the size of cold water pipework using any method that can suitably demonstrate the required level of performance is met. The metric allows the design of an individual system to be tailored to any combination of fixture types, number of fixtures, fixture flowrates and probability of fixture usage.

The prescriptive standard for the design of water supply systems in buildings in Australia is AS/NZS 3500.1, which is based on Hunter's method of using fixture units to calculate Probable Simultaneous Flow Rate. Hunter's method is premised on the calculation of water demand at the 99th percentile of likely demand during congested use, however the assumed values of flowrates and probability of use of fixtures are fixed.

In reality, different buildings will vary in their fixture flowrates and probabilities of use, and therefore systems are designed at flowrates that can be higher or lower than the 99th percentile of actual demand. The result is that supply water pipework in Australia is frequently oversized, resulting in sub-optimal cost and design outcomes.

The key metric proposed to be included in the NCC Performance Requirement is for pipework water velocity not to exceed 3m/s at the 99th percentile of likely non-zero flow during the hour of peak downstream usage. Pressure-based requirements equal to existing requirements are also specified. Specifying the level of performance that must be achieved by a pipework system, rather than specifying how it must be calculated, will enable designers to use more sophisticated methods of determining the appropriate size of pipework, allowing improved design outcomes in cold water systems in Australia.

Keywords

Plumbing water supply; building water pipe sizing; design flow rate; performance based design; regulation

1 Introduction

The National Construction Code (NCC) contains the minimum regulatory requirements for buildings, structures, plumbing and drainage systems in Australia.

The NCC is a performance-based code, where compliance is demonstrated by meeting the Performance Requirements. In NCC 2019, the Performance Requirement that determines the sizing of cold water pipework is qualitative in nature, making it difficult to demonstrate compliance with the requirement without referring to the prescriptive optional method of demonstrating compliance, known as a Deemed to Satisfy (DTS) method. This paper investigates how the Performance Requirement may be changed in NCC 2022 to be quantitative and objective, clarifying the level of performance that must be achieved for an alternative method to demonstrate compliance with the Performance Requirement.

There are a number of valid methods of sizing cold water pipework which aren't currently referenced in the NCC. By clarifying the level of performance that must be achieved by a cold water system, any method that can satisfactorily demonstrate that the required level of performance is met may be used to meet the Performance Requirement.

Alternative methods may already be used to demonstrate compliance with the existing qualitative Performance Requirement. However, subjective requirements act to discourage practitioners due to lack of clarity in the level of performance that must be demonstrated, and lack of confidence that a regulating authority will interpret the level of performance required to be at the same level as the judgement of the practitioner. A quantitative Performance Requirement is intended to allow for improved design outcomes in a cold water system by more easily allowing design methods that are more sophisticated and accurate than the DTS method.

2 The basis of current design requirements

The current Performance Requirement for the sizing of cold water piping, as included in NCC 2019, is shown in Figure 1.

BP1.2 Design, construction and installation

(1) A cold water service must ensure the following:

(a) Water is provided at *required* flow rates and pressures for the correct functioning of fixtures and appliances.

Figure 1: NCC 2019 Performance Requirement

The Performance Requirement is fundamentally qualitative and subjective, making it difficult to demonstrate that the requirement is met without referencing the DTS method of compliance. To determine the de-facto level of performance specified by the Performance Requirement, the DTS methodology must be considered.

The DTS method references AS/NZS 3500.1, which in turn specifies three primary parameters that relate to the sizing of cold water pipework:

(1) Maximum pipework design velocity of 3m/s at the Probable Simultaneous Flow Rate (PSFR)
(2) Minimum fixture design pressure of the greater of 50 kPa, or minimum required by the fixture to function
(3) Maximum fixture design pressure of 500kPa

In the case of (1), PSFR is calculated using the loading unit methodology, which was originally developed in the early 20th century by Roy B. Hunter (Hunter, 1940). The loading unit methodology described by Hunter is premised on the calculation of PSFR at the 99th percentile of likely demand during congested use. The loading unit methodology has provided an easy to use method of cold water pipework sizing, however the method also has limitations. The assumed values of flowrates and probability of use of fixtures are fixed when using the loading unit method, meaning designs cannot be tailored to the unique circumstances of different buildings.

Including the above minimum performance metrics within the Performance Requirement itself is considered in the following section.

3 Performance metrics for inclusion in the NCC Performance Requirement

In the public comment draft of NCC 2022 it is proposed to reference the three identified parameters directly within the Performance Requirement of the NCC. The Performance Requirement for cold water pipework sizing is tentatively proposed to be re-written, as shown Figure 2.

A cold water service must ensure the following:

(a) Pipework water velocity must not exceed 3m/s at the 99th percentile of likely non-zero flow during the hour of peak downstream usage; and
(b) The water pressure at any outlet must not be less than the greater of 50 kPa or the minimum pressure required by the fixture to function; and
(c) The water pressure at any outlet must not exceed 500 kPa.

Figure 2: Draft NCC 2022 Performance Requirement

The key difference between the proposed Performance Requirement and the Deemed to Satisfy method is the explicit inclusion of the flow rate to be considered at the 99th percentile of likely non-zero flow during the hour of peak downstream usage. In contrast, Hunters work considers the 99th percentile of flow during congested use.

The new metric is intended to align with established contemporary methods of performance-based cold water system design, and is for instance similar to the underlying performance target of the IAPMO Water Demand Calculator (Buchberger, Omagomi, Wolfe, Hewitt, Cole, 2017).

Restating the Performance Requirement in this way is intended to add clarity on the use of methods of sizing cold water pipework other than the DTS loading unit method. The loading unit method has fixed assumptions in regards to expected usage patterns of plumbing fixtures. In reality, plumbing fixture usage may vary between building types. For instance the usage pattern in an apartment block may vary significantly from usage in an office building. This will cause the loading unit method to result in design flowrates to vary from the originally modelled 99th percentile of likely flow rate, potentially resulting in sub-optimal sizing of plumbing systems. Quantifying required system performance, rather than specifying a particular method, is intended to allow practitioners to more accurately size pipework in cold water systems.

4 Further work

This work is one step to allowing improved methods of designing cold water systems in Australia to show compliance with the NCC. Other areas the Australian Building Codes Board are interested in exploring further include:

- Consideration of unintended consequences.
- Direct reference in the NCC to methods of demonstrating compliance with the Performance Requirement.
- Collation of fixture usage data for different building types to aid practitioners in completing designs to meet the Performance Requirement.
- Quantification of other plumbing Performance Requirements in the NCC.

5 Conclusion

Including quantified metrics in the NCC Performance Requirement for cold water pipework sizing is intended to give practitioners and regulators confidence in assessing methodologies that are not referenced in the DTS of the NCC.

Specifying the level of performance that must be achieved by a pipework system, rather than specifying how it must be calculated, will allow designers to use more advanced methods of calculating the probable simultaneous flowrate in cold water systems, and to size pipework accordingly, allowing improved design outcomes in cold water systems in Australia.

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7 Presentation of Authors

Alex Zeller is a Project Officer and Chartered Engineer at the Australian Building Codes Board. Alex works to quantify the Performance Requirements of the National Construction Code to reduce uncertainty due to the possibility of subjective interpretation. Prior to joining the ABCB Alex worked as a mechanical building services engineer.

Brian Ashe is a Chartered Fire Engineer and Director at the Australian Building Codes Board with over 20 years' experience delivering risk management solutions across a diverse range of organisations.

Verification of accuracy of the dynamic calculation method for cold and hot water supply loads by each fixture usage model and unit model as the whole in an office building

Saburo Murakawa (1), Daisuke Ikeda (2)
(1) saburo.murakawa@gmail.com
(2) d.ikeda@socon.co.jp
(1) Hiroshima University, Japan
(2) Sogo Setsubi Consulting, Japan

Abstract

It has been pointed out that the estimated values by the conventional calculation methods of water consumption show considerably larger than the actual demands in buildings because of the progress of water saving, including problems of the existing calculation methods. Therefore, a method for accurately estimating the loads is required in the optimal design of cold and hot water supply systems.

The authors have developed a new dynamic calculation method of water supply loads in buildings that can estimate a series of design values from instantaneous maximum flow rate to water consumption per hour and day. The developed computer program is called MSWC: Mutakawa's Simulation for Water Consumption, which has been presented many times at international symposium of the CIB-W062. The calculation models are proposed not only as each fixture using behaviour of people but also as one unit of the whole in a building. As for the method, at present, verification of the calculation accuracy has been carried out by plumbing designers in Japan through comparison of measurement values in buildings.

In this paper, the authors show the calculation results of water supply loads in the toilets and the hot water service rooms in an office building called TE. The calculation results based on each fixture usage model by the employees in the building are compared with the measurement results recorded at one second time intervals, and both results are shown to be closely similar. As for the building, the authors propose unit model treated as the whole building, and the calculated instantaneous maximum flow rates by the unit model are compared with the calculated results by each fixture usage model. Also, the hourly and daily values calculated by the unit model are compared with measurement values, and usefulness of the unit model is discussed.

Keywords

Office building; Toilet; Hot-water service room; Water supply load; Simulation technique; Calculation model using each fixture; Unit model as a whole building

1 Introduction

The authors have developed a 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 presented at the international symposium of CIB-W062, as shown in the references. 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; Murakawa's Simulation for Water Consumption. Now, the program is improved for plumbing designers to easily operate to analysis the water demands in buildings. And the program is being prepared for public release later this year

In order to expand the application of the simulation technique, the authors proposed the calculation methods by setting up the model based on the BEMS data recorded every hour at the 42nd and 43rd CIB-W062 symposium (2016,2017). As contents related to these papers, in this paper, the accuracy of the calculation results is confirmed by comparison with the measurement values of an office building that is called the TE-building. Also, the authors propose unit models treated as the whole building. The calculation values based on the unit model are compared with the measurement results and calculation results by each fixture usage model. And, the authors discuss the validity of unit model application.

2 Analysis of water supply loads in an office building

2.1 Simulation models of each fixture usage to apply the MSWC program

The investigated building is an office building located in Tokyo. The scale of the building is 6 floors above ground, with a total floor area of 2,384m^2. The city water is directly supplied to the fixtures installed at each floor by the water service system with booster pump. In this paper, the values per second which are measured on August 5th, 2015 are used for comparison with the calculated values. By the way, the measurement values applied in this paper were slightly recalibrated for zero point. Therefore, the values are slightly different from those of previous paper[12)].

The simulation models of the TE- building are shown in Table 1. The number of fixtures for each usage is the actual number of fixtures installed in the TE-building. The average discharge flow rate and duration time of water discharge of water closet for male and

Table 1 Simulation models of each fixture usage in the TE-building

			Male's restroom			Female's restroom		Hot-water service room (summer)		
			Water closet	Urinal	Wash basin	Water closet	Wash basin	Mixed water	Hot water	Cold water
Arrival model	Arrival interval distribution		Exponential distribution, randam arrival							
	Arrival ratio	[people/min]	Set in each time zone every hour							
	Number of fixtures		6	12	7	13	12	6	6	6
Occupancy model	Average dulation time of occupancy	[sec]	260	37	12	110	17	45	16	14
	Distribution		Erl.3	Erl.7	Hyp.2	Erl.3	Hyp.2	Exp.	Exp.	Hyp.2
Water discharge model	Average time of water discharge	[sec]	17.2	5	6	17.2	11	45	16	14
	Distribution		Exp.	Erl.10	Erl.3	Exp.	Erl.3	Exp.	Exp.	Hyp.2
	Average flow rate	[L/min]	49.8	30	5	49.8	5	10	8	10
	Distribution		Erl.6	Erl.10	Erl.10	Erl.6	Erl.10	Erl.3	Erl.4	Erl.3
Fixture operation model	Average frequency of fixture operation		1.60	1.00	1.00	1.30	1.00	1.00	1.00	1.00

Note: The values of shaded parts apply the office standard values in the MSWC program.

female are set up based on the measured values. Each approximate distribution shown in Table 1 conforms to the standard model of office building on the MSWC program. The average values of each fixture, except water closet, are also according to the standard values of the MSWC program.

According to the questionnaire survey, the maximum number of occupant people per day in the TE-building was 136 men and 52 women, and the ratios of hourly presence to the total occupied people per day are shown in Figure 1. The total number of men and women during the 9 o'clock time zone reaches about 1.0 as the ratio. After that, the ratio goes down from 12 o'clock to 16 o'clock time zones due to increase of people going out, and the ratio returns to about 1.0 at the time zone of 18 o'clock. The percentage of men shown at night is relatively high compared to that of women. The number of women decreases slightly from 10 to 11 o'clock time zones, but generally they are present at the office during working hours from 9 to 17 o'clock.

Figure 2~Figure 4 show the hourly frequencies of each fixture usage per person in the toilets and the hot-water service rooms of the TE-building. When the number of people in the building is small, the frequencies of fixture usage per person during one hour at early morning and night increase.

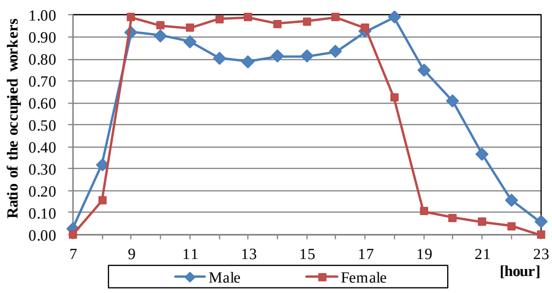


Figure 1 Model of the occupied ratio of workers per hour to the total occupied people per day

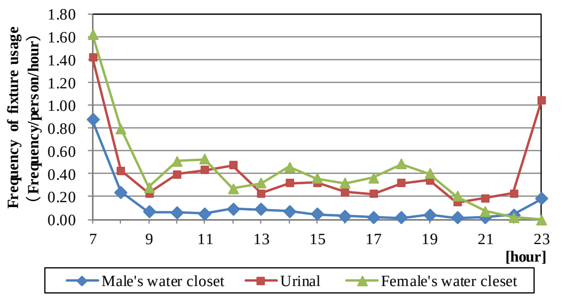


Figure 2 Hourly frequencies of fixture usage per person; in the system of toilet bowl

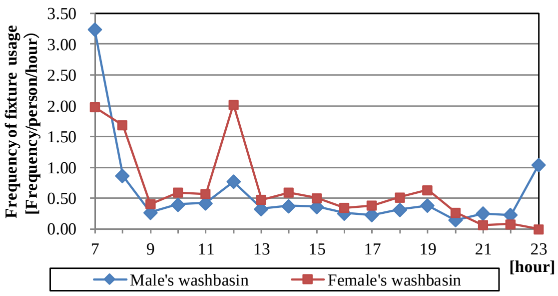


Figure 3 Hourly frequencies of fixture usage per person; in the system of washbasin

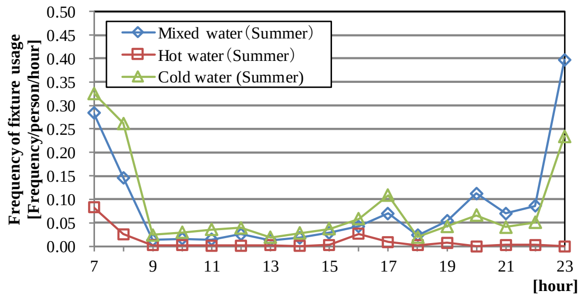


Figure 4 Hourly frequencies of fixture usage per person; in the system of hot-water service room

2.2 Comparison between the measurement results and the calculation values

2.2.1 Instantaneous water supply loads

The fluctuations of measured instantaneous flow rates per minute are shown in Figure 5. Also, Table 2 shows statistical values of instantaneous water supply loads at each time interval of 1 second to 60 seconds based on the fluctuations of water supply flow rates throughout the day. However, the values of 1 second and 2 seconds time intervals were analysed for 3 hours, which is a time zone from 10 to 12 o'clock.

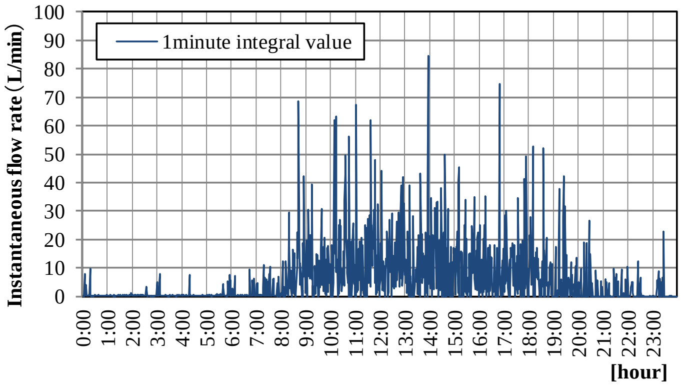


Figure 5 An example of the fluctuations of flow rates per minute by measurement

Table 2 Statistical values of instantaneous water supply loads in each time interval; in case of an actual measurement

	Time interval	Falure factor						
		Maximum	0.1%	0.2%	1.0%	2.0%	5.0%	10.0%
Whole building measurement value August 5, 2015 〔L/min〕	1 second	202.2	152.2	136.9	111.8	102.2	82.4	61.4
	2 seconds	187.6	150.2	135.0	108.8	100.2	81.4	58.4
	5 seconds	198.7	128.5	111.6	87.8	75.6	40.5	16.3
	10 seconds	163.6	120.2	109.0	78.8	68.0	37.8	19.6
	60 seconds	84.5	72.0	67.6	44.8	35.4	25.0	17.9

Note: 1 second and 2 seconds values indicate the values from 10 to 13 o'clock

According to Figure 5 and Table 2, it is predicted that the values of failure factor 0.2% by 60 seconds time interval exceeded 60 L/min will occur only several times throughout the day. However, in case of instantaneous flow rates by 5 seconds time interval, the occurrence frequency is 1.65 times compared to the value of 60 seconds time interval, and the frequency of occurrence in 10 hours from 8 to 18 o'clock is estimated to be 14 times or more. Therefore, on the system installed with the fixtures of large water flow rate in a short time such as water closet with flush valve, it may be appropriate to determine the instantaneous maximum water supply loads in the range of failure factor 0.2 to 1.0% based on the data of flow rate fluctuations at time intervals of 5 to 10 seconds.

The calculation values of instantaneous flow rates in each failure factor are shown in Figure 6 for each time zone of one hour. The statistical values were analysed based on the data of 1 second time interval to find the correspondence with 1 second measurement values. In case of simulation, as the number of trials increases, the appearance of larger maximum value is predicted. Therefore, at the time zone of 13 o'clock, the calculated maximum value is about 270 L/min, which is higher than the measurement value.

However, the calculated values of failure factor 0.1%, 0.2% and 1.0% closely approximate the values of 1 second and 2 seconds time intervals in Table 2 shown as measurement values.

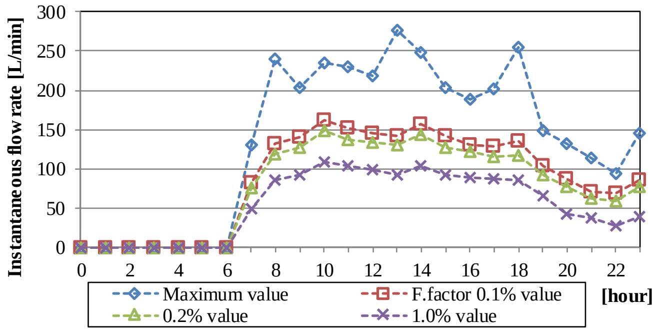


Figure 6 Calculation values of instantaneous water supply loads in each failure factor

One sample showing the average water supply loads per day was selected from 100 trials of the simulation. Then, using the case of instantaneous flow rates of 1 second time interval throughout the day, the results of the same statistical processing as Table 2 are shown in Table 3. When the calculated values and the measurement values are compared with failure factor 0.2% value, the values of 1 second and 2 seconds time intervals approximate each other. However, the calculated values by 5 seconds and 10 seconds time intervals are approximately 10 L/min lower than the measurement values. On the other hand, the calculated results by 60 seconds time interval is about 15 L/min higher than the measured values. From the results shown above, it can be said that the calculation results by using simulation models well represent the fluctuations of instantaneous water supply flow rates in the TE-building.

Table 3 Statistical values of instantaneous water supply loads in each time interval; in case of the calculation results by simulation

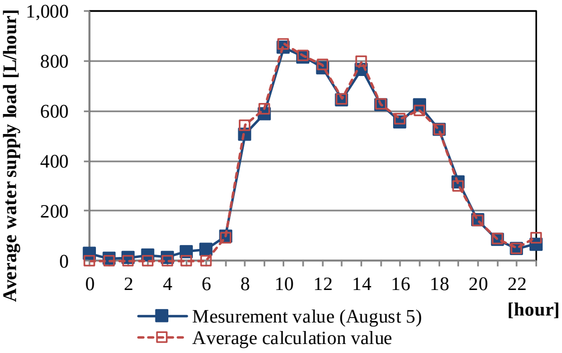
	Time interval	Falure factor						
		Maximum	0.1%	0.2%	1.0%	2.0%	5.0%	10.0%
Whole building calculation value ［L/min］	1 second	174.4	164.5	138.3	104.9	92.8	70.5	49.3
	2 seconds	174.4	164.5	136.6	103.8	92.8	70.5	49.3
	5 seconds	183.7	122.2	101.3	82.6	69.1	41.1	17.3
	10 seconds	181.1	116.1	98.0	81.0	65.9	38.0	16.6
	60 seconds	100.8	87.0	84.9	61.6	46.9	29.2	17.2

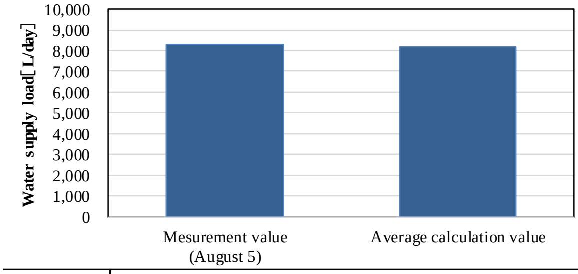
Note: 1 second and 2 seconds values indicate the values from 10 to 13 o'clock

2.2.2 Hourly and daily water supply loads

A comparison of the measurement and calculation values for water supply loads per hour is shown in Figure 7. Since the frequency of fixture usage as the calculation model was set based on the measurement values for each hour from 7 to 24 o’clock, the measurement and calculation values per hour are closely similar. Both values increase to 500 L/h or more from 8 to 9 o’clock at the beginning of work, and the values show about 850 L/h which becomes the maximum at 10 o’clock time zone throughout the day, decrease after 18 o’clock time zone.

A comparison of daily water supply loads based on the measured and calculated values is shown in Figure 8. The measured value and the average value based on 100 simulation trials are almost same.





Recalibrated mesurement value [L/day]	Calculation value [L/day]				
	Average	Maximum	F.factor 0.1%	0.20%	1.0%
8,315	8,193	9,386	9,386	9,386	9,317

Figure 7 Comparison of the measurement and calculation values for the water supply loads per hour

Figure 8 Comparison of the measurement and calculation values for the water supply loads per day

3 Setting of the unit models as the whole in an office building to apply the MSWC program

Based on the simulation models for each fixture usage of the TE-building shown in Table 1, we set up the simulation model for the system including toilets and hot water service rooms as one unit of the whole in a building. Also, we set up the simulation model for the system including water closets and urinals as one unit for the whole toilet. Each unit model is made based on the fluctuations of instantaneous flow rates of 5 seconds time interval occurred by uses of each fixture installed in the system.

In order to explain for setting of the unit model, an example of schematic instantaneous flow rates is shown in Figure 9. From the fluctuations of flow rates in the figure, the load continued with same flow rate is regarded as one usage of water in the system. This value of flow rate is extracted as one sample of continuing water discharge flow rate in the

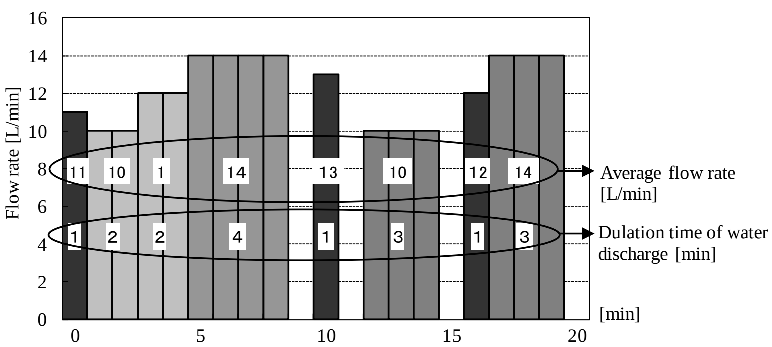


Figure 9 Analysis to set up the unit model of flow rate and duration time of water discharge based on instantaneous flow rates in a water supply system

system, and the duration time of the same flow rate is extracted as one sample. By accumulating the values of each discharge water flow rate and duration time obtained through the simulation, the average values and approximate distributions are set up for the unit model.

Table 4 shows the simulation models as “the whole building unit” and “the toilet bowl unit”. The average discharge water flow rate and the average duration time in the whole building unit are 24.7 L/min and 6.0 seconds, respectively, and similarly, each value of the toilet bowl unit shows 33.6 L/min and 6.9 seconds. The average flow rate of the whole building unit is smaller than this value of the toilet bowl unit because the value of zero flow rate is not included in the calculation. The hourly frequencies of water usage of each unit are shown in Figure 10 as percentage to the frequency of water usage per day. The total frequency per day can be obtained by dividing the daily water consumption by the average amount of water consumption per frequency, which is calculated by multiplying the average flow rate and average duration time of discharge water flow rate in each unit. As shown in Table 4, the daily frequency of water usage of the whole building unit is about twice as high as that of the toilet bowl unit.

Table 4 Simulation models as the whole building unit and the toilet bowl unit

		Whole building unit	Toilet bowl unit
Water discharge model	Average dulation time of water discharge	6.0	6.9
	Distribution	Hyp.2	Hyp.2
	Average flow rate	24.7	33.6
	Distribution	Exp.	Exp.
Frequency	Hourly frequancy	See Figure 10	
	Daily frequency	3314	1724

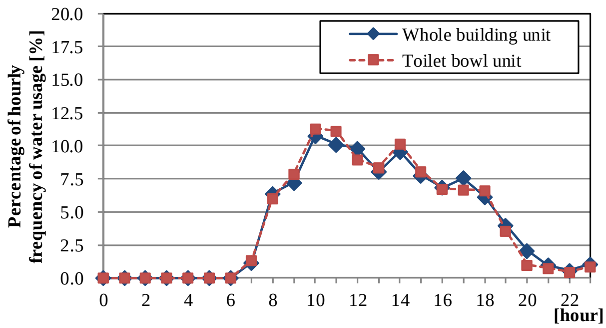


Figure 10 Unit models of the hourly frequencies of water usage as percentage to the frequency per day

4 Verification of accuracy for the calculation results by using the unit models

As instantaneous water supply loads calculated by the simulation, Figure 11 shows the hourly results of failure factor 0.2% value with 5 seconds time interval of flow rates which applied the models based on the individual fixture usage and the whole building unit. Also, the failure factor 1% values with 5 seconds time intervals of flow rates which were calculated by the model of toilet bowl unit are shown in the same figure. The calculated values of flow rate by the model of toilet bowl unit show large fluctuations due to the occurrence of short time peak compared to that by the whole building unit, so we set the failure factor 1% values as the maximum instantaneous water supply load.

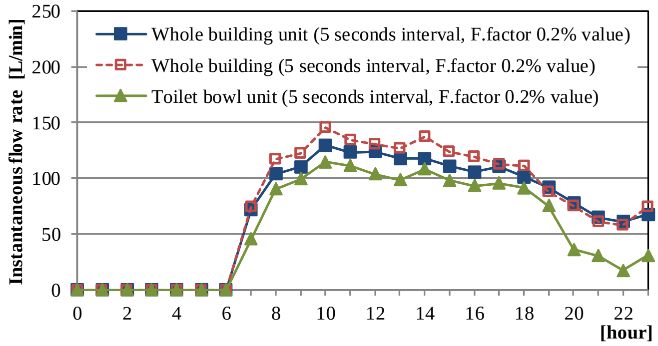
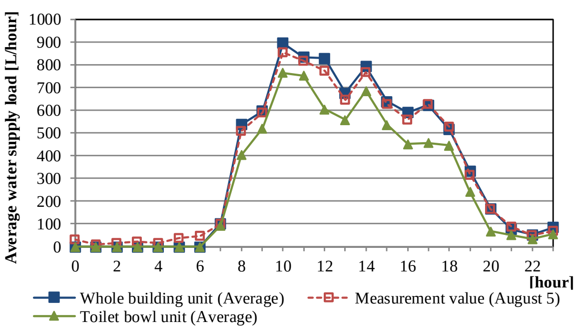


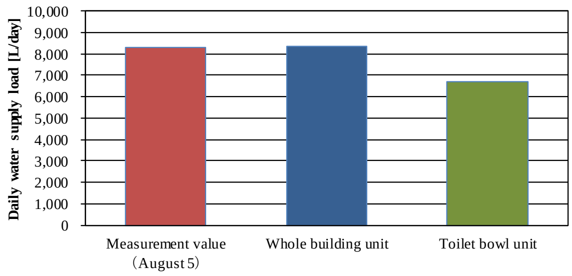
Figure 11 Calculation results of the instantaneous water supply loads by each model

During 10 hours of working hours from 8 to 18 o'clock, the hourly maximum flow rates calculated by the model of individual fixture usage show a slightly larger than the calculated value by the unit model, but it can be said that the both results are almost similar. It will be understood from these simulation results, that the setting of probability values of failure factor and time intervals of flow rates will be important for prediction of the maximum water supply load.

Figure 12 shows a comparison between the calculation results by the whole building unit and the measurement values for water supply loads per hour. In addition, the figure also shows the calculation results by the model of toilet bowl unit. Both values of the building as the whole are almost same in each time zone. The hourly fluctuations of the calculated values by the model of toilet bowl unit show the same fluctuations pattern as the whole building unit, but each value calculated by the model of toilet bowl unit is slightly lower.

Moreover, the comparison of the average water supply load per day is shown in Figure 13 by taking the same three cases as Figure 12. The lower part of the figure shows the statistical processing values based on the calculated results per day by the whole building unit and the measurement value. The measured value closely approximates the calculated average value.





Recalibrated measurement value [L/day]	Calculation value (Whole building unit) [L/day]				
	Average	Maximum	F.factor 0.1%	0.2%	1.0%
8,315	8,333	8,999	8,999	8,999	8,816

Figure 12 Comparison of the measurement and calculation values for the water supply loads per hour

Figure 13 Comparison of the measurement and calculation values for the water supply loads per day

5 Conclusion

The authors have attempted to calculate the water supply loads for various buildings using the developed simulation program; the MSWC program. The usefulness of this dynamic calculation method has been clarified up to now at the CIB-W062 symposium.

In this paper, we tried to further enhance the applicability of the dynamic calculation method to practical plumbing design. After clarifying that the results of measured values and calculated values by simulation models for each fixture usage agree well for an office building, we considered to utilize the hourly water consumption which is recorded by BEMS etc. in order to set up the calculation models. Such hourly data is generally measured for the whole building or the same water supply system. As for setting a calculation model based on these data, it is necessary to regard the entire building or the system as one unit.

Therefore, based on the instantaneous flow rate fluctuation patterns of the whole building and the toilet flushing system which were calculated in an office building, two models were set, which are called “the whole building unit” and “the toilet bowl unit”. It was clarified that the calculation results using the whole building unit agrees well with the calculation values obtained from the usage of individual fixtures, which also closely approximate the measured values.

The accuracy verification of the calculation results by using the unit model as a whole building clarified that the model of other use buildings for which the calculation conditions have not been shown can be set by utilizing the recorded hourly water consumption data. With the setting of such a model, the versatility of the MSWC program is expected to be widespread.

Acknowledgment

The measurement of water demands in the TE-building shown in this paper was carried out at the laboratory of Professor Kyosuke Sakaue, Meiji University. And the information and measurement data of the subject building were provided by this laboratory. The authors appreciate for the kind cooperation.

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7 Presentation of Authors

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 the MSWC program. In addition, he is working to spread the harvesting of rainwater in buildings and urban areas.

Mr. Daisuke. Ikeda works as a design engineer at the company of Sogo Setsubi Consulting after completing master program at Hiroshima University, and he is currently engaged in the planning and design of building services engineering. In addition to practical design work, he is researching and developing a new dynamic calculation method of cold and hot water supply loads jointly with Dr. S. Murakawa et al.

Study on Force-Feed and Gravity Combined Drainage System Corresponding to Conversion of Business Building

G. Z . Wu (1), Masayuki. Otsuka(2), Yudai Motomura(3), Ryota Oba(4)

1. kure@kanto-gakuin.ac.jp
2. dmotsuka@kanto-gakuin.ac.jp
3. motomura.yuudai@takenaka.co.jp
4. m18J3002@kanto-gakuin.ac.jp

(1), (2), (4) Dept. of Architecture and Environmental Design, College of Architecture and Environmental Design, Kanto Gakuin University, Japan
(3) Takenaka Corporation, Japan

Currently, in Japan, methods for effectively using building stock are being rigorously examined, and the conversion of existing buildings, as well as the renovation thereof, is attracting much attention. Construction design with consideration of conversion requires a method that allows flexible plumbing to create space for toilets, basins, etc., and a "force-feed drainage system" is one such method which is attracting interest. In this drainage system, a force-feed pump is connected to a sanitary fixture, and wastewater can be discharged through a small-diameter drainage pipe without gradient restriction. Even in the case where some floors have not been laid with drainage pipes underneath, smooth drainage is ensured by combining the force-feed drainage system with gravity-type horizontal drain branches that receive wastewater from upper floors. This also realises the conversion of a target space to a plumbing space for a kitchen, a toilet, etc. In this paper, based on the assumption that said system is installed to an existing drainage stack system, the drainage capacity of an experimental stack system and the drainage capacity of the existing stack system combined with a force-feed drainage type toilet system are compared, and possible influence on the drainage capacity in practical use is discussed.

Keywords

conversion; force-feed drainage system; business building

1 Introduction

Currently in Japan, methods for effectively using building stock have been vigorously discussed, and much attention has been paid to the conversion of existing buildings as well as the renovation thereof. Construction design with consideration of later conversion seeks a practical method that allows flexible plumbing to create space for toilets, washbasins, etc., and a “force-feed drainage system” is one such method which is attracting interest. In this drainage system, a force-feed pump is connected to a sanitary fixture, and wastewater can be discharged through a small-diameter drainage pipe without gradient restriction. By using this drainage system, even if a floor has not been laid with drainage pipes underneath, as shown in Fig. 1, the existing gravity-type horizontal fixture drain branch can be used for drawing wastewater down from the floor above, thereby allowing flexible plumbing to create sanitary space. The authors of this report proposed this system as a “force-feed and gravity combined drainage system” comprising a force-feed type toilet connected to the existing horizontal fixture drain branch of the floor above and examined the drainage performance and practicality of the system by using an experimental horizontal fixture drain branch[1].

In this report, experiments were carried out on an experimental drainage stack system, based on the assumption that the force-feed and gravity combined drainage system was installed to an existing drainage stack, and how the drainage performance could be influenced was discussed.

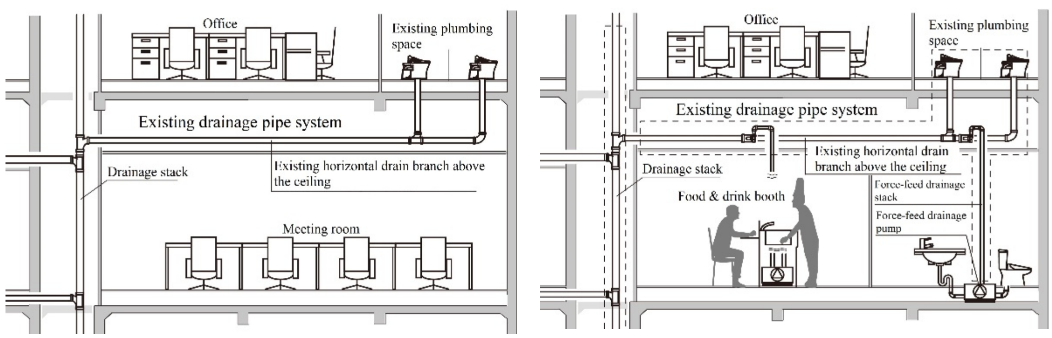


Fig. 1 Concept of office conversion

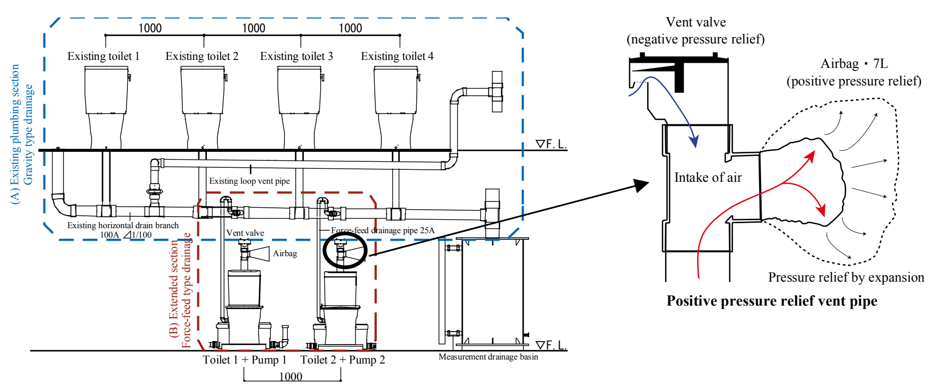


Fig. 2 Force-feed gravity combined drainage system[1] and positive pressure relief vent pipe

2 Experiment overviews

In this study, a force-feed drainage system for toilets was applied to an existing drainage stack system, and it was necessary to quantitatively identify how the combined system would affect the drainage performance. Therefore, as a preliminary stage, drainage loads were applied to the system at different constant flow rates, in a manner that simulated real load conditions, to determine the drainage performance of a standard system which could be used for comparison. For this purpose, a “constant flow rate drainage load experiment” was carried out, and a “combined drainage load experiment” was also carried out to identify the drainage performance in introducing a force-feed drainage type toilet system to the abovementioned system.

2.1 Experimental horizontal fixture drain branch system

Fig. 3 shows plan and elevation views of the force-feed drainage type toilet system as installed. Fig. 4 illustrates an experimental drainage stack system comprising the force-feed drainage type toilet system connected to the drainage stack in a manner that simulates the case of a high-rise building. The horizontal fixture drain branches installed on the 7th, 8th and 9th floors of the system are connected to constant flow rate discharge devices which are capable of applying drainage loads at constant flow rates from said floors to the experiment drainage stack system. Moreover, force-feed drainage type toilets are installed on the 7th and 8th floors, from which drainage loads are applied to identify how the drainage performance of the drainage stack system is affected. As for the measurement/evaluation items, the

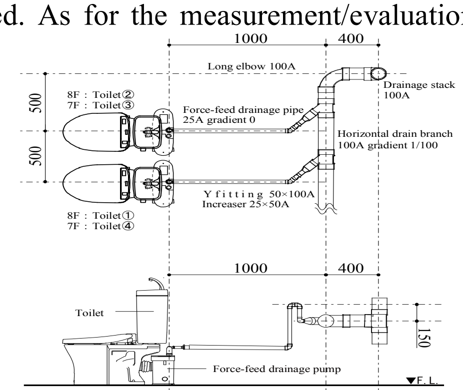
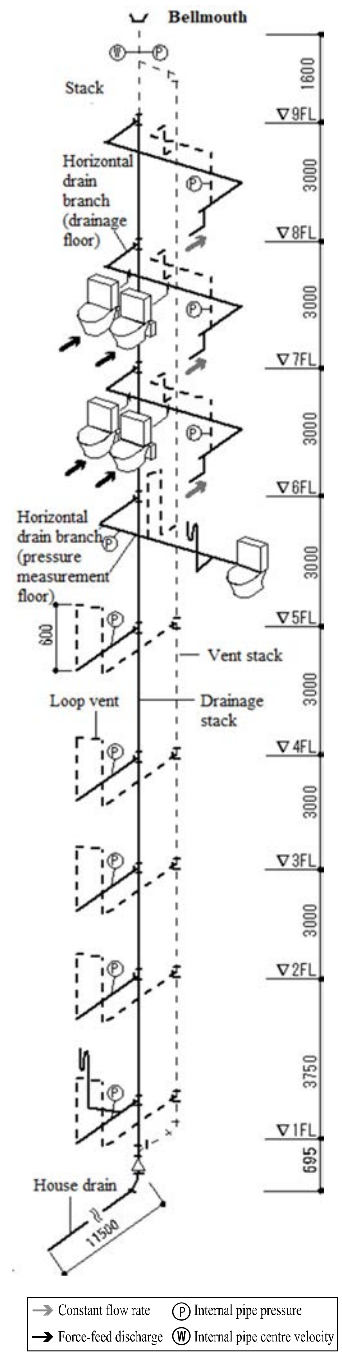


Fig. 3 Force-feed drainage type toilet system - plan and elevation views



Pipework	Pipe dia.	Gradient
Stack vent	100A	-
Drainage stack	100A	-
Horizontal drain branch (drainage load floor)	100A	1/100
Horizontal drain branch (pressure measurement floor)	75A	1/50
Vent stack	75A	-
Loop vent pipe	50A	-
House drain	125A	1/150

Fig. 4 Experimental drainage stack system

internal pipe pressure P was measured near the horizontal fixture drain branch on each floor, and the trap seal loss ΔH of the experimental trap P and the toilet trap installed on the 1st and 6th floors were also measured. Incidentally, the pipe diameters and gradients of the pipes used are also shown in Fig. 4.
Moreover, the force-feed drainage pump in Fig. 3 was used according to the specifications shown in Table 1. The pump body was directly connected to the discharge port of the experimental toilet and was provided with a positive pressure relief vent pipe in the upper part thereof (Fig. 2).

Table 1 Experimental force-feed drainage pump

Specifications	For sewage and drainage
	Wall to core 155mm
	Activated when 3L of water is discharged
	Max. lift 5m (approx. 50kPa)
	Max. horizontal pumping distance 100m

2.2 Drainage load methods

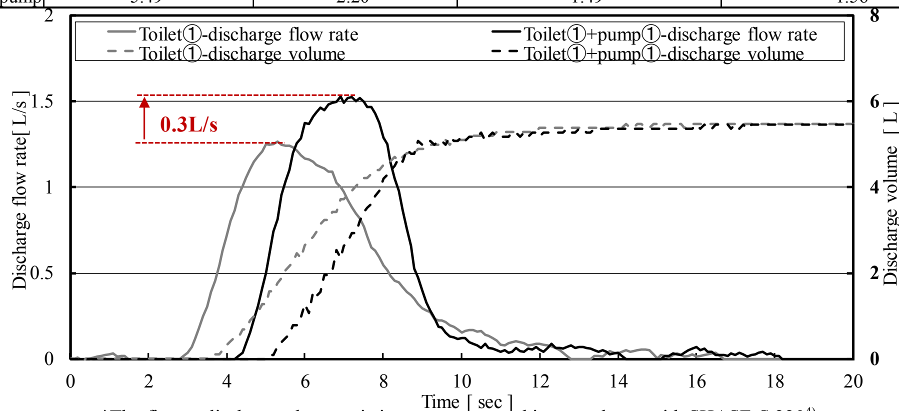
(1) Constant flow rate drainage load method
Drainage loads were applied at constant flow rates in a manner that simulated the use of multiple toilets (see the gravity type drainage system in Fig. 2 (A)), and the experiment was carried out in accordance with SHASE-S 218[2)]. The experimental drainage stack system used for this study is assumed to be for a 9-storey building with 4 toilets installed on each floor. In accordance with the steady flow rate method of SHASE-S 206[3)], the drainage load flow rate Q_L in the drainage stack is calculated to be approximately 7.5L/s (when the average fixture discharge interval T_0 is 190[s]). Accordingly, using the drainage load patterns shown in Table 2, loads at flow rates of 0.5 to 2.5L/s were applied from the 7th, 8th, and 9th floors with total drainage load flow rate ΣQw of 7.5L/s as an upper index.

Table 2 Drainage load patterns (constant flow rate drainage experiment)

Drainage floor	No.	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12	No.13	No.14	No.15
9F	Constant flow rate											0.5	1.0	1.5	2.0	2.5
8F		0.5	1.0	1.5	2.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
7F							0.5	1.0	1.5	2.0	2.5	2.5	2.5	2.5	2.5	2.5
Total load flow rate ΣQd [L/s]		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5

(2) Combined drainage load method
Fig. 5 shows the fixture discharge characteristics of the force-feed drainage type toilet system comprising the experimental toilet installed with the force-feed drainage pump. The maximum drainage pipe-connected fixture discharge flow rate q_{max}' of the force-feed drainage type toilet is 0.30L/s, which is slightly greater than that of the common type. Assuming that wastewater is discharged from a sanitary fixture that is connected

	Fixture discharge volume W [L]	Avg. discharge flow rate t_d [s]	Avg. fixture discharge flow rate q_d [L/s]	Max. fixture discharge flow rate q_{max} [L/s]
Toilet①	5.54	3.10	1.07	1.26
Toilet①+pump	5.49	2.20	1.49	1.56



*The fixture discharge characteristics were measured in accordance with SHASE-S 220[4].

Fig. 5 Fixture discharge characteristics

to the existing horizontal fixture drain branch of the same system, the wastewater and a constant flow rate load were combined to simulate the drainage load of the force-feed and gravity combined drainage system to examine the influence of the combined drainage on the experimental drainage stack system. q_{max}' was 4.22L/s[1)] when drainage loads from 4 gravity drainage type toilets and drainage loads from 2 force-feed drainage type toilets were combined and flowed down the drainage stack. In the experiment, based on said value as a maximum drainage load from one floor, the discharge volume (Fig. 5) of the force-feed drainage type toilet system was combined with a constant flow rate drainage load at a total flow rate of approximately 4.2L/s (see No.5 in Table 3). Moreover, the total flow rate of combined drainage from 2 floors was adjusted to 8.62L/s (See No.16 in Table 3), roughly twice as much as 4.2L/s. Each of the drainage load patterns was applied 5 times to obtain the average value. In applying drainage loads from the force-feed drainage type toilet systems installed on the 7th and 8th floors, when it was from only one floor, drainage loads were applied simultaneously to the toilets connected to force-feed drainage pumps on that floor, and when it was from both floors, drainage loads were applied from the 8th floor and then from the 7th floor after a time lag of 2 seconds.

Table 3 Drainage load patterns (constant flow rate + pumped drainage)

No.	8F			7F			Total drainage load flow rate ΣQd
	Existing assumed fixture	Extended section – force-feed drainage		Existing assumed fixture	Extended section – force-feed drainage		
	Constant flow rate	Toilet ① q_d' =0.87[L/s]※	Toilet ② q_d' =0.90[L/s]※	Constant flow rate	Toilet ③ q_d' =1.02[L/s]※	Toilet ④ q_d' =0.95[L/s]※	
		Toilet ①+Toilet ② qd' =1.75[L/s]※			Toilet ③+Toilet ④ qd' =1.87[L/s]※		
No.1	-	○	-	-	-	-	0.87[L/s]
No.2	-	○	○	-	-	-	1.75[L/s]
No.3	1.5[L/s]	○	○	-	-	-	3.25[L/s]
No.4	2.0[L/s]	○	○	-	-	-	3.75[L/s]
No.5	2.5[L/s]	○	○	-	-	-	4.25[L/s]
No.6	-	○	○	-	○	-	2.77[L/s]
No.7	1.5[L/s]	○	○	-	○	-	4.27[L/s]
No.8	2.0[L/s]	○	○	-	○	-	4.77[L/s]
No.9	2.5[L/s]	○	○	-	○	-	5.27[L/s]
No.10	-	○	○	-	○	○	3.62[L/s]
No.11	1.5[L/s]	○	○	-	○	○	5.12[L/s]
No.12	2.0[L/s]	○	○	-	○	○	5.62[L/s]
No.13	2.5[L/s]	○	○	-	○	○	6.12[L/s]
No.14	2.5[L/s]	○	○	-	○	○	7.62[L/s]
No.15	2.5[L/s]	○	○	2.0[L/s]	○	○	8.12[L/s]
No.16	2.5[L/s]	○	○	2.5[L/s]	○	○	8.62[L/s]

* The fixture discharge characteristics values, which were obtained from the fixture discharge characteristics experiment using the experimental horizontal fixture drain branch shown in Fig. 1, are different from the fixture discharge characteristics values obtained by using the system shown in Fig. 3.

2.3 Determination criteria

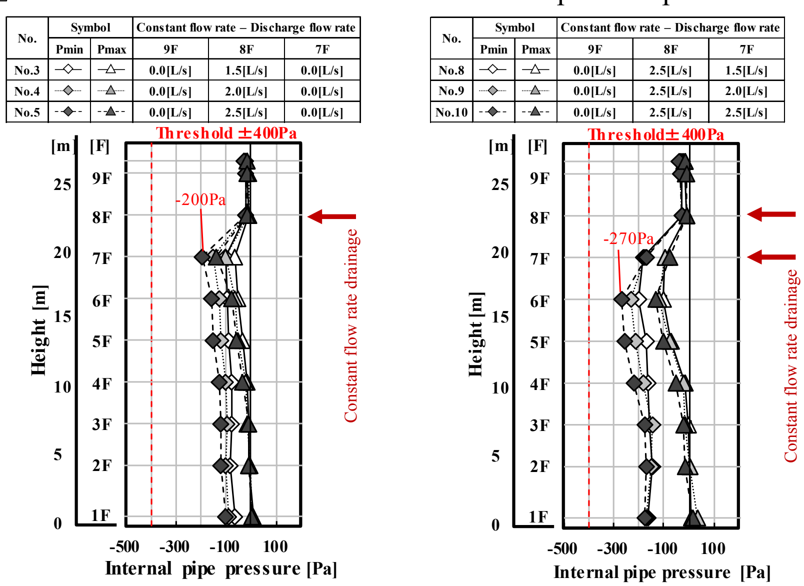
In accordance with SHASE-S 218[2)], the threshold range of the internal pipe pressure P is ±400Pa and the threshold of the trap seal loss ⊿*H* is half or less than half of the trap seal depth.

3. Experiment results and observations

3.1 Constant flow rate drainage load experiment

In simulating the condition of drainage from the existing toilet system comprising multiple toilets, drainage loads at constant flow rates of 1.5-2.5L/s were applied from the 8th floor, and drainage loads at constant flow rates of 1.5-2.5L/s were also applied from the 7th and 8th floors simultaneously (5.0L/s at most). The distributions of maximum and minimum internal pipe pressures, *Pmin*, *Pmax*, are shown in Fig. 6. At 2.5L/s, the minimum system pressure *Psmin*, which is the highest value among the minimum internal pipe pressure values measured on the floors, was approximately -200Pa, and it increased by approximately -30Pa when a drainage load was added from the 7th floor.

Fig. 7 shows the correlation between the total drainage load flow rate, *ΣQw*, and *Psmin* and *Psmax*, which are the highest value among the minimum internal pipe pressure values and the highest value among the maximum internal pipe pressure values, respectively. The graph confirms that every time *ΣQw* increases, *Psmin* likely increases. In the case of No.5, in which a drainage load was applied from the 8th floor at a constant flow rate of 2.5L/s, *Psmin* was approximately -200Pa, and in the case of No.10, in which a drainage load was added from the 7th floor at a constant flow rate of 2.5L/s, the internal pipe pressure increased to approximately -270Pa. Moreover, when a drainage load was applied at 7.5L/s (No. 15), which was calculated by the steady flow rate method described in 2.2 (1), *Psmin* was -290Pa, i.e., in the threshold range, and the trap seal loss ⊿*H* was measured to be less than half of the trap seal depth.



(8) Discharge from 8F (2) Discharge from 7F and 8F

Fig. 6 Internal pipe pressure distributions *Pmin*, *Pmax*

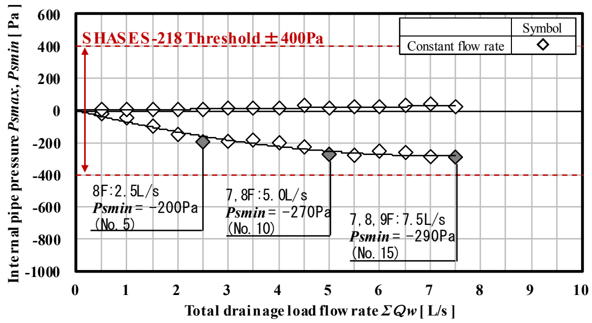
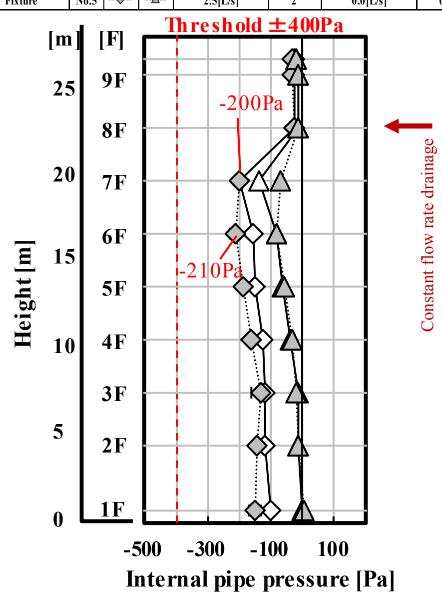


Fig. 7 Correlation between the total drainage load flow rate *ΣQw* and the internal pipe pressure values *Psmin*, *Psmax* (during drainage at constant flow rates)

3.2 Combined drainage load experiment

The total drainage load flow rate *ΣQw* was at its maximum when drainage load patterns No.5 (2 force-feed drainage type toilets + a drainage load at 2.5L/s) and No.16 (2 force-feed drainage type toilets each on 2 floors + a drainage load at 2.5L/s) were applied. Fig. 8 shows the distributions of the internal pipe pressures measured on the floors. As indicated in Fig. 8 (1), when drained from the 8th floor, *Psmin* was approximately -200Pa with the constant flow rate drainage only, and when the constant flow rate drainage was combined with the drainage from the force-feed drainage type toilets, *Psmin* increased to approximately -210Pa, but only slightly. Moreover, as shown in Fig. 8 (2), when drained from both the 7th and 8th floors, *Psmin* was -290Pa with the constant flow rate drainage only, and when the constant flow rate drainage was combined with the drainage from the force-feed drainage type toilets, *Psmin* increased to approximately -350Pa, but still remained in the threshold range of ±400Pa.

Pattern		Symbol		8F		7F	
Type	No.	Pmin	Pmax	Constant flow rate	Fixture	Constant flow rate	Fixture
Constant flow rate	No.5	◇	△	2.5[L/s]	0	0.0[L/s]	0
Fixture	No.5	◆	▲	2.5[L/s]	2	0.0[L/s]	0



Pattern		Symbol		8F		7F	
Type	No.	Pmin	Pmax	Constant flow rate	Fixture	Constant flow rate	Fixture
Constant flow rate	No.10	◇	△	2.5[L/s]	0	2.5[L/s]	0
Fixture	No.16	◆	▲	2.5[L/s]	2	2.5[L/s]	2

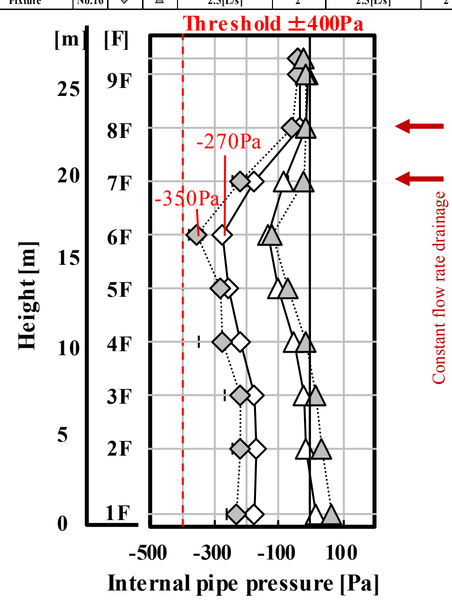
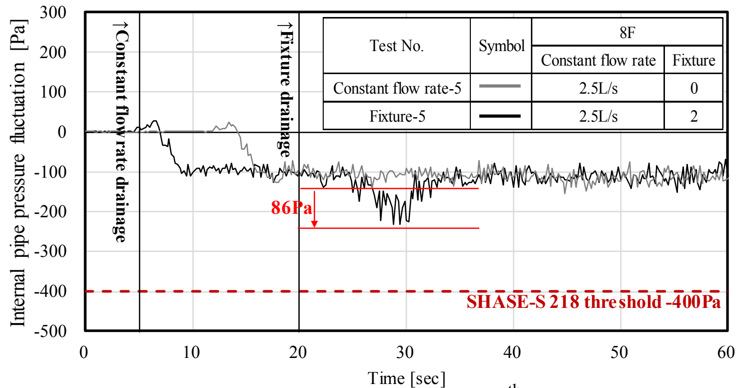
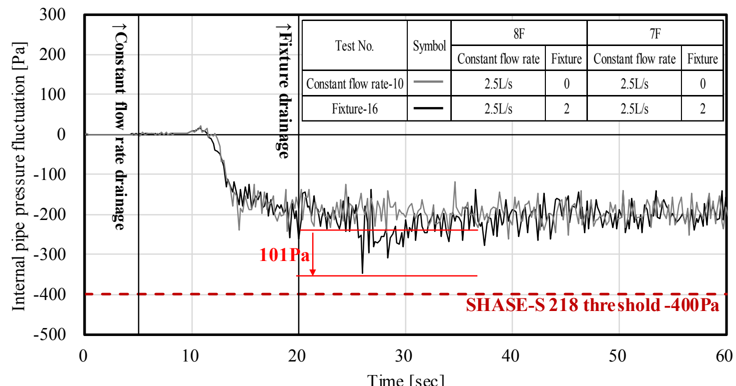


Fig. 8 Internal pipe pressure distributions *Pmin*, *Pmax*



(1) During drainage from the 8th floor



(2) During drainage from the 7th and 8th floors

Fig. 9 Internal pipe pressure fluctuation during drainage (the 6th floor)

Fig. 9 shows the variations in the internal pipe pressure measured on the 6th floor in comparison between the drainage patterns shown in Fig. 8. During drainage from the 8th floor, the internal pipe pressure instantaneously increased by approximately 90Pa towards the negative pressure side about 10 seconds after fixture drainage, and during combined drainage from the 7th and 8th floors, said pressure also increased by approximately 100Pa towards the negative pressure side. It is considered that the internal pipe pressure increased as the airflow resistance in the inflow part was caused to increase by the combined pumped drainage.

Fig. 10 shows the correlation of the total drainage load flow rate ΣQw of each of the patterns shown in Table 3 with the other factors: the minimum and maximum values, *Psmin*, *Psmax*, of the internal pipe pressures measured at all measurement points; the ventilation flow rate *Qav* in the stack vent pipe; and the trap seal loss $\triangle H$ of each of the trap seals. Fig. 10 (1) compares, across all drainage load patterns, the internal pipe pressures in the case of constant flow rate drainage loads and the internal pipe pressures in the case of drainage loads combined with pumped drainage from the force-feed type toilets. There are no sharp increases in *Psmin* and *Psmax*, and all values are in the threshold range. Moreover, Fig. 10 (2) compares the ventilation flow rates in the case of constant flow rate drainage loads and the ventilation flow rates in the case of drainage loads combined with pumped drainage, and again, there is no significant difference. Furthermore, Fig. 10 (3) indicates that the when applying No. 16, which generated the largest drainage load, a trap seal loss of approximately 30mm was caused to the toilet

trap seal on the 6th floor, which is more than half of the trap seal depth, while the two types of experimental drainage traps did not suffer breakage.
Accordingly, it is considered that the installation of a force-feed drainage type toilet system consisting of two toilets to an existing drainage stack system does not hinder the drainage performance of the drainage stack system.

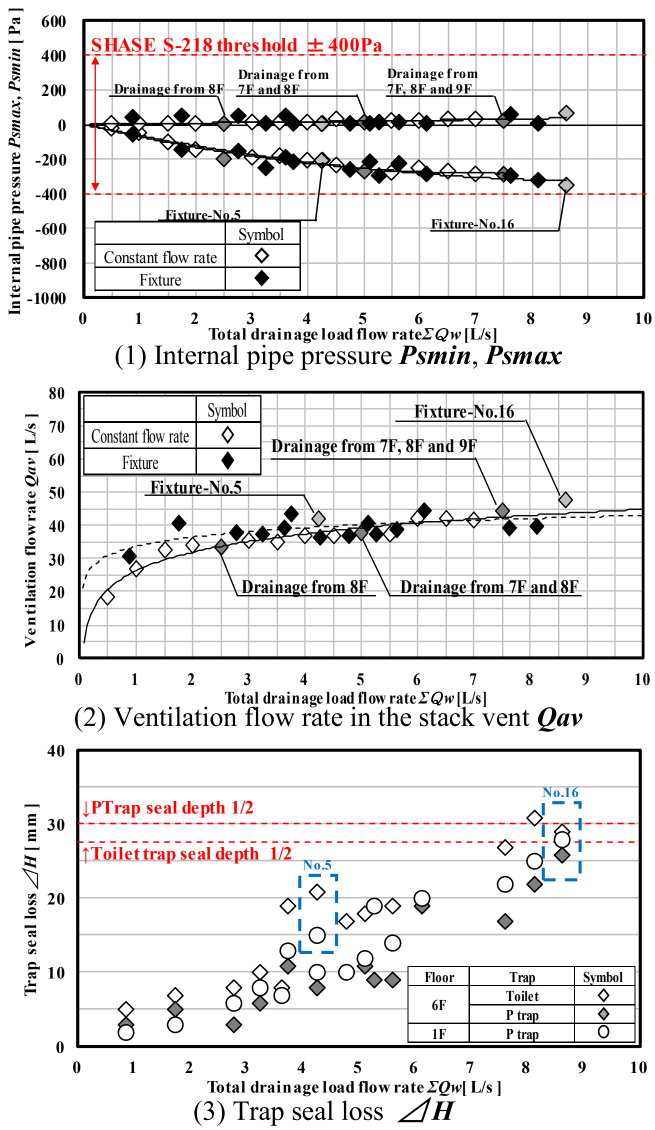


Fig. 10 Correlation of the drainage load flow rate with the other factors

4. Summary

In this study, a force-feed drainage type toilet system was installed to an existing drainage stack system, and the influence of the toilet system on the drainage performance of the stack system was examined. Consequently, it was found that when applying the largest drainage load, the minimum system value (negative pressure), *Psmin*, of a proposed force-feed and gravity combined drainage system reached approximately -350Pa, but it remained in the threshold range (±400Pa) specified by

SHASE-S218. Moreover, the drainage traps did not suffer breakage. Therefore, it is considered that the installation of the proposed system to an existing drainage stack system is feasible and does not cause problems, and therefore is industrially applicable.

Acknowledgment
The authors would like to express their gratitude to the Japan Society for the Promotion of Science (JSPS), Grants-in-Aid for Scientific Research (Subject: 18K04468, Research Category: (C), Chief Researcher: Masayuki Otsuka), for supporting this study.

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Guangzheng Wu (Dr. Eng.) is an assistant at Department of Architecture and Environmental Design, College of Architecture and Environmental Design Kanto Gakuin University.
He is engaged in research / development of plumbing system.

Masayuki Otsuka (Dr. Eng.) 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 (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.

Yudai Motomura is a Construction manager (MEP) at the Osaka Head Office of Takenaka Corporation.
He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating,Air-Conditioning and Sanitary Engineers of Japan).

Ryota Oba is a graduate student of the Otsuka 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 latest 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.

A Basic Experimental Study on Carrying Performance with Low Discharge Flow Rate Loads

Norihiro HONGO(1), Masayuki OTSUKA(2)

(1) hongou@yamagata-cit.ac.jp

(2) dmotsuka@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

Abstract

In recent years, while using less water to flush toilets has been encouraged, there have been concerns about degradation of carrying performance of horizontal drainpipes and stagnant wastewater in the pipes. In this experimental study, horizontal drainpipes having pipe diameters of 75A, 100A, 125A and 150A are used, and different factors; pipe gradient, flow rate and waste type, are applied in various conditions to the pipes, while small amounts of water are drained through the pipes to deliberately degrade the carrying performance thereof. The study aims to identify the influence of these factors on the carrying performance and to acquire some basic knowledge from the experiment results, which is conducive to the design of horizontal drainpipes.

Using a hypothetical case where a water-saving toilet was connected to a drainage pipe system, and clean water and wastewater were drained, separately at low volumes and low flow rates, this report clarified the flow-velocity relationship between the clean water and the wastewater as well as clarifying the drainage conditions that keep wastewater flowing again after the wastewater stagnated in the horizontal drainpipe. Moreover, by applying some hardest piping conditions to affect the carrying performance, the influence of two particular factors; low drainage flow rate and pipe gradient, on the carrying performance was also examined.

Keyword

Carrying Performance; low volumes flow rate; horizontal drainpipe; waste substitute

1. Introduction

Over recent years, amounts of flush water have been reduced along with the promotion of water-saving toilets. In particular, in drainage systems, the carrying performance of the horizontal drainage pipe is degraded as the length thereof increases, and problems caused by the stagnation of wastewater containing waste or toilet paper create many concerns both inside and outside Japan[1)2)].

Previous reports describe studies carried out in Japan regarding the carrying performance of horizontal drainage pipes with water-saving toilets installed thereto, and conclusions were drawn from the studies with the main focus on 75A-diameter fixture drainpipes and horizontal drain branches used in dedicated sections of apartment houses[3)] and with the main focus on 100A-diameter horizontal drain branches with serially-arranged multiple toilets installed thereto in office buildings[4)].

However, the problem of degradation of carrying performance is less related to diameters of horizontal drain branches than it is to the degradation of carrying flow velocities, discharge volumes and discharge flow rates in house drains having larger diameters than horizontal drain branches.

In recent cases, piping design is newly added, at the time of renovation of building stocks, to existing pipes which are left as they were, and the installation of water-saving toilets[5)] raises issues in terms of ensuring good carrying performance in house drains.

Some studies[6)7)] regarding the above issues were previously carried out both inside and outside Japan. However, there has hardly been any study on large-diameter horizontal drainage pipes corresponding to house drains and on-site drainage pipes, which focuses on the influence of various pipe diameters, pipe gradients and waste substitute types which are causal factors of wastewater stagnation when carrying performance deteriorates under conditions of low discharge volume or low discharge flow rate.

Therefore, this study first aimed to clarify, in the case of a water-saving toilet drainage system, the relationship of flow velocities between flushing clean water and flushing an experimental waste substitute, using low discharge volumes and low discharge flow rates which hinder drainage performance, and to identify conditions by which the experimental waste substitute starts flowing again after it became stationary. The study then examined, on the basis of the obtained results, the degree of influence of two factors; low discharge volume and flow rate/pipe gradient, had on the carrying performance when most severe conditions were applied to the horizontal drainage pipe.

2. Study overview

Fig. 1 shows the carrying performance experiment device which was proposed in this study. The device was used for examining the carrying performance of the pipework including a water-saving toilet, from the communal section of the horizontal drainage pipe to the house drain in the dedicated section. This device was used for carrying out a "basic carrying performance experiment" to identify carrying conditions of an experimental waste substitute (toilet paper), in which a waste substitute was placed in the horizontal drainage pipe, and the gradient and diameter of the horizontal drainage pipe were changed. Discharge load flow rates were also applied in small values. The experiment results were then used as a basis for determining pipe diameter, pipe gradient and waste substitute type so as to create severe carrying performance conditions, which were used in an "application experiment" to examine the carrying performance.

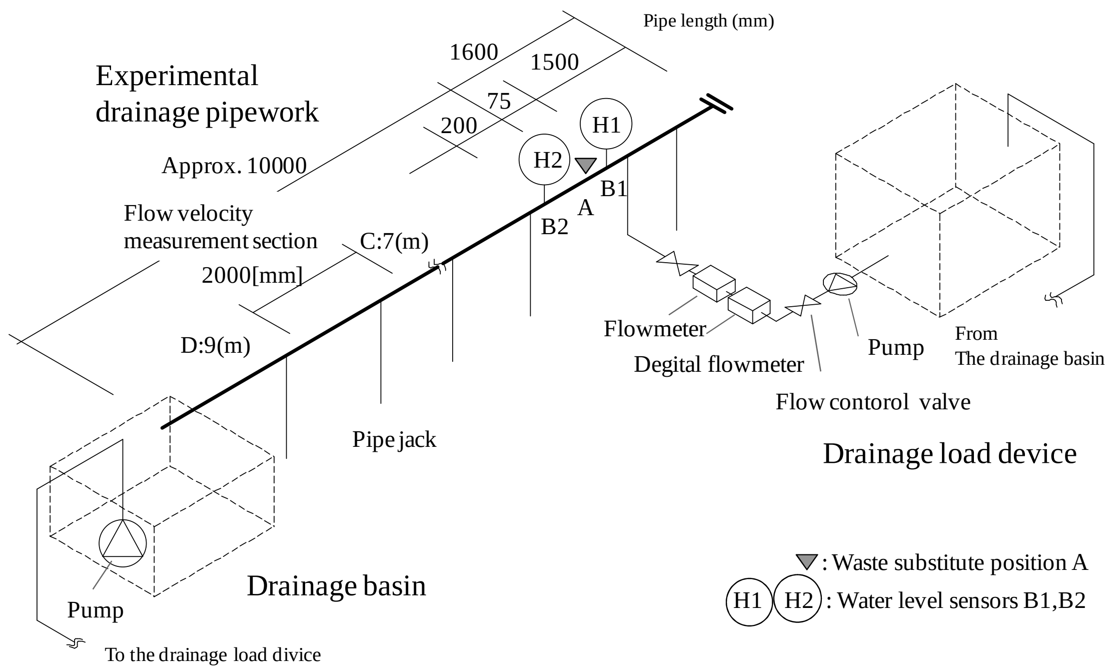


Fig. 1-Carrying performance experiment apparatus

2.1 Basic carrying performance experiment

Fig. 2, (1)-(3), illustrates a typical model of the experimental waste substitute being carried along the horizontal drainage pipe.

In the basic carrying performance experiment, as illustrated in Fig. 2, (1) and (2), basic knowledge was obtained regarding the actual state of toilet paper becoming stationary in the drainage pipe, the state of the waste substitute with backwater (follow-up water) flowing from the upstream side and gradually accumulating behind the waste substitute, and the conditions under which the hydrostatic pressure of the accumulated water pushes the waste substitute so that it starts flowing again.

Moreover, as illustrated in Fig. 2 (3), an average Manning's flow velocity calculated by Manning's equation (formula (1)) was compared with a carrying flow velocity of the waste substitute when the waste substitute was realistically mixed and carried in the wastewater.

Furthermore, comparisons were made against the minimum flow velocity (hereinafter referred to "min, flow velocity 0.6[m/s]") specified by SHASE-S206[8], which is required for carrying waste in house drains.

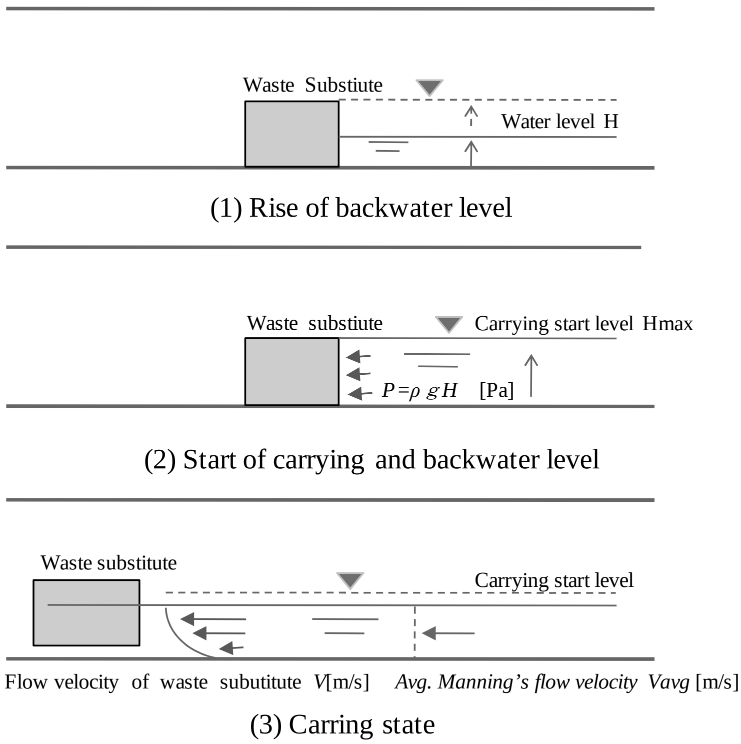


Fig. 2-Carrying model

Formula (1) $$v = \frac{1}{n} R^{\frac{2}{3}} I^{\frac{1}{2}}$$

v: flow velocity [m/s] (Vavg: average flow velocity)
n: roughness coefficient (calculation value :0.009)
R: hydraulic radius [m] I: gradient

2.2 Carrying performance application experiment

In the carrying performance application experiment, the results of the basic carrying performance experiment in (1) were used as a basis for a preliminary experiment of carrying the waste substitute where different pipe gradients, pipe diameters, etc. were applied to an experimental drainage pipework to create the most severe conditions for drainage performance.

By using the set conditions, the influence of the pipe gradient and the drainage load on the carrying performance was examined with respect to the carrying distance as an index in order to understand the carrying performance in the horizontal drainage pipe under severe conditions.

3. Experiment overview

3.1 Basic carrying performance experiment

(1) Experimental drainage pipework

The experimental apparatus shown in Fig. 1 was used with transparent vinyl chloride horizontal drainage pipes with different pipe diameters; 75A (inside diameter 77[mm]), 100A (inside diameter 100[mm]), 125A (inside diameter 125[mm]), and 150A (inside diameter 146[mm]), respectively.

The experimental waste substitute, as explained later, was placed at the position A indicated in the drawing. Incidentally, the gradients of the experimental horizontal drainage pipes are 100A: 1/100, and 125A: 1/150 and 1/50 (very steep) with reference to minimum pipe gradients for different pipe diameters specified by SHASE-S206. Under these conditions, drainage loads were applied at constant flow rates from the upstream side to the experimental waste substitute by the drainage load device.

(2) Drainage load application

Drainage loads were applied at constant flow rates of 0.3-1.5[L/s] by the drainage load device arranged on the upstream of the experimental drainage pipework.

The constant flow rates of the applied drainage loads were set, hypothetically, to 1.5[L/s] (from a wash-out toilet), 1.0[L/s] (from a bathtub), 0.5[L/s] (from a urinal) and 0.3[L/s] (from a washbasin) with reference to the average discharge flow rates qd[L/s] for sanitary fixtures which are used in the steady flow rate method by SHASE-S206.

Moreover, these constant flow rate drainage loads were applied to the stationary experimental waste substitute, from the upstream side, until the waste substitute started travelling.

(3) Experimental waste substitute

The experimental waste substitute refers to the specifications in the previous report[3)]; toilet paper (length 0.9[m], 8 folds, 4 layers, specific gravity 0.98).

(4) Measurement items and measurement methods

In the experimental pipework, water level sensors (B1 and B2 in Fig. 1) were used to measure variations in water level on the upstream and downstream sides of the experimental waste substitute position A.

The amount of time the experimental waste substitute took to pass from C to D in Fig. 1 was measured. The distance between C and D was divided by the measured time to obtain the carrying flow velocity (hereinafter referred to “actual carrying flow velocity V”) of the experimental waste substitute while travelling, with the experimental waste substitute in the drainage pipe defined as an index.

Moreover, the variations in water level measured on the upstream side were used to measure the time the waste substitute started travelling.

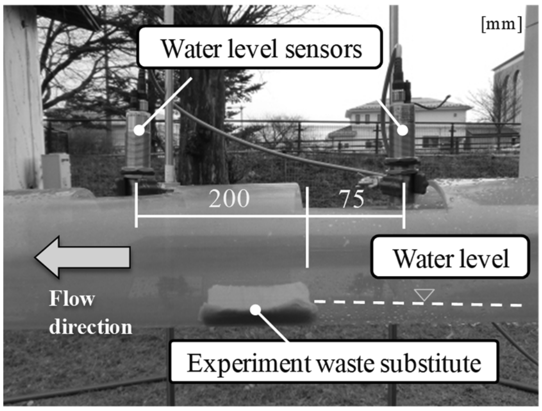


Photo 1- Waste substitute position and water level sensors

3.2 Carrying performance application experiment

In the carrying performance application experiment, the measurements items and the measurement methods refer to 2.1 Basic carrying performance experiment, and drainage loads were applied using the pipe diameter and gradient which were determined from the results in 2.1 to create the most severe conditions for carrying performance.

Moreover, in this experiment, the linear carrying distance (hereinafter referred to “carrying distance”) from the waste substitute position A to the position where the waste substitute stopped was added to the list of measurement items.

4. Experiment results and observations

4.1 Basic carrying performance experiment

(1) The average clean water flow velocity and the actual carrying flow velocity of the experimental waste substitute

Fig. 3 (1)-(4) shows the relationship between the average flow velocity (hereinafter referred to “calculated average flow velocity Vavg”) and the actual carrying flow velocity V at each drainage load flow rate. The calculated average flow velocity Vavg was obtained by Manning’s equation from the average water level of clean water, used as a drainage load, calculated from variations in pipe diameter, gradient and drainage flow rate applied to the experimental drainage pipework. The pipe diameters used are 75A, 100A, 125A and 150A.

The actual carrying flow velocity V refers to the flow velocity at which the experimental waste substitute was carried the entire distance using each of the pipe diameters 75A-150A and a corresponding gradient at each drainage load flow rate.

Fig. 3 indicates that the actual carrying flow velocity increases as the drainage load flow rate or the gradient increases.

Using the pipe diameters, respectively, the flow velocities reached their maximum values when the gradient was 1/50 and the drainage load flow rate was 1.5[L/s], and the highest was 1.0[m/s]. Moreover, using the pipe diameters, respectively, the minimum flow velocity dropped to their minimum values when the gradient was 1/150 and the drainage load flow rate was 0.3[L/s], and the lowest was approximately 0.39[m/s]. Compared to the maximum flow velocities, the minimum flow velocities drop by approximately 40%.

Moreover, the flow velocities at the gradient of 1/50 and the drainage load flow rate 0.3[L/s] did not reach the minimum flow velocity of 0.6[m/s] by SHASE-S206, which confirms that gentle gradients and reductions in flow velocities due to low discharge flow rates are conditions that affect the carrying performance.

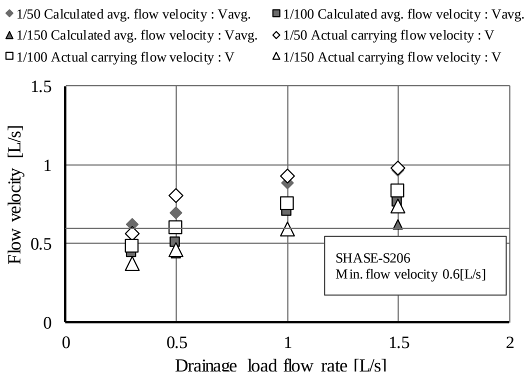
Similarly, with regard to the calculated average flow velocities Vavg, the maximum value is 1.0[m/s] when using the pipe diameters, respectively, at the gradient of 1/50 and the drainage load flow rate of 1.5[L/s], and the minimum value is 0.37[L/s] when using the diameters, respectively, at the gradient of 1/150 and the drainage load flow rate of 0.3[L/s], and this also confirms the influence of gentle gradients and drainage load flow rates.

Furthermore, the calculated average flow velocities, which were calculated from drainage load flow rates using the pipe diameters respectively, the actual carrying flow velocities V and the flow velocities are compared against the minimum flow velocity of 0.6[m/s] specified by SHASE-S206. The calculated average flow velocities Vavg are slower than the minimum flow velocity, except the Vavg value obtained when the drainage load flow rate is 0.3[L/s], the pipe diameter is 75A and the gradient is 1/50. Meanwhile, the actual carrying flow velocities V meet the minimum flow velocity of 0.6[L/s] even when drainage load flow rates are lower than the calculated average flow velocities Vavg.

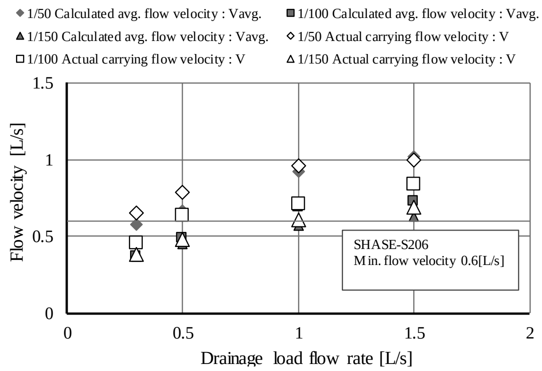
Next, with the focus on the gradients with different pipe diameters, the relationship between the actual carrying flow velocity V and the calculated average flow velocity Vavg was observed per gradient and three different cases were compared, as shown in Fig. 4. In the case of the gradient of 1/50, the flow velocities vary among the pipe diameters. However, the actual carrying flow velocity V and the calculated average flow velocity Vavg per pipe diameter more or less correspond to one another. Moreover, the waste substitute floated at this sharp gradient, and therefore hardly having any influence on the flow velocities.

Furthermore, in the case of gentler gradients of 1/100 and 1/150, the actual carrying flow velocities V are faster than the calculated average flow velocities Vavg by 7-12%.

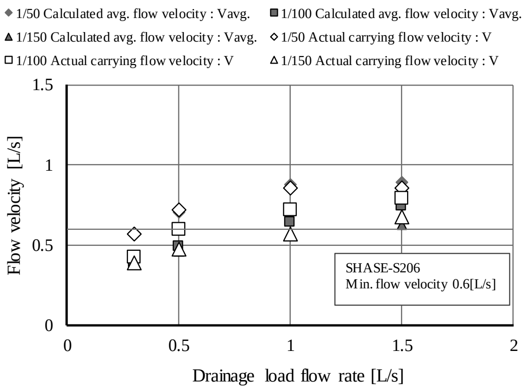
By using the waste substitute as an index, a matter, such as toilet paper, affects the carrying flow velocity when the gradient is gentle, although it readily floats.



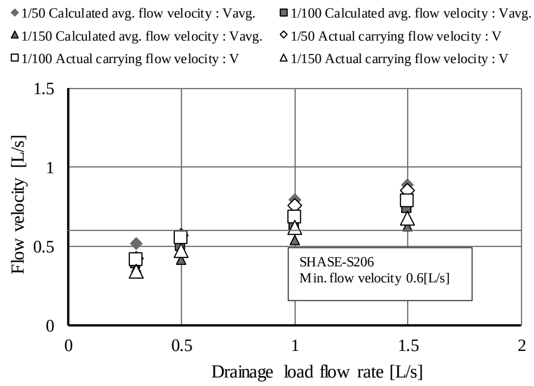
(1) Pipe diameter 75A



(2) Pipe diameter 100A

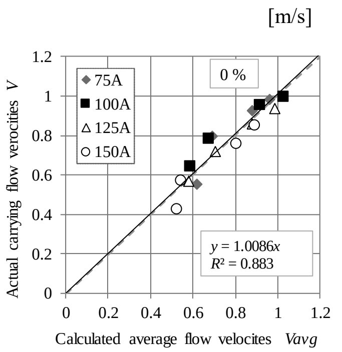


(3) Pipe diameter 125A

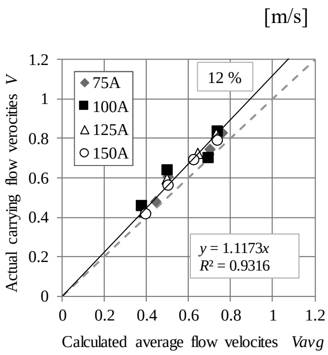


(4) Pipe diameter 150A

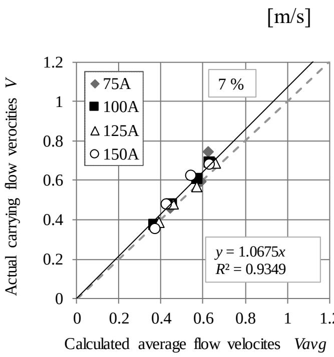
Fig. 3-Calculated average flow velocities *Vave* and actual carrying flow velocities *V* at different drainage load flow rates



(1) Gradient 1/50



(2) Gradient 1/100



(3) Gradient 1/150

Fig. 4-Calculated average flow velocities *Vave* and actual carrying flow velocities *V* at different gradients

(2) Carrying water volume and carrying time

Fig. 5 shows an example of the water level variation on the upstream side H1 of the experimental waste substitute. As illustrated in Fig. 2 (1) and (2), the flow of wastewater which is blocked by the waste substitute starts building up and increases the water level, but the wastewater starts flowing again once a discharge water volume required for carrying the waste substitute is secured.

Fig. 6 shows the volume of discharge water [L] (hereinafter referred to as “carrying water volume”) built up on the upstream side before the wastewater starts flowing again, which is obtained by multiplication of a drainage load flow rate [L/s] from the carrying time T[s] which is between the moment at which the water level is at its highest value, Hmax, and the moment at which the wastewater starts flowing again is used for calculating.

The average carrying water volume is 1.9[L] when the gradient is 1/50, 2.2[L] when the gradient is 1/100, and 2.4[L] when the gradient is 1/150. That is, a larger carrying water volume is required as the gradient becomes gentler.

Furthermore, the hydrostatic pressure [Pa] of carrying water volume on the experimental waste substitute was calculated from the maximum water level Hmax on the upstream side of the waste substitute, assuming that there was no overflow on the downstream side of the waste substitute. Calculation results were sorted to correspond to the pipe diameters, as shown in Fig. 7.

Among the pipe diameters, there was no hydrostatic pressure difference despite the gradient variation, and the pressure was more or less consistent when the same drainage load flow rate was applied. That is, the carrying performance is only slightly affected by the required carrying pressure that varies depending on the pipe diameter.

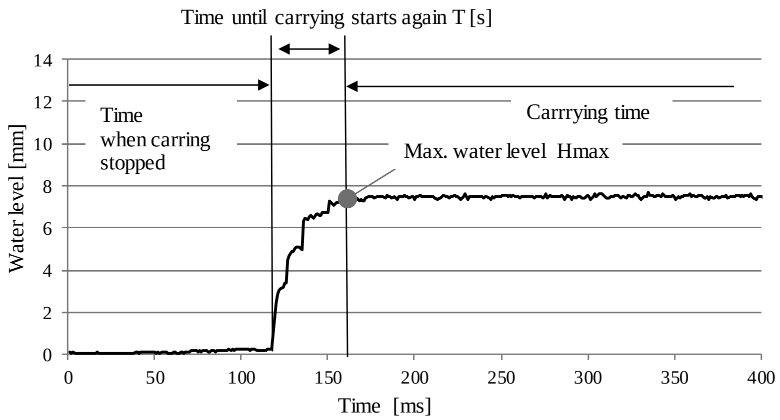
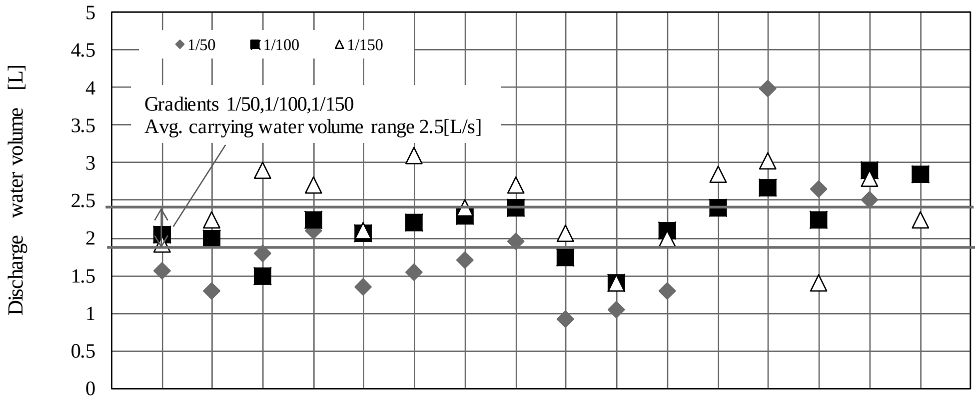


Fig. 5-Upstream water level H1 required for carrying the waste substitute



Load flow rate ［L/s］	0.3	0.5	1.0	1.5	0.3	0.5	1.0	1.5	0.3	0.5	1.0	1.5	0.3	0.5	1.0	1.5
Pipe dia. ［A］	150				125				100				75			

Fig. 6-Carrying water volumes

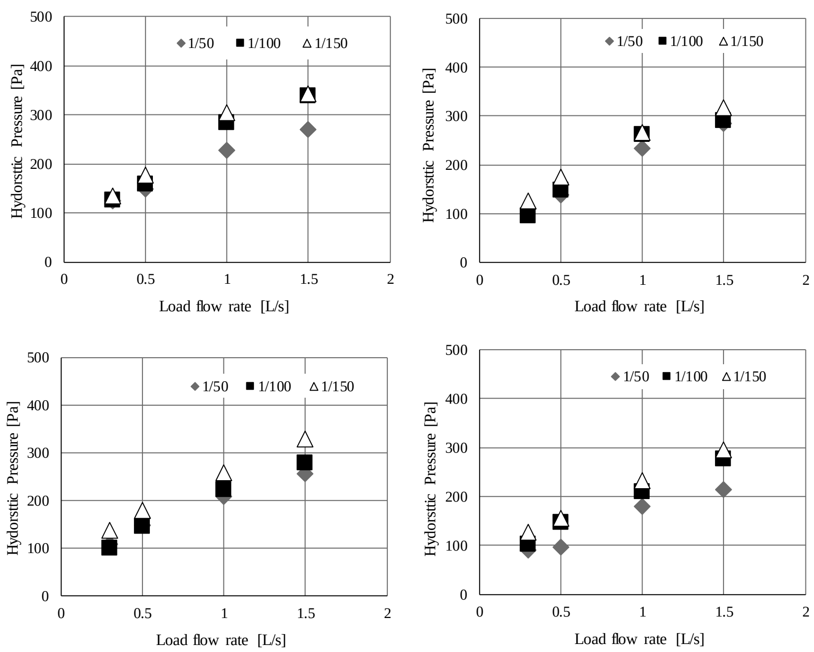


Fig. 7-Load flow rates and hydrostatic pressure by carrying water volumes

4.2 Carrying performance application experiment

(1) Carrying distance in relation to load flow rate

According to the basic carrying performance experiment in 3.1, the results (Fig. (4)) indicated that the most severe piping conditions were created when the pipe diameter was 150A and the gradient was 1/150. In addition to that, in this experiment, the number of toilet paper sheets was increased and added to the experimental waste substitute, which was placed in the drainage pipe, and the carrying distance was observed. The results are shown in Fig. 8.

As for the drainage load, in a hypothetical situation where a type II water-saving toilet was used with a volume of flush water of 4.8[L], said volume of flush water of 4.8[L] was divided by a drainage load flow rate of 0.3[L/s] to obtain 16[s] discharge time, and during this period of time, a constant drainage load flow rate (hereinafter referred to “drainage load 0.3[L/s]”) was applied and the carrying distance was measured for evaluation.

In Fig. 8, when comparing with the carrying distance of the waste substitute containing four layer of toilet paper, the longest carrying distance of the waste substitute containing eight layers of toilet paper was 100[mm], i.e., the waste substitute became stationary almost immediately. Meanwhile, the longest carrying distance of the waste substitute containing six layers of toilet paper was 600[mm], and therefore, this waste substitute was selected as a severe condition for the carrying performance.

Together with this waste substitute condition which is difficult for the carrying performance in the drainage pipe, constant drainage load flow rates of 0.5, 1.0 and 1.5[L/s] were applied during lengths of discharge time of 10, 6 and 3[s], respectively, in the same manner as when the drainage load of 0.3[L/s] was applied using the flush water volume of 4.8[L]. Fig. 9 shows the measured carrying distances.

The carrying distance increases as the drainage load flow rate increases. However, when the drainage load flow rate is 1.0[L/s], the average carrying distance is 3000[mm], and when the drainage load flow rate is 1.5[L/s], the average carrying distance is 5700 [mm].

According to the previous document[9)], in drainage systems of existing stock houses, a typical length for the house drain between the drainage stack and the drainage basin is 5[m]. Therefore, the carrying distance can be increased, even under the severe waste substitute condition, by changing the drainage load flow rate while using the flush water volume of 4.8[L].

No. of toilet paper layers	Carrying distance [mm]		
	avg.	max.	min.
4	Entire distance	Entire distance	Entire distance
6	353	600	160
8	67	100	0

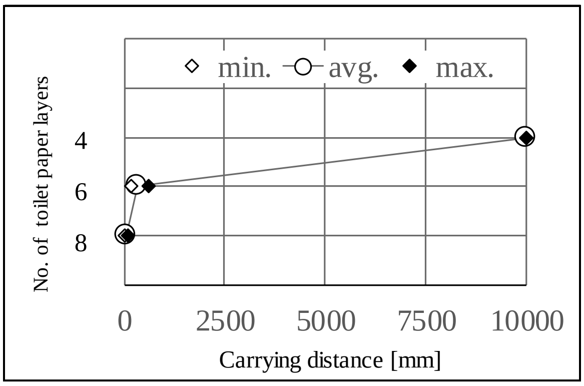


Fig. 8-Selection of the most appropriate waste substitute volume
(Pipe dia. 150A, gradient 1/150, drainage load flow rate 0.3[L/s])

Drainage load flow rate [L/s]	Carrying distance [mm]		
	avg.	max.	min.
0.3	353	600	160
0.5	2050	2300	1550
1.0	2983	3100	2800
1.5	5667	Entire distance	2000

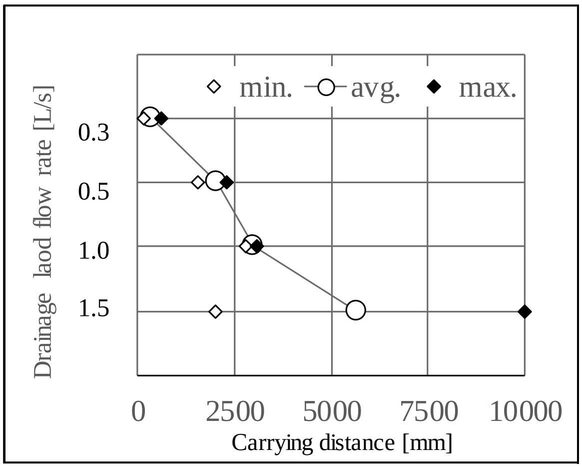


Fig. 9-Carrying distance in relation to drainage load flow rate
(Pipe dia. 150A, gradient 1/150)

(2) Carrying distance in relation to gradient

Fig. 10 shows different carrying distances which were measured when the pipe diameter was 150A, the waste substitute contained six layers of toilet paper, and the drainage load was 0.3[L/s], i.e., the minimum load flow rate indicated in Fig. 9. Different gradients, 1/50, 1/100 and 1/150, were also applied to the horizontal drainage pipe.

When the gradient was 1/150, the average carrying distance was approximately 350[mm]; when the gradient was 1/100, the average carrying distance was approximately 6170[mm]; and when the gradient was 1/50, the entire carrying distance was reached. Accordingly, even with a small volume of discharge water at approximately 0.3[L/s] drainage load, the entire carrying distance can be reached depending on the gradient. Moreover, the influence of gradients on the carrying performance is more prominent than the influence of drainage load flow rates shown in Fig. 9.

Gradient	Carrying distance [mm]		
	avg.	max.	min.
1/150	353	600	160
1/100	6167	6200	6100
1/50	Entire distance	Entire distance	Entire distance

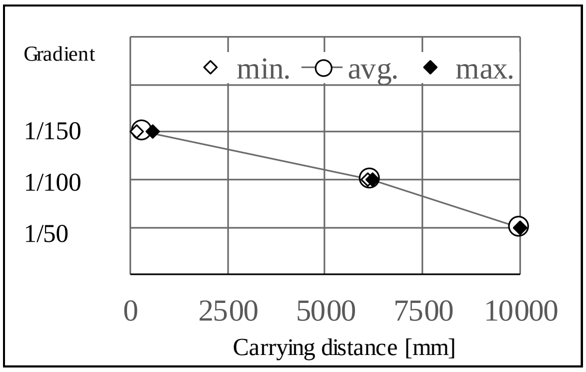


Fig. 10-Carrying distance in relation to gradient
(Pipe dia. 150A, drainage load flow rate 0.3[L/s])

5. Conclusion

The following knowledge was acquired from the results of the experiments.

(1) By referring to the calculated average flow velocity in the pipe, which was obtained by Manning's equation, in the case of using clean discharge water, the actual carrying flow velocity of wastewater containing the waste substitute increased by approximately 7-12% when the gradient was gentle, i.e., 1/100 or 1/150. Moreover, the minimum flow rate of 0.6[m/s] specified by SHASE-S206 was satisfied by using a drainage load of 1.0[L/s].

(2) When water was discharged at a constant drainage load flow rate of 0.3-1.5[L/s], it was possible to carry the waste substitute 5[m] or further even if the waste substitute contained toilet paper and its flow velocity was approximately 0.35[m/s].

(3) The volume of carrying water that was required to start carrying the waste substitute again after it became stationary was irrelevant to the pipe diameter or the gradient. Moreover, the amount of water accumulated on the upstream side of the waste substitute was approximately 2.0-2.5[L].

(4) Under severe conditions by adjusting the pipework and the waste substitute, the influence of reducing the gradient, 1/50, 1/100 and 1/150 in this order, had a more prominent adverse influence on the carrying performance than the variation of 0.3-1.5[L/s] in the drainage load flow rate.

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7. 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).

Applicability of building drainage design codes for use in tall buildings

M. Gormley (1), D.A. Kelly (2) and D.P Campbell (3)
(1) m.gormley@hw.ac.uk
(2) d.a.kelly@hw.ac.uk
(3) d.p.campbell@hw.ac.uk

(1), (2) & (3) School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, Scotland, UK.

Abstract

National codes provide essential guidance for the design of building drainage and vent systems (BDS) which, in the main, ensure the basic objectives of preventing odour ingress and cross-transmission of disease through water-trap seal retention. However, there are no specific design guides for the BDS design for tall buildings, and so the same codes and methods are used for a high-rise skyscraper as would be used for a low-rise building. The historical development of codes and standards (including the interpretation of the governing fluid mechanics principles and the degree of safety built in) mean that many design differences exist between them. For example, there are differences in minimum trap seal retention requirements and differences in the recommended interval between cross-vents linking the wet stack to the vent stack The codes also differ in the size and scale of the systems they cover and most make no allowance for the specific building-drainage design requirements of tall buildings on the scale of super- or megatall buildings. An investigation of the development of these codes and their implication for future use is explored in this paper.

Keywords
Design Codes, Building drainage, tall buildings,

1. Introduction
National codes provide essential guidance for the design of building drainage and vent systems (BDS) which, in the main, ensure the basic objectives of removing wastewater

from the building whilst preventing odour ingress and cross-transmission of disease through water-trap seal retention.

However, there are no specific design guides for the BDS design for tall buildings, and so the same codes and methods are applied to the design of high-rise skyscrapers as would be used for single-story and low-rise buildings. Whilst the height of the building does not necessarily affect the velocity of fluid falling in the vertical stack due to the phenomenon of terminal velocity, there are significant other issues at play (pressure transient generation for example) for which the height of the building plays a significant role[1].

The historical development of international design codes and standards (including the interpretation of the governing fluid mechanics principles and the degree of safety built in) mean that many design differences exist between them. For example, the UK code accepts trap-seal depletion of 25%, i.e. 37.5 mm minimum retention for a 50 mm trap seal, whilst the Australian and New Zealand code accepts a minimum retention of 25 mm. Furthermore, the recommended interval between cross-vents linking the wet stack to the vent stack differs considerably between codes: one-floor interval (UK and Australian/ New Zealand codes); five-floor interval (US code – UPC); and 10-floor interval (US code – IPC). The discussion around distances between venting component arrangements and the application of particular approaches to venting often revolves around anecdotal evidence of the efficacy of one approach over the other, or particular interpretations of inadequately described codes, rather than a scientific investigation leading to a concrete conclusion.

The codes also differ in the size and scale of the systems they cover and most make no allowance for the specific building-drainage design requirements of tall buildings on the scale of super- or megatall buildings. An investigation of the development of these codes and their implication for future use is explored in this paper.

This paper introduces the issue in a broader context to that hitherto explored and looks at interpretation of a sample of BDS arrangements and implications using a turbulent, transient approach rather than a steady state probabilistic approach adopted by most designers and code authorities globally.

2. Historical Perspective

With the industrial revolution came a dramatic shift in living. The move from a predominantly agrarian, rural society to a more urban, industrial one brought many challenges, least of these was how to deal with sanitation on a massive scale.[1]

The 19th Century, often referred to as 'Victorian times' after the monarch who reigned from 1837 to 1901, saw many changes in Britain. These changes in approaches to living and work were exported to many parts of the world as part of the 'imperial package' where 'development' was 'done' to the colonized for their own benefit. With this export and the increasing influence of the super powers of the day a 'standard' was created in hygiene and sanitation with notably European origins.

Regardless of its origins, it is without doubt that the idea of public health reform as universally advantageous accords not only with our own sense of the desirability of sanitary techniques, such as flush-toilets and water-borne sewerage, which have become naturalized in the West, but also with a narrative of historical progress .

The consequences of an 'evangelization of sanitation' linked with colonialization has been a long - standing connection between the colonized and the colonizer in terms of trade and progress. In terms of sanitation standards this has often meant the adoption of codes and standards which are not tailored for particular needs. For example in Hong Kong, where the use of seawater to flush WCs is widespread, BDS design is based on the U.K. standards which were derived using clean cold water which displays different properties to that of seawater in many respects, which will, in combination, lead to deviation by more than 10% from performance predicted by Standards. This anomaly is just one example of how the use of standards produced for a particular place and time can be totally irrelevant to another place at another time.

2.1 Embryonic codes for plumbing

For most people, the BDS lurking beneath their pristine ceramic and stainless steel appliances presents a mystery beyond their usual 'need to know'. How their sink full of soapy water gets from their newly refurbished kitchen island to the municipal treatment plant is of little or no interest, and likewise, few people ponder the similar journey from the WC, bath or bidet in the bathroom; until that is, they are suddenly faced with a foul smell from 'somewhere down there' or are met by a filling WC bowl which keeps on filling and pours onto the new floor covering. The mystery surrounding the BDS suddenly deepens on the presentation of an unfeasibly costly repair bill.

The disposal of human waste is an issue the world over - cultural perspective and local taboos governing many of the practices surrounding its management. It has been conjectured that in many ways the approach taken to waste management is a very useful representative indicator of the 'level of development' within a society. Whilst a fuller discussion of this falls out with the remit of this paper it is useful to note that many of the great 'civilizations' in history are remembered for the attention paid to sanitation[2] .

In truth, there are few real mysteries about the operation of a building drainage system. The underlying principles governing the flows of all fluids (water and air) have been well described and indeed applied to the building drainage system for both design (making the system work) and forensic analysis (finding out why it didn't work) for many years[3-7]. It is worth remembering that while humans have many cultural taboos surrounding the bathroom, which have contributed to the myths surrounding the drainage system, there is a strong scientific basis for the movement of waste by means of water which has a long tradition, going back thousands of years. However, it is the advances made in the past two centuries that form the basis of our modern systems.

As discussed previously by Gormley [8], the age in which the innovation of safe and practical building drainage and plumbing were at the cutting edge of technology was in the late 19th Century. Many of the important factors of maintaining the system's integrity by preventing sewer gases from entering living spaces, the water trap seal and system venting, had already been introduced and much work on improving the system's response to the inevitable pressure fluctuations encountered in an unsteady fluid transport system were well under way. This work was carried out by notable Scientists and Engineers of the time. In the U.K., the water trap seal was invented by Cummings as early as 1775[1]. Cummings was an Engineer and a watchmaker and resurrected the idea of a flushing WC originally invented by Harrington in the 17th Century.

Whilst many of the components of the system had been around for some time, it wasn't until the mid-19th Century that any impetus existed to address the poor sanitary conditions that existed in large towns and cities. In 1842, Edwin Chadwick, an English civil servant, published his *'Report into the Sanitary Conditions of the Labouring Population of Great Britain)*. This report initiated a process of reform which prompted investment in sanitation as a public health priority in the slum conditions created by the rapid expansion of British cities as a result of the Industrial Revolution[9].

Whilst these principles were understood, the practical applications of them to plumbing installations were still a long way off. It wasn't until the seminal work by Hunter[10] that a simplified, usable approach was developed and adopted. The use of Hunters' techniques took hold during the building expansion programs following the end of World War II in what has become known as 'modern times'. Hunter's technique employed probabilistic

2.2 The growing trend of tall buildings

The number of tall buildings being constructed around the world is growing rapidly. Whilst the definition of what constitutes a 'tall building' is subjective due to its relative height and proportion in comparison to its setting, a building of more than 50 m (roughly equating to 14 floors[1]) in height is typically used as the lower threshold of what constitutes a tall building. A building over 300 m (or roughly 84 floors) in height is classed as a 'supertall building', and a building over 600 m (or roughly 168 floors) in height is classed as a 'megatall building'[11].

In 2018, a total of 18 supertall buildings (300 m +) were completed. By the end of 2019, the total number of buildings of 300 m height or greater around the world will be 197 (an increase of over four times the number in 2000 when just 47 existed), with three of those being classified as megatall buildings: the Burj Khalifa (828 m); Shanghai Tower (632 m); and the Makkah Royal Clock Tower (601 m). The number of supertall and megatall buildings is expected to grow each on year, with an additional 126 buildings of 300 m height or greater due to be completed by 2025[12].

3. Methods

To assess the impact of the current codes on BDS design and, particularly, on building height, the numerical model, AIRNET, was used to simulate the operational performance of the BDS of a 10-storey (medium-rise) building and a 50-storey (high-rise) building. A 50-storey building was chosen as it represents the lower threshold of what is accepted to be a "tall building" and is also the upper building height limit of what AIRNET is considered capable of simulating.

3.1 The AIRNET numerical model

AIRNET is a method of characteristics based finite difference numerical model developed through extensive research at Heriot-Watt University[1].

By applying the method of characteristics solution to the fundamental St Venant equations of continuity and momentum, AIRNET simulates whole system responses to water flow and air pressure transients in a BDS.

For the simulation to begin, conditions throughout the network at time zero must first be defined. For the analysis to progress, theoretical or empirical relationships describing the physical conditions at system boundaries are required. Use of such equations, commonly referred to as boundary conditions, allows the continuation of the model into subsequent time steps. Common boundary conditions within the building drainage system include; pipe junctions, trap seals, open terminations, and air admittance valves, see Figure 1.

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1 Although the number of floors can vary due to the different floor-to-floor heights of different buildings, these are stated here as an important comparator in terms of BDS design. A floor-to-floor height of 3.6 m has been assumed to correlate with that used by the Council on Tall Buildings and Urban Habitat.

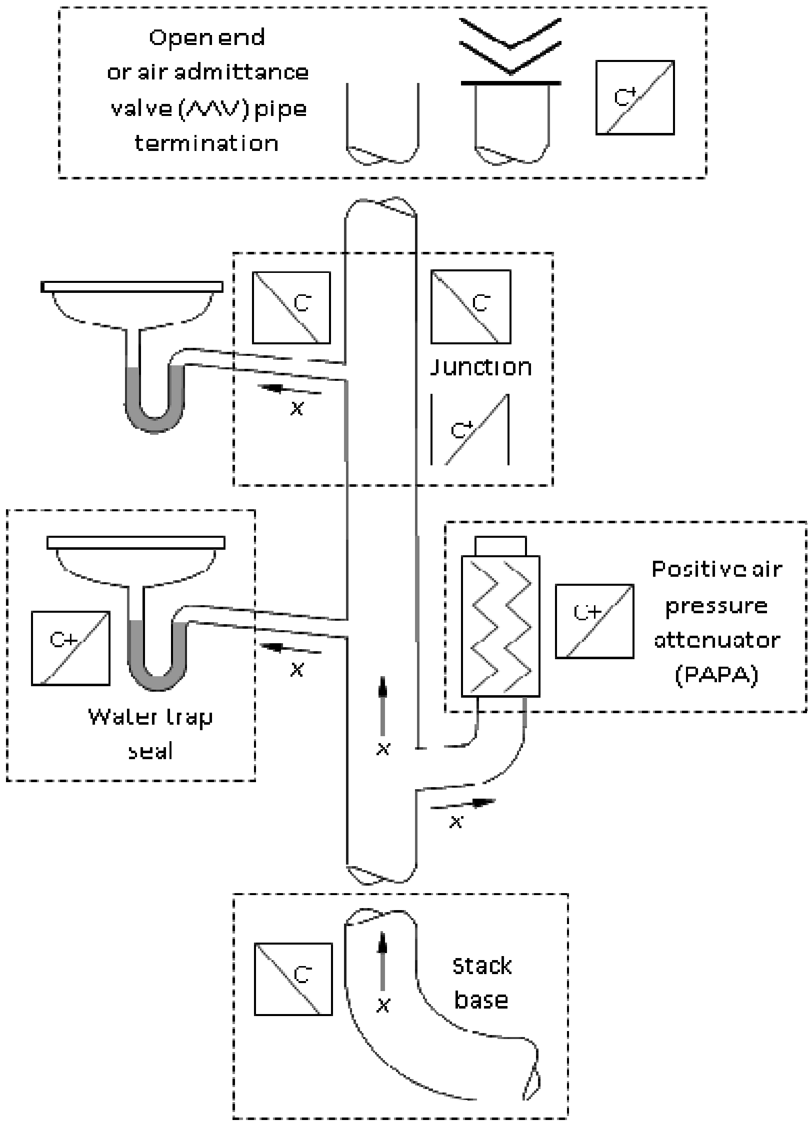


Figure 1: Boundary conditions and available characteristics for a typical BDS

3.2 Simulated BDS design approaches

For both building heights, three different BDS design approaches were simulated based on those outlined in the UK's design code, BS EN 12056-2:2000: (i) a single stack system; (ii) a modified one-pipe system; and (iii) an active system incorporating air admittance valves (AAVs), see Figure 2.

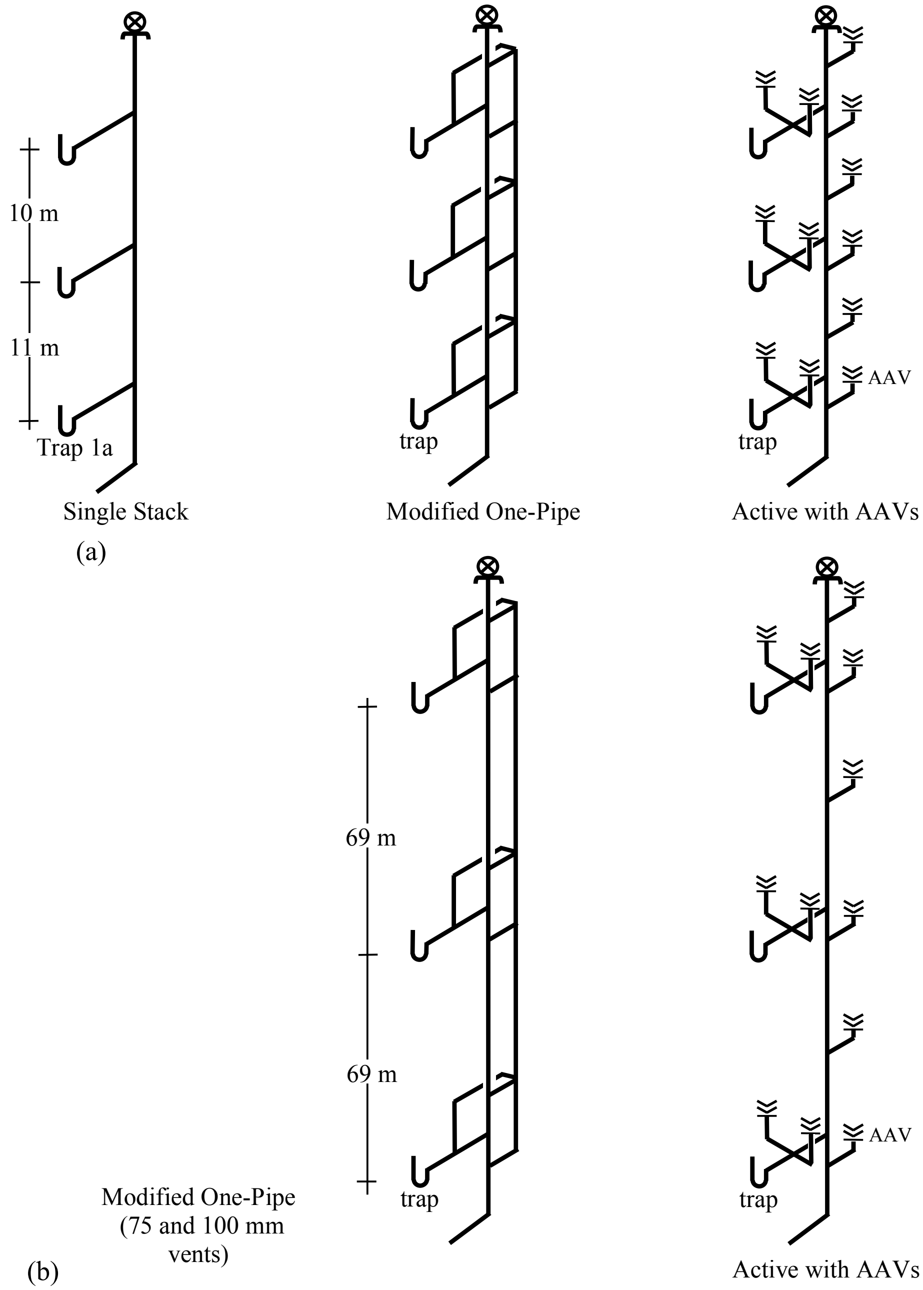
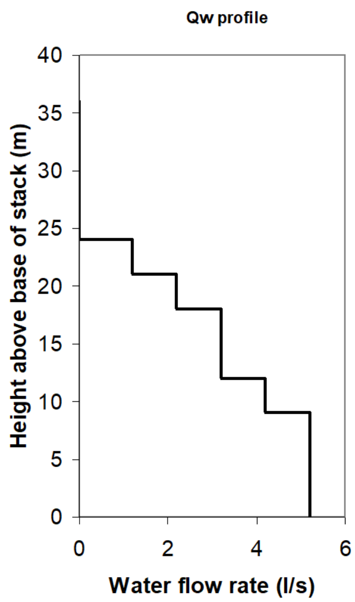


Figure 2: Simulated BDS design approaches for: (a) the 10-storey building; and (b) the 50-story building. System pipe diameters: 100 mm (a) and 150 mm (b), all other pipes are 100 mm, and all traps are 50 mm.

In each case, an appliance discharge flow profile as that shown in Figure 3 was applied and the operational performance of the BDS was simulated and assessed. Trap seal retention was used as the assessment criteria for comparison between the three different BDS design approaches and the two building heights.

The water input was staggered along the length of the stack to ensure all water did not enter at the same point and to simulate accumulation of flow in the vertical stack from adjoining branch flows. Figure 3 shows the distribution of inflow for the 10 storey simulations, a similar procedure was carried out for the 50 storey simulations for which the water profile at the base of the stack is shown in Figure 4.



(a)

Figure 3. Water inflow rate for 10 storey simulations

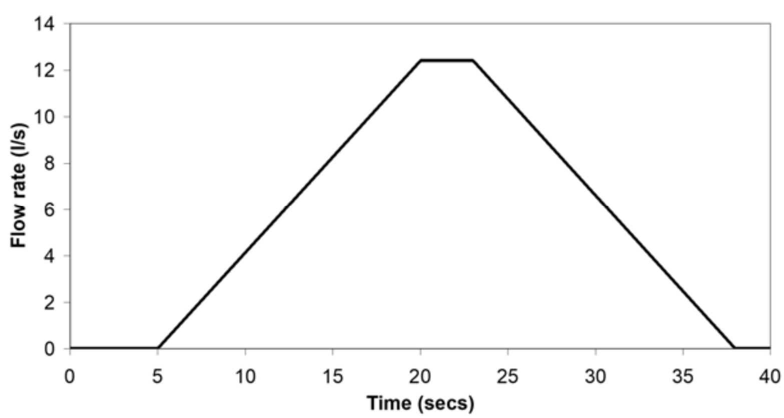


Figure 4. Water flow rate at base of stack for 50 storey simulations

4. Results and discussion

The operation of all simulated systems was carried out under the conditions given above. An assessment of the water retained in the trap nearest the base of the stack was carried out for each case and the water retained noted. An example of the output is shown in Figure 5.

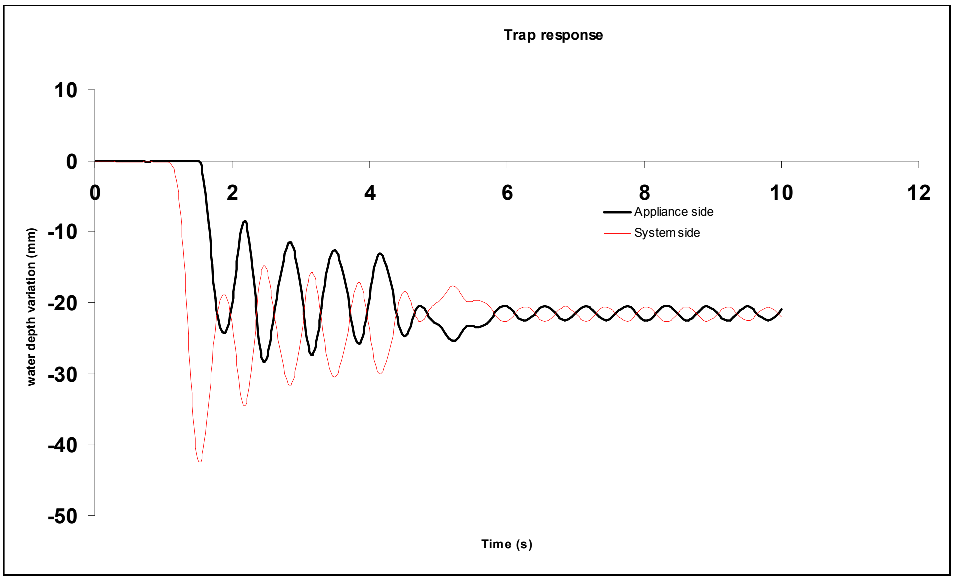


Figure 5. Example of AIRNET output for a fully loaded 10 storey single stack showing trap fluctuations and final retained water level (0 mm= no loss – 50mm = all water lost. In this example 20mm of water was lost)

The simulations were carried out to show the different trap retention from different configurations. The results are shown in Figure 6 and Figure 7 below. It can be seen for the 10 storey building water is retained under all three configurations however Active ventilation is much superior in this regard.

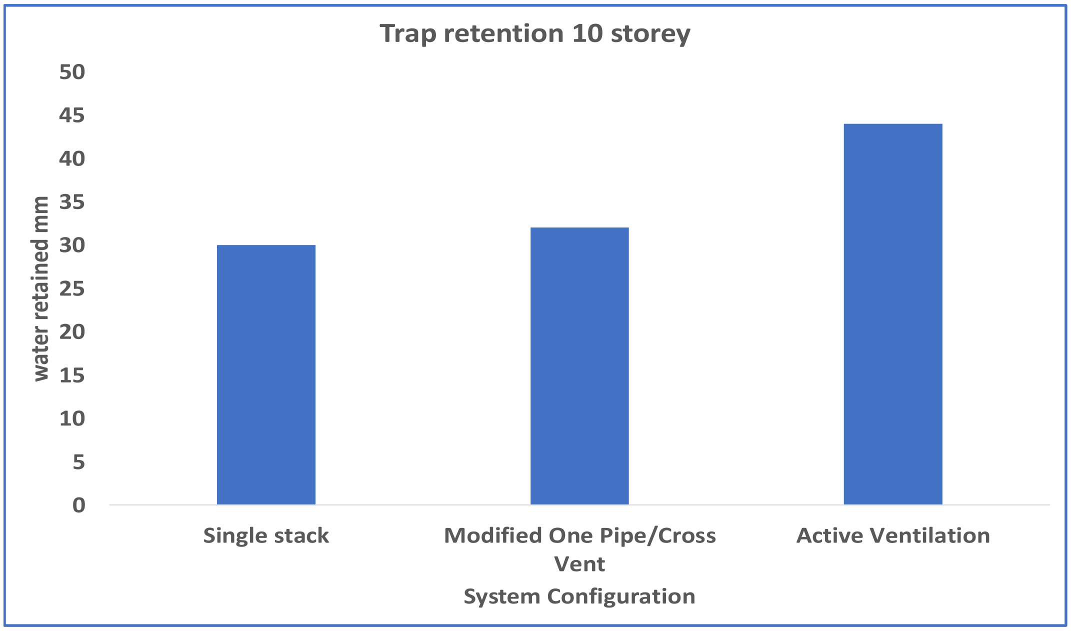


Figure 6. Trap retention for the three simulations of different configurations in a 10 storey building.

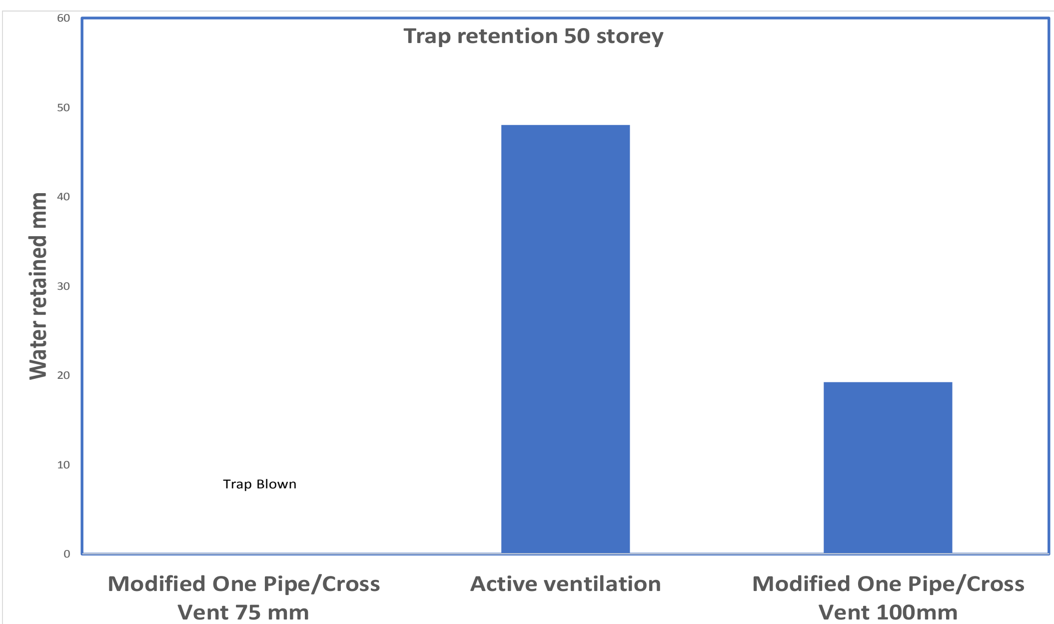


Figure 7. Trap retention for the three simulations of different configurations in a 50 storey building.

For the 50 storey example the modified one pipe system (with cross vents) where the vent pipe is 75 mm is not adequate to ventilate the system under full load conditions and the trap near the bottom was completely lost. When the diameter of this vent pipe is increased to 100 mm, some water is retained (19.2 mm) however this falls far short of the requirement for all codes and standards. The reason for this is the very high friction associated with long vent pipe runs and thus the high resistance to flow exhibited by the vent configuration. This explains the slightly better performance of the larger pipe diameter, having a lower friction. The best performance in this scenario is again the active pressure alleviation using AAVs. This provides air at the point of need with limited associated losses.

6. Conclusions

This paper has discussed the development of codes and standards in relation to building drainage evolution. In light of the explosion in number of supertall buildings and the current dissatisfaction amongst designers with the use of the same design codes for high rise buildings and low rise buildings, improvements are required to design methodologies to deal with the particular difficulties associated with BDS design in tall buildings.

The paper has shown the difference in system performance between a 10 storey building and a 50 storey building. It can clearly be seen that cross venting is not an adequate solution under heavy loading conditions, and if it is to be used, a vent pipe of at least the same diameter as the main stack would be required. In all scenarios an active approach to ventilation produces the best results, with AAVs providing air at the point of need. Overall the paper has demonstrated that more work is required in the area of high-rise building drainage research and this needs to feed into updated codes and standards as soon as possible.

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7. Authors

Dr. Michael Gormley is Director of the Institute for Sustainable Building Design at Heriot-Watt University and a lecturer in Architectural Engineering. His research interests are pressure transient modelling and suppression in drainage systems, solid transport in above ground drainage systems and Pathogen identification and control in building drainage and ventilation systems	
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.	
Dr. Campbell has a BSc Biochemistry and PhD Mathematical Modelling. Originally a Design Engineer developing chemical treatment and simulation packages for Royal Navy propulsion plant, joining Heriot Watt University in 1989 as a Research Associate. Continuous research activity in the field of water supply and drainage in the built environment and a series of EPSRC funded research grants at national level and publication of national-international level research.	

Principles of a high-flow space-saving waste water system allowing an in-pipe integrated ventilation in the entire building piping

R. Weiss (1), A. Öngören (2)

(1) rolf.weiss2@geberit.com
Basic Sanitary Technologies Dept., Geberit International AG, Switzerland
(2) abdullah.oengoeren@geberit.com
Basic Sanitary Technologies Dept., Geberit International AG, Switzerland

Abstract

The number of high-rise buildings increases worldwide rapidly as the technologies in building and construction industry advances. Besides the new buildings requires substantially more complicated wastewater installations. The architects and contractors need new drainage system concepts in planning such buildings since this highly competitive industry demands cost saving compact systems which are installable with substantially less space. Newly designed systems obviously lead to construction of technically and commercially optimized buildings. It is the aim of this study to develop a new system which meets the requirements mentioned above. The newly designed system in this study is expected to cause minimal additional installation costs but yields higher functioning capacity which leads to substantial material and labour-saving advantages.

In this study, a series of new fittings have to be designed in order to extend the high capacity functioning of the new concept to complicated wastewater installations including bottom turn bend and off-set configurations in the buildings. The individual technical properties of the new genuinely designed fittings which generate a continuous column of air in the piping from the roof down to the collector pipes are explained in detail. It is shown that these special fittings provide an effective pressure compensation in the whole discharge line preventing the surge to a substantial extend.

The findings of this study are based substantially on the results of experimental investigations which have been conducted in a high tower test-stand. The tower allows the installation of a ~30m high vertical discharge stack combined with off-setted connections at each floor equipped with flow supplies up to maximum allowable design levels. The flow characteristics and pressure distributions along the stack are measured in the newly designed system. The technical characteristics of the new system will be presented as compared to the relevant systems already available in the market today.

Keywords

Wastewater drainage; Bottom turn bend ; Back flip bend

1 Introduction

Not only the number of high-rise buildings increases rapidly in the last decades but they also become more complex. This complexity in return has a strong impact on the wastewater systems which are installed in such buildings. Therefore, the architects, MEP planers and contractors are challenged to find compact and cost saving concepts for their drainage systems in planning such buildings. Single stack Sovent systems have been an appropriate compromised solution for high-rise building wastewater applications since years with their relatively less space claim and simplified install-lation requirements. The compete-tive ventilated stack systems occupy more cross-sectional area in in general and have higher mate-rial costs. Typical configurations of these systems are illustrated in Figure 1 for comparison.

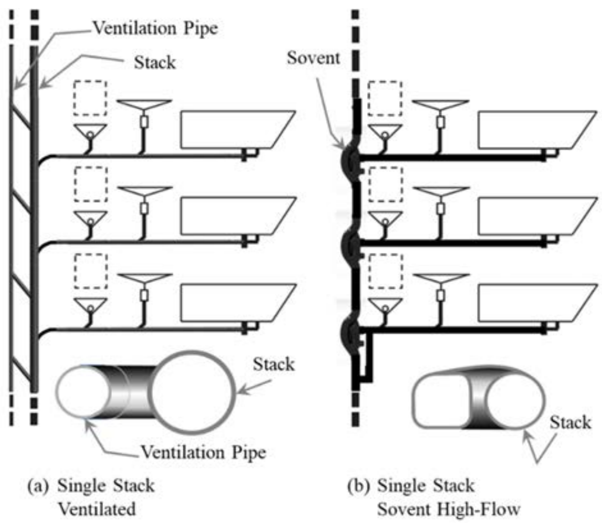


Figure 1 - Typical single stack ventilated and Sovent high-flow systems for similar flow conditions.

The seal water loss by the traps connected to the system is the limiting factor which determines the allowable capacity of a stack regardless of the type of the selected system. A trap which according to Standard EN12056-2 [1] must always contain seal water at least having a height of 50mm. It is supposed that such a trap can hold wastewater gases back from inside of buildings effectively. For this reason, every sanitary discharge equipment, i.e. washbasin, bathtub, water closet (WC) etc., must always possess a trap externally or internally integrated. Commonly the flow capacity causing a 50mm seal water loss at any location in a stack is considered to be the maximum allowable capacity for that stack system.

The ventilated single stack and Sovent systems possess similar capacities, 7.4 and 8 lt/s respectively, in their conventional forms and for a stack size of DN100. These systems have provided reasonable solutions for the construction industry so far, however especially the high-rise building projects demands higher capacities without increasing the space requirement. It is only recently a new high flow version of Sovent fitting has been developed offering a substantially higher discharge potential, namely 12 lt/s, possessing the same stack size DN100 as its predecessor. Such an increase in the flow capacity means an increase in the number of apartments connected to the wastewater system by a factor of more than 2 times (x2.25) when the standard 'Design Unit (DU)' calculation approach is used for estimation. The technical details of the new high flow Sovent fitting has been discussed previously in the literature [9].

In order to secure a problem free functioning of a wastewater system under high flow conditions, not only the floor connections as in the case of Sovent fittings but also every part of the system where a direction change in flow occurs should be treated specially and correctly. This requires improvements in almost all of the fittings of a wastewater system. In almost every wastewater system, the stack is turned from vertical to horizontal at least once at the bottom of the building before it reaches the sewage line. This particular direction change in wastewater systems has been considered as one of the main sources of disturbance and therefore a major factor limiting the capacity of that system. This issue has been investigated by many researchers in the literature [2-6] in the past in order to find countermeasures which eliminate or at least alleviate such effects on the seal loss.

It should also be considered that a wastewater system is often composed of off-setted parts where a stack is displaced to another location in the building because of structural reasons or reasons related to the laying technique. In this case, at least two direction changes are required at the offset location typically from vertical to horizontal and from horizontal back to vertical. If a special treatment is not applied at those locations, both water and air flow in the stack will be interrupted and become instable because of higher turbulences, clogging and excessive pressure pulsations [7-8]. The maximum capacity of the system will be limited to a lower level under such conditions. To prevent such inadequate effects, it is necessary to extend the in-pipe integrated ventilation and separated water flow concept to the bends so that the concept becomes continuous through the whole wastewater system. A proper system is Super Tube Technology concept which offers a solution to high flow wastewater systems. In this paper, the set improvements in fittings contained in this concept as applied to a typical wastewater system are described and discussed. The discussions are based on the results of detailed laboratory tests.

2 Hydraulics of Super-Tube technology fittings

2.1 Hydrodynamics of drainage stacks and fittings

It is commonly known that excessive turbulence is generated in the stack near the side branch junctions which causes dynamic pressure pulsations at the traps and causes high water losses from the traps when they interact with them. Secondly, the pressure surges appear because of rapid velocity changes in the stack caused by the interruptions of airflow at the side branch junctions and/or at the bends, e.g. extending the stack to the collector pipes or to the off-set piping, are responsible for excessive seal losses. Moreover, these surges are often augmented by resonance like acoustical pressure pulses which are triggered in the stack by the pressure surges themselves. Such a coupled event worsens the effect of pressure surge in emptying the traps significantly. A waste water drainage system can be improved effectively if all these influence factors are minimized.

The Super Tube technology is consisted of parts which are hydraulically redesigned to achieve significantly reduced flow disturbance levels at all critical locations. Firstly, these parts have been designed in geometry-optimized shapes so that they clearly separate the two flow-media, water and air, in the wastewater system in two longitudinally continuous layers. Simultaneously, it is attempted to keep especially the air layer cross-section as constant as possible. In order to achieve this condition, the water flow should not experience strong accelerations and decelerations since it drives the air layer in the piping through slip-free contact. When this happens a relatively constant speed state for both water and air flows is accomplished.

The Super Tube System is composed of fittings designed by considering the principals mentioned above for low disturbance, low pressure surge and no-blockage features. With these features, the system becomes a one physical piping without any need for an external ventilation piping. In this system, a water layer composed of partly film flow and partly wall jet flowing on the piping walls. On the other hand, a continuous air channel separated from the water layer is formed extending along the whole stack system as if an invisible ventilation pipe is integrated in the centre of the stack system. The characteristics of three main components of this system is discussed in more detailed in the following.

2.2 High-flow Sovent fitting

The Sovent fitting concept as it is originally introduced to the building industry attempts to improve the hydraulic configuration of the joint and to reduce the influence of pressure surge simultaneously in the stack system. This is achieved by bypassing the side branch joint by means of the special design of Sovent as displayed in Figure 2 (a). This configuration prevents a strong interaction of the flows on the stack and the side branch sides with each other. The water flow from the side branch piping proceeds in the direction of the stack flow before meeting it in the joint area. The two water flows have the same

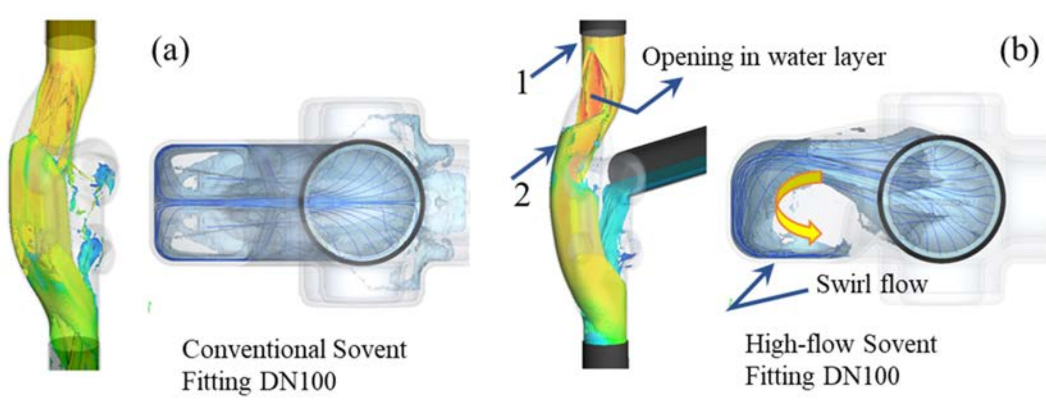


Figure 2 - Flowfeatures in conventional and high-flow Sovent fittings in comparison.

directions as they join together therefore they do not brake each other hence do not cause any disturbances in this critical area which can be directly transmitted to the side branch [3]. Additionally, with a proper change in the direction of flow from the side branch, less turbulence is generated and only a partial termination of air column in the stack is permitted. Besides, the consequence of these positive changes in stack flow results in weaker pressure surges in the system. The maximum capacity of a Sovent stack of DN100 can reach 8.0 ℓ/s as compared to 4.0 ℓ/s of a conventional single stack system.

The new high flow Sovent fitting concept is based on the genuine idea of combining the advantages of both ventilated and Sovent systems in one physical unit. It is assumed that a system with better technical features might emerge from the combination of the functioning principles of these two present systems. The new concept should then reduce the effect of flow related disturbances and it is expected to reduce the seal water loss to a minimum. High-flow Sovent consists of two main parts as depicted in Figure 2(b). The first part (1) consists of a flow divider. The flow divider cuts the water film developing on the stack walls to form an open window on the outer side of the Sovent fitting as the water film approaches the first yield of the fitting. At the same time the divider collects the film flow as a wall jet and guides it to the opposite side of the stack. The swirl zone (2) of the Sovent high-flow fitting possesses at the immediate downstream of the flow divider an asymmetric off-set which is designed to guide the wall jet tangentially to the pipe wall before it proceeds further in the downstream direction. A slight rotation is created in the flow also as a consequence of this guidance. The rotation helps to keep the flow attached to the fitting wall (Figure 2b). The special asymmetric off-set should also be positioned properly in the vertical direction in such a way that any congestion of the stack flow is avoided at the location where the side branch flow yield into the stack.

These chain of flow activities result in two separated layers of flow in the Sovent fitting. The water layer is collected to flow on the fitting walls as a rotating film whereas the air flows in a channel appearing in the centre of the fitting extending from inlet to the outlet. The air channel developing in the fitting is connected to the air channel naturally forming along the centre of the stack through the window created by the flow divider which is described above. Consequently, a continuous air channel along the whole stack system as if an invisible ventilation pipe is integrated in the centre of the stack system.

Furthermore, the rotating water film flow stays always in contact with the pipe wall which results in a constant and increased friction resistance. Besides, the water flow follows a longer streamline because of its rotational motion in the vertical direction so that an additional reduction in the terminal velocity is experienced. Both characteristics point out a hydrodynamic stabilisation of the stack flow. These optimizations significantly reduce flow related disturbances in the system, which explains an increase from ~8.0 to 12.0l/s performance of the dimension DN100 system.

2.3 Bottom Turn Bend

With a direction change from the vertical stack pipe into a horizontal pipe, the annular flow in the vertical section changes to a separated wall flow in the horizontal section downstream after turning the bend. Critical overpressure in the drainage system is mainly caused by such direction changes. The geometry of the bend used for the direction change has a major influence on how much overpressure is generated in the piping.

If a conventional 90° turning bend or a 2x45° bend is used for the direction change, the water closes down the flow channel as it reaches the bend inlet. Consequently, an accumulation of water occurs in the bend which then slows down the flow significantly (Figure 3a). These events, in return, lead to transient blockages of the flow channel. This causes excessive turbulence and pressure surges which force the flowing water to splash up the sides of the pipe after the direction change (Figure 3a). In such a situation, the water possesses extra space in the pipe and displaces some of the air flowing in the pipe. The displaced air can then cause critical overpressure in the upstream piping, which can lead to excessive expelling of the traps. Moreover, the reduced speed causes the solids settle more quickly and they are transported less distance in the horizontal section.

The Bottom Turn Bend has an idealized geometry for turning the stack flow into a horizontal collector or underground pipe by its capability of improving and correcting many of the deficiencies appearing in a bend from vertical to horizontal piping.

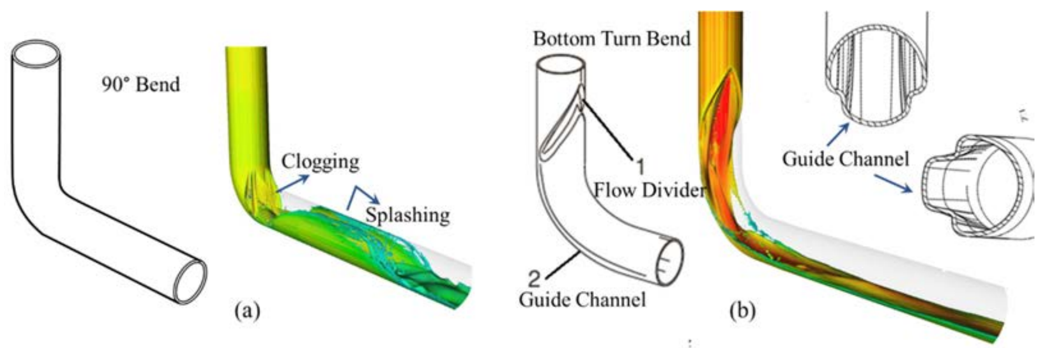


Figure 3 - Special features of the Bottom Turn Bend in comparison to a 90° bend.

The Bottom Turn Bend with Super Tube technology has two exceptional features (Figure 3b), namely a flow divider (1) and guide channel (2). The flow divider has the same function as it is described above in section High-flow Sovent. It divides the water film developing on the stack walls to form an opening on the inner side of the bend at the up-stream as the water film approaches the inlet of the bend. At the same time the divider collects the film flow as a wall jet and guides it to the opposite side of the bend inlet. This vertical jet is redirected to the horizontal section on the outside of the bend (Figure 3b). The turning geometry of the bend has a constantly increasing curve radius, which provides a hydraulic advantage by generating a radial acceleration due to centrifugal effects. This radial acceleration causes a flattening of the jet flow created by the flow divider. The flattening, however, is suppressed as the jet flows through the guide channel. At the end of the bend after the jet flow is laterally stabilised the pipe cross-section is converted back to a round shape to connect it to a standard pipe. All these optimizations lead to the fact that the usual lateral waves are almost completely damped and a steady flow forms in a short distance (Figure 3b). Measurements have shown that the solids are transported on the average 20% further than those with a conventional deflection because of the increased velocity and the more constant flow depth due to the separated layered flow.

On the other hand, the optimized geometry of thee bottom turn bend ensures a continuous column of air alongside a steady and constant water flow, as the flow divider prevents the water from accumulating in the turning section. The minimized losses in the deflection and the resulting higher speed in the horizontal pipe also result in the filling degree remaining smaller despite the higher volume flow. This has the advantage that the horizontal pipe can be loaded with much larger volume flows than specified in the tables in EN12056-2 [1] for systems having similar size piping. This makes it possible to attach a horizontal off-set up to 6m to the stack with the dimension DN100 despite a high flowrate of 12.0l/s. The dimension of the stack is taken to be DN100 in this case. This enables a completely new dimensioning of the wastewater system.

5.2 Back-Flip Bend

The Back-Flip Bend is the idealized fitting for diverting separated layer flow from a horizontal connection pipe to a vertical stack. This bend diverts the separated air-water flow back into the vertical stack without changing its flow characteristics. The bend does not allow any congestion in the bend, furthermore it regenerates the annular flow in the stack extending downstream of the bend as it is usually observed in the stacks. In conventional bends, the excessive accumulation of water and the consequent high turbulence tend to cause an overpressure on the upstream of the bend in the horizontal pipe and a negative pressure on the downstream side in the subsequent vertical pipe.

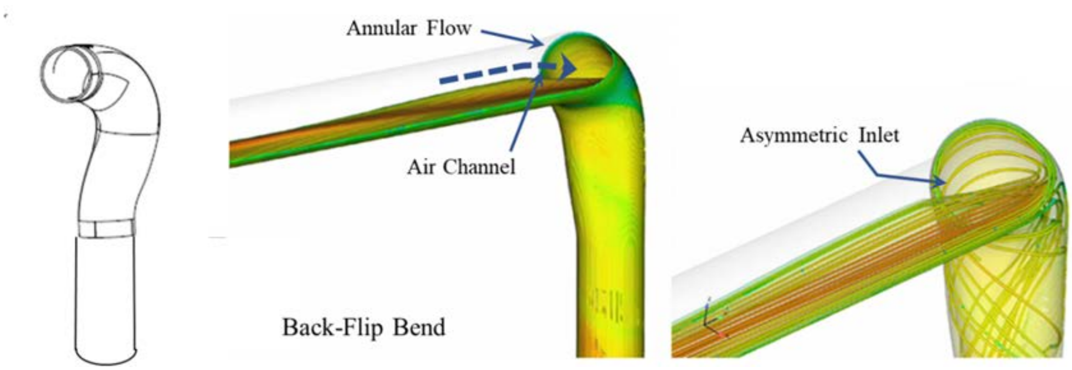


Figure 4 - Special features of the backflip bend used in Super Tube Technology.

The asymmetry implemented in the design of this bend leads to a rotational motion of the flow as it approaches the inlet of the bend. This rotational motion extends up to the outlet of the bend (Figure 4). As with the High-flow Sovent, the rotation causes a radial acceleration, which forces the water layer to flow near the wall in an annular manner and causes the air to flow separated near the center of the bend. Due to this physical effect, the air volume remains continuous as it flows through the back-flip bend leading to a continuous air column along the piping (Figure 4). The blockage of the air way is prevented this way and over- and under-pressure can therefore equalize each other effectively, resulting in a suppression of excessive pressure fluctuations occurring as the flow change direction in the bend. A favourable change in the flow conditions is expected as a consequence which will allow an increase in the capacity of the system as compared to those systems equipped with conventional bends.

2 Testing Approach

Experimental investigations have been conducted in the high tower test stand of Geberit Labs, which allows the installation of a 30.5m high wastewater system. A wastewater system corresponding to that of a 13 storeys high building including a horizontal offset up to a length of 10m can be fitted in the tower. composed of Sovent fittings and combined with soil and waste piping. Different types of systems, conventional, single stack ventilated, conventional Sovent or Super Tube, can be tested in the tower. The main stack size can be varied as well up to DN150 PE-pipe. A sketch displaying the overall configuration of the piping system in the test tower is given in Figure 5.

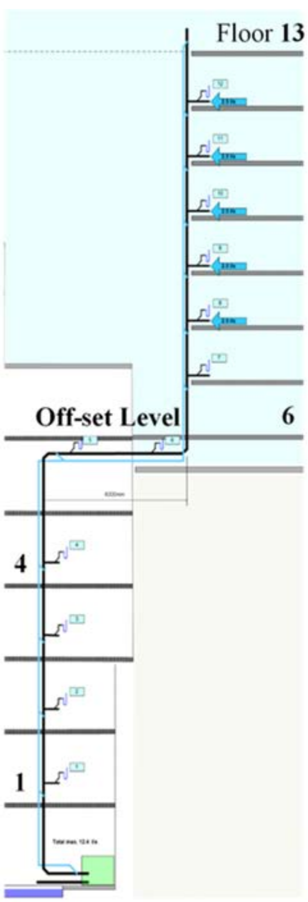


Figure 5 - An overview of the test stand.

The water is supplied to the stack at locations as many as necessary starting from the top level towards the bottom to reach the required test flowrate. At each level the flow is supplied to the stack at a maximum rate of 2.5 ℓ/s. To reach a maximum test level of the stack, 12.0 ℓ/s, the water is fed to the system at the top 5 stories as indicated in Figure 2. The tests with the stack systems considered in this paper are carried out for flowrates of 9.5 and 12 ℓ/s. The water feeding is adjusted to the necessary flowrate at the lowest level to come up with the exact values of testing.

The seal loss has been measured utilizing a series of traps mounted on the side branches along the main stack at each level of the test tower. The instrumented traps are expected to loose water under the effect of pressure transients ocurring in the stack and in the soil and wastewater piping branches in a similar way to those of real drainage systems. The flush water is fed directly into the side branch pipe without the help of any sanitary appliance however experience in previous studies have proven that this type of feeding is also capable of generating pressure transients in the pipings similar to the flushings of sanitary devices as long as the feeding possesses equivalent flow conditions. It is experienced in Geberit lab tests that a 45 second stabilized water feeding by a pump to the stack resembles the actual loading of a stack closely. Such a feeding creates testing conditions similar to actual flushing situations. In fact, this type of loading can be considered even slightly stronger than the reality. The stabilization of water feeding is reached after a 15 seconds start-up. Combined with a 15 seconds of start-up time at the beginning, a total duration of 60 seconds has been set for each case. The seal water loss is higher if the trap is exposed to a longer loading, i.e. a longer flushing time. Therefore, it is important to set not only the flow rate but also the duration time appropriately to obtain accurate seal loss results.

The pump of the tower is run up to the predetermined flow rate gradually and slowly enough so that an excessive seal loss due to start-up transients is prevented. By this quasi-stationary method, it is aimed to achieve a high reproducibility in testing. The time dependent behavior of flushing devices is neglected in this study assuming in is assuming that their effects are minor as compared to stack transients. The trap water level as detected by the ultrasound meter on each trap has been recorded on a portable computer at the end of the test period. The testing procedure and technical details are discussed elsewhere in literature [9] and will not be repeated here.

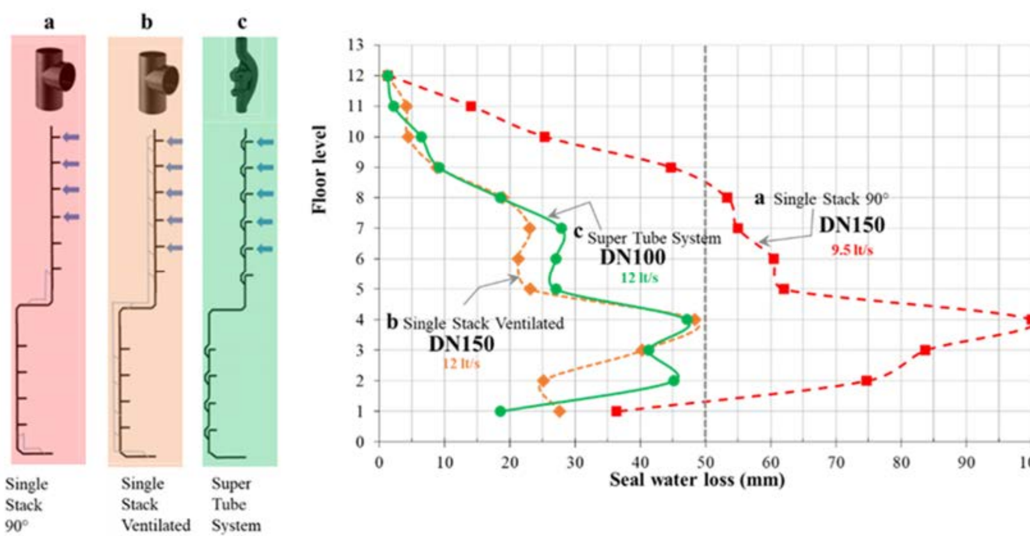


Figure 6 - Seal loss characteristics of a Super Tube system in comparison to a conventional and ventilated single stacksystem at the maximum capacity loadings.

3 Results

3.1 Seal loss in a drainage system with high-flow Sovent fittings

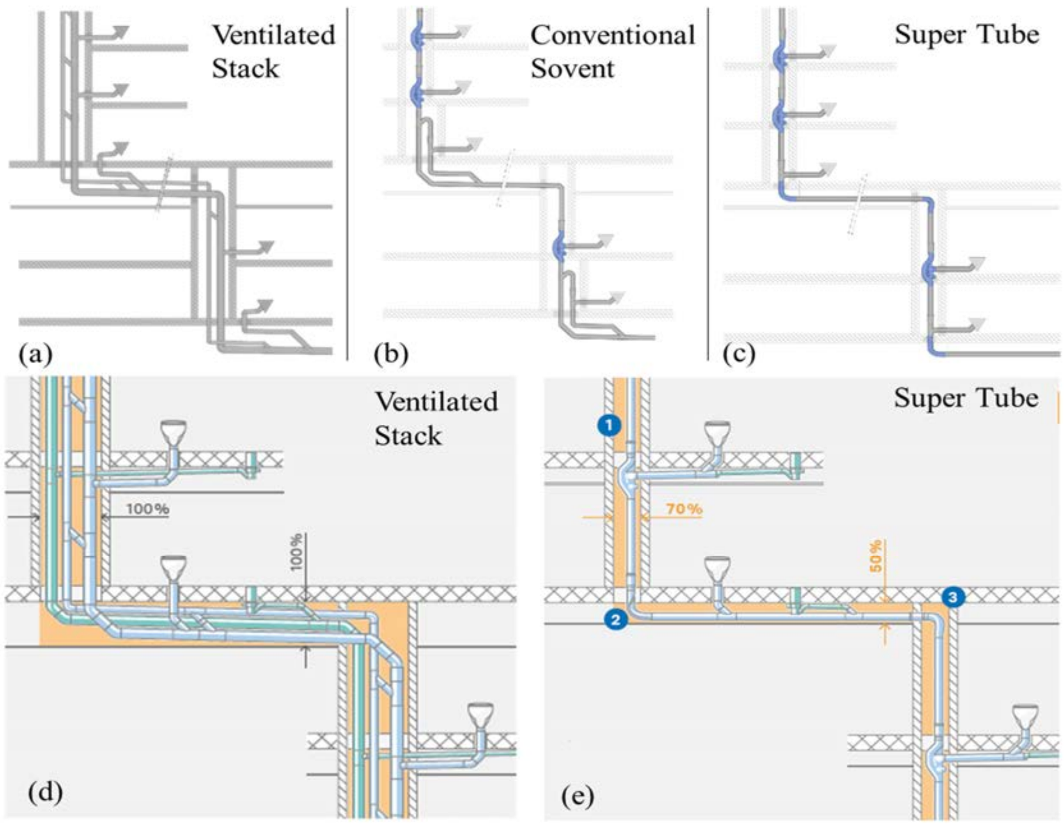
As discussed earlier in this paper, the flow conditions causing the emptying of the traps mounted on the drainage systems define the maximum capacity limits. These conditions are determined best and most directly by measuring the seal loss characteristics of the drainage systems. The seal water loss is a parameter to determine the severity of the dynamic pressure pulsations in the drainage piping systems. This method is used widely in the literature [6-8] for such purposes. In Figure 6, seal water loss for three different stack systems are given in comparison. Two reference systems, a conventional single stack 90° and a ventilated single stack, are included in the tests. The conventional 90° and the ventilated systems have stack size of DN150, whereas the Super Tube System composed of High-Flow Sovent, Back-Flip and Bottom Turn Bend fittings has a stack size of DN100. Such testing makes it possible to compare all the systems at loads which are the same or near the maximum load of Super Tube, namely 12.0 ℓ/s. All systems are composed of 12 storeys and possess a 6m long horizontal off-set between 5th and 6th levels.

As observed in Figure 6, the single stack 90° reaches a maximum average seal loss of ~100mm (Curve a) near the 4th storey despite its oversize (DN150) and relatively lower flowrate of 9.5 ℓ/s. This level is significantly higher than the commonly allowable 50mm for such stack systems and size. Curve b designates the seal loss values along a ventilated single stack loaded by a flowrate of 12.0 ℓ/s. The average maximum seal loss reaches to a level of 48mm near the 4th storey. This seal loss level is below the commonly acceptable level of 50mm for building drainage systems. The Curve c depicts the seal loss distribution along the Super Tube system loaded by a flowrate of 12.0 ℓ/s. As the flowrate is increased to this capacity, the seal loss increases to a maximum average level of ~47mm near the 4th storey likewise the previous reference cases. This loss level is very similar to that of ventilated stack system and remains below the acceptable risk level of 50mm. However, it is important to consider that this loss level of Super Tube system is achieved with a stack size of DN100 which is two sizes smaller than the reference systems with DN150 stacks.

3.2 Comparison of installation situations

The wastewater systems of high-rise buildings require considerably higher capacities, therefore according to EN12056-2, the drainage stacks of such buildings are composed of large dimension piping. It is also usual that an external ventilation system equipped with a secondary vent pipe which is connected to the stack at regular intervals is required to reach the necessary high flow capacities. This means that larger dimension pipe shafts are required in the buildings at the expense of the living or usable area. Moreover, the horizontal piping, soil pipe or horizontal collector pipes, must be installed with a gradient in order to secure a low clogging risk for solid transport. Such installation becomes very complicated and requires significantly more space especially when they are extended to long distances. A second option is to use a Sovent system installed with large dimension Sovent fittings. Such systems require, in fact, no ventilation piping on the stack, however, the bends of such systems should be treated with a ventilation unit specially at the connections to the collector pipes and off-set locations where a direction change of the flow occurs. These measures require additional space for installation.

On the contrary, the Super Tube system contains high-flow Sovent fittings and a set of new technology bends which does not require an external ventilation from the roof to the ground level even if the wastewater piping undergoes flow turning and off-sets several times. The system generates a continuous air column at the center of the piping from the roof to the collector duct on the ground level which serves as an integrated ventilation system. With these features, the Super Tube System enables the wastewater drainage systems of tall buildings to be installed simply and space-saving without any risk of excessive seal loss and pressure surges. The simplicity and space-saving advantages of the new technology is clearly depicted in Figure (7).



- Stack pipe size DN150 - Additional parallel venti-lation pipe size DN90 - Horizontal pipe size DN150 with an inclination of 1.5 - 3% - Discharge capacity 12.4 l/s	- Stack pipe size DN150 - No external ventilation - Ventilation is necessary at direction changing locations - Horizontal pipe size DN150 with an inclination of 1.5-5% - Discharge capacity 17 l/s	- Stack pipe size DN100 - No external ventilation - Ventilation is <u>not</u> necessary at direction changing locations - Horizontal pipe size DN100 with an inclination 0.5% up to 5 m length - Discharge capacity 17 l/s

Figure 7 - Comparison of system characteristics and space saving features of ventilated single stack, conventional Sovent and Super Tube systems.

In Figure 7, the special flow characteristics of the new Sovent high-flow fitting including the air channel flow is exhibited in comparison to two stacks, one consisting of a swept entry joint and the other a conventional Sovent fitting. In Figure 7(a), it is clearly observed that as the cylindrical film flow passes by the swept entry joint it is forced to totally collapse on the stack side opposite to the joint by the effect of side branch flow. This causes the air channel close and terminate at this location. A new film flow is started from Figure 7(c) displays the flow characteristics of the new Sovent high-flow fitting. Here, the cylindrical film flow passes through the fitting without experiencing any appreciable disturbance. Therefore, the air channel along the centreline of the fitting does not show any collapse or closing, either. A continuous air channel extending from the inlet up to the outlet of the stack including the fitting is clearly visible in this figure.

4 Conclusions

In this paper, it is reported on the main characteristics of a new high-flow wastewater drainage technology which is capable of elevating the capacity of system discharge in buildings significantly over the presently available systems. This new technology provides such advantages even if there are off-sets and flow turnings in the system. The hydrodynamic features of the elements designed for this technology are described in detail based on the results of extensive experimental investigations. The results obtained with the new fittings are always verified by comparisons with those of well-known reference systems as well as with those of some commonly installed systems in today's buildings.

It is shown before [9] that the new Sovent high-flow fitting has the potential of increasing the maximum attainable capacity of a discharge stack as much as 40% by combining the positive features of externally ventilated and conventional Sovent systems. It is shown in this paper that the maximum capacity of a discharge stack fitted with Super Tube fittings of dimension DN100 is elevated to 12.0 ℓ/s as well even if off-setted parts are contained in the installations. Moreover, this increase is achieved without upgrading the piping dimension of the high-flow fitting to a larger size than the present conventional fittings and hence providing a significant space saving in large buildings.

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6 Presentation of Authors

Dr. Abdullah Öngören is the head of Basic Sanitary Technologies Department at Geberit International A.G. (Switzerland), where he is widely involved in research and development of sanitary equipment, and rain and waste water drainage systems. He is specialized in flow induced vibration and noise and CFD applications in sanitary equipment and systems. He is currently conducting research in sanitary ceramic production processes.

Rolf Weiss is working at the Basic Sanitary Technologies Department at Geberit International A.G., where he is widely involved in research and development of sanitary equipment, and rain and waste water drainage systems. He is specialized in hydraulics and CFD applications in sanitary equipment and systems. His current research interest involves performance of building drainage systems.

The Construction Design Using Rain Water and Potential Effective Use of Rain Water

Tamio NAKANO (1)

(1) t-naka@suac.ac.jp

(1) Department and Faculty of Design, Field of Architecture and Environment, Shizuoka University of Art and Culture, Japan

Abstract

In Japan, the construction using rain water is positively planned to a climate change in recent years and global saving resources. In a public building, furnishing using rain water will become indispensable and it will become the duty of equipment using rain water also in a private building in the future. From now on, it is necessary to consider use of rain water in the stage of a plan or a design in a building.
In planning rain water use in a building, rain water is not effectively utilizable in one building in many cases. In order to use rain water effectively in a building, it is necessary to make a plan not in the narrow range but in the wide range. The result of having considered effective use of the rain water between collective housing and an office, and the effect of the incentive by a water network are introduced.
The subject and possibility of use of rain water in a building and a city were considered from a facility designer's engineering viewpoint, and the building designer's designing viewpoint. Moreover, processing of rain water, not only reuse but the design of rain water, and potential practical use of rain water are proposed. I would like to tie to the construction which utilizes resources and energy of rain water in the future.

Keywords

Design using rain water; Potential effective use of rain water; Private building; Facility design; Engineering viewpoint; Designing viewpoint

1. Introduction

In Japan, "the law about promotion of use of rain water" was enforced as a measure to a climate change in recent years and global saving resources. In a public building, furnishing using rain water will become indispensable and it will become the duty of equipment using rain water also in a private building in the future. From now on, it is necessary to consider use of rain water in the stage of a plan or a design in a building.
Generally, the design of rain water was aimed at discharging rain water outside a building promptly, and also discharging promptly to the exterior of a site. On the other hand, rain water outflow control is taken under local severe rain in recent years or the influence of sewer load increase. Rain water is made to store temporarily at a pit or a site, or the rain water outflow control made to permeate is taken.
From now on, it will use the rain water of a building or a city positively, and it not only discharges it, but it will attain resource saving. It is necessary to aim at conversion of the thinking to rain water in the position of a chief mourner, a designer, or an engineer.
It can be said that it is an important problem for rain water use construction to spread in society.
This research considered the subject and possibility of use of rain water in a building and a city in Japan from a facility designer's engineering viewpoint, and the building designer's designing viewpoint. In the future, the design and potential use of rain water will be needed. It refers to the building which utilized rain water, and explores the possibility of rain water use construction.

2. The subject and possibility of rain water use in construction

It is important to grasp the process of processing of rain water collected on the roof of a building. In order to examine the method of rain water processing, and the subject and possibility of rain water in a common building, the rain water processing flow in a building is shown in Figure 1.
Rain water collected on the roof of a building is collected in a roof drain, and results on the ground through a drainspout. Then, it is connected to the sewer pipe or storm drain outside a site from stormwater inlet in a site. Rain water outflow control makes rain water permeate underground with stormwater infiltration inlet and the stormwater infiltration pipe of a site, or performs temporary storage of rain water using the pit of a building. After a rain water use system removes early rain water by a knife gate valve, it installs grit tank and removes sand and a pebble. Furthermore, rain water use is divided, when using from a rain water storage tank, and when using through a disinfection tub. In the design of construction, rain water serves as a plan observed to discharge or a rule, and a plan to use has not become.
On the other hand, water usage is reusing rain water positively for the purpose of reduction of a running cost like an office or a school in the building for which the water for miscellaneous use of the rinse water of a toilet occupies most.
However, supposing tap water is very cheap, the meaning which reuses rain water will be lost. It stops in that case, considering using rain water in almost no buildings.
That is, although saving resources and global environment are considered and rain water use is important, if cost and maintenance expense are taken into consideration, rain

water use has only a demerit. This is the actual condition and the present condition that rain water use construction does not spread, in Japan.
But, the system which brings about an incentive is also possible for rain water. Moreover, rain water can unite a design and can also bring about value. It is necessary to consider the measure which brings forth a new possibility of using rain water, by aiming at conversion of the way of thinking from now on.

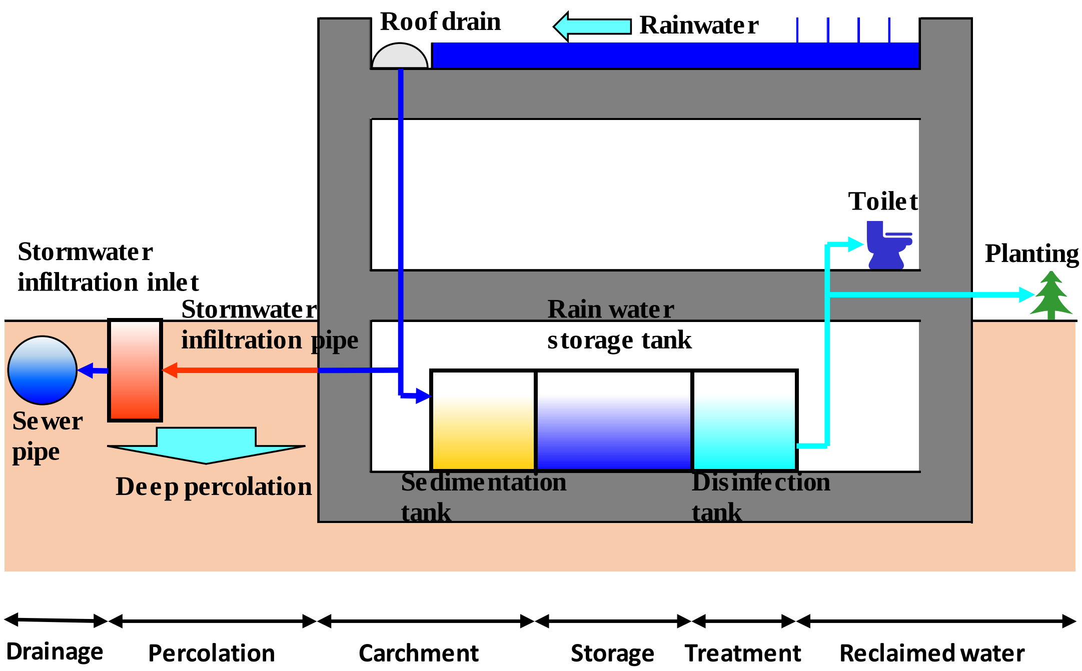

Figure 1. The rain water processing flow in a building

3. Incentive of Rain Water Utilization Plan in Broad Sense Range

In planning rain water use in a building, rain water is effectively unutilizable in one building in many cases. For example, when it is going to use rain water in collective housing, there is almost no place which can utilize rain water, such as watering of planting and toilet rinse water of a common part. In order to perform rain water use effectively in a building, I think that it is necessary to plan rain water use not in the plan of the narrow sense range but in the broad sense range. The flow and water network of a rain water utilization plan (collective housing and office) in the broad sense range are shown in Figure 2 and Figure 3, respectively. Moreover, the incentive trial calculation by a water network is shown in Table 1.
A plan is introduced about field use of the rain water of collective housing and an office. As the practical use method of rain water, it is a very effective plan. There is two point about rain water use, and they are "rain water use natural cool spot formation" and "the mutual incentive by a water network."
First, "natural rain water use cool spot formation" is explained. Technical innovation is the advanced plan which utilized for rain water the technology of holding remarkable

water. Although the rain water which fell to the site is promptly discharged out of a site, natural osmosis is urged to it by holding rain water at a site, and it forms cool spot in building exterior space using open air cooling and evaporation heat. Although the technology of holding water is used for the measure against an area with little precipitation, or desertification, it is diverting to rain water use, and changes to what brings forth a new possibility.

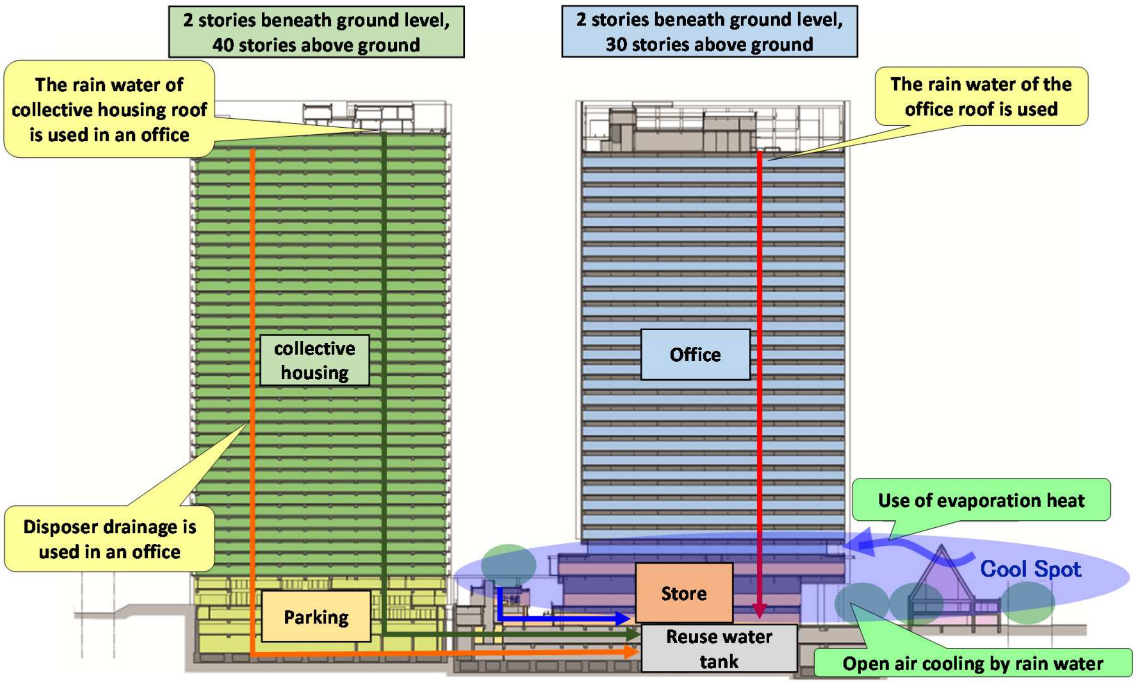

Figure 2. The rain water utilization plan which cooperated collective housing and an office

Next, "the mutual incentive by a water network" is explained. It is obliged to process drainage of a building in a site in principle. In this plan, field use of drainage was planned taking advantage of the advantage of redevelopment. The rain water of collective housing is collected to the rain water storage tub of an office, and it is scheduled for about 70 percent of water use to process rain water by the office side which is rinse water of a toilet, and to utilize rain water effectively. The greatest point is the exemption effect of the effluent charge expense which produces not only rain water but all raw water by using for reuse water. By a water network, the office can use the rain water of collective housing and can reduce water service expense and sewer expense sharply rather than the usual rain water use system. Moreover, the cost reduced in the office can be accommodated to collective housing, and reduction of the administrative expenses of collective housing can be aimed at. An incentive can work in both buildings and the water network can bring forth a win-win relation mutually.

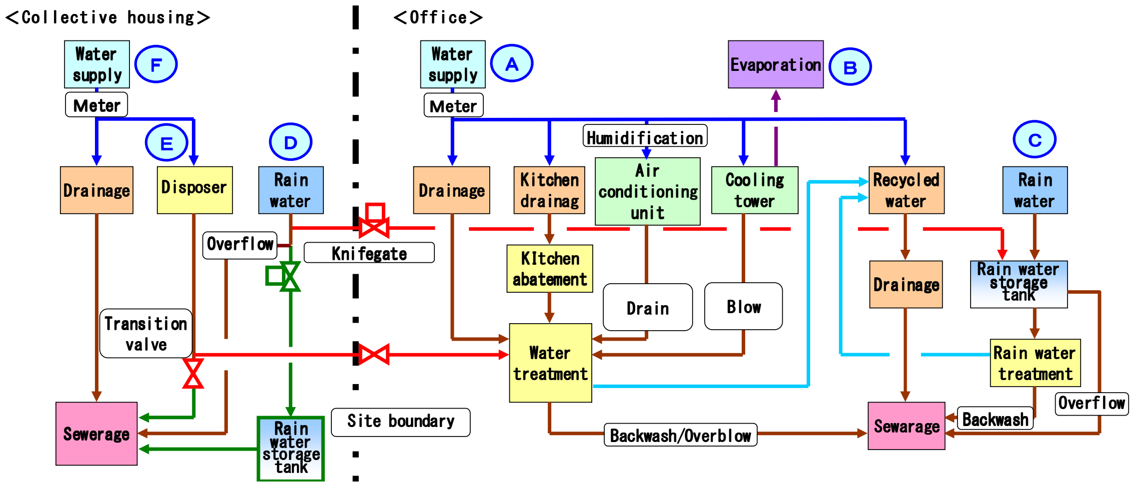

Figure 3. Water network flow (collective housing and office)

Table 1. Water network effects (collective housing and office)

	Water Network		Water network effects		
	Nonexistance	Existance	Reduction cost	Water treatment cost	Equipment cost Management cost
Office	Water rate				
	A	A－ (D＋E)	－5, 000, 000 yen/year	＋1, 500, 000 yen/year	Equipment cost ＋12, 000, 000yen Management cost ＋300, 000yen/year
	Sewarage charge				
	(A＋C) －B	(A＋C) －B－E	－3, 900, 000 yen/year		
Collective housing	Water rate		±0 yen/year		Equipment cost ＋1, 000, 000yen Management cost －100, 000yen/year
	F	F			
	Sewarage charge				
	F	F			

4. Rain Water Use Construction Which United Design

4.1 Visualization of Rain Water

The fault of rain water use construction is not being a foregone conclusion that it is utilizing. It does not appear until rain water collected on the roof passes through the inside of a gutter, passes through underground and results in a sewer pipe. However, I think it possible to raise value to enjoying oneself from discharging rain water by attaining visualization of rain water. Here, the rain chain of Hougonin is shown in the photograph 1.

A rain chain is a kind of a gutter which leads the rain water of the roof of a building to the ground. There are some which connected the ring and the chain of a design like a petal. It has been used for shrines and temples construction or construction in Japanese style as building materials expressing the four seasons and emotion of Japan for many years. A rain chain is culture peculiar to Japan, and is a drainspout used by shrines and temples construction or sukiya-zukuri. The century half ago, it came to be used also for

a common residence. Then, although the opportunity used by Westernization of a residence progressing also decreased, the new practical use methods, such as taking in from the fun of the design to a modern business complex, are born by recent years.
Water can flow into a rainy day and it can direct the atmosphere which left automatically and is different also in when. Moreover, a plant can be harvested and green curtain can also be made. A rain chain is the culture which showed "the playfulness over rain." While the material of a building changes from a tree to concrete with a time, technology also progresses and the wave of cost reduction and increase in efficiency rolls in, the view over rain water has become neglectful. I think it required for a future time to consider the construction using rain water from a viewpoint learned from ancient times of "enjoying rain water."

Photograph 1. Rain chain of Hougonin

4.2 Usage of Rain Water Which United Design

In the present age, a "design" is insufficient in the rain water use construction in Japan.
Uniting a design with rain water thinks that it is important for future rain water use construction. The amenity water facilities and rooftop gardening using rain water are shown in the photograph 2 and the photograph 3, respectively.
This amenity water facilities uses rain water and groundwater. The shallow flower basin and the art work have given people pleasure. The light of glass reflects in the water surface and it is visible just like a marine wave. Moreover, although the building is generally enclosed on the fence as a measure against crime prevention, the shallow flower basin has substituted for the fence. And the shallow flower basin assimilated to the surrounding landscape, and it has given the pedestrian relief and healing. Furthermore, it contributes also to reduction of air conditioning load, and has become dirt prevention of building appearance. A demerit is that the expense for maintenance management is high. From increase of administrative expenses, the amenity water facilities whose water was exhausted is increasing in a town.
The rooftop gardening of the building was in fashion as a measure against a heat island 20 years ago in Japan. It went out of use gradually on the load of the ground, or the problem of the maintenance. This rooftop gardening hardly manages but the lawn in vivid green is growing thick. About 20 years passed only by rain water in the state of the no maintenance mostly. It has contributed to environmental impact reduction of a university very much over a long period of time. Furthermore, the greatest strong point of the rooftop gardening of this study is the design which combined an art work and tree planting. Therefore, I am a place of relaxation of local residents and children, and think that it is an ideal form of a rooftop gardening design.

Photograph 2. Amenity water facilities

Photograph 2. Rooftop gardening

5. Effective Use of Rain Water Potential

The near future construction using the potential which rain water has was considered. Upper layers and a raise in dense of a city building are being enhanced. Rain collected on the roof is a precious energy source with "potential energy." Moreover, it leads to outer cover load reduction by storing rain collected on the roof in a rooftop pool. Furthermore, it is possible to utilize fall energy and to also perform small scale hydropower. Moreover, rain water can be used for glass coating as curtain, and reduction of air conditioning load can also be aimed at. Although use of rain water was restrictive until now, it will become the time of utilizing rain water positively from now on. Moreover, also in achievement of global SDGs, I think that the important role is played.

6. Conclusion

If it catches a glimpse of the role which construction should play to the state of the world and global environment of these days, you will have to spread rain water use construction widely in the future. On the other hand, don't forget for there to be various obstacles for spread, either. In rain water use, there are many restrictions of technical innovation, cost reduction, law, a design, etc. However, I think that the thing most important for the spread of the construction using rain water is changing the consciousness of the minus to rain water into plus not only to domestic but to the whole world. Although it is not "the north wind and the sun" of the Aesop fable, it is required to build the system that the organization which must use rain water forcibly is not fixed, but the various strong points are born by using rain water, and everyone becomes fortunate. It will change to the world which becomes natural using rain water in the near future.
I would like to tell children the importance of rain water, the fun of rain water, and rain water use construction finally. According to making it spread in the environmental education of an elementary school, I think that it is the first shortcut that changes not only Japan but the world.

7. References

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8. Presentation of Author

Dr. Tamio Nakano is Associate Professor at Shizuoka University of Art and Culture, Faculty and Department of Design, Field of Architecture and Environment. He is conducting various researches on his major field of study of Plumbing system, Energy saving and Resource saving. And he is also facility designer of building equipment. Before, when he was belongs to Maeda Corporation, he was designing many architecture.

A Proposal for a Simplified Method for Predicting the Carrying Performance of Water-saving Toilets

Ryota Oba (1), Masayuki Otsuka (2), Shintaro Gomi (3),
(1) m18J3002@kanto-gakuin.ac.jp
(2) dmotsuka@kanto-gakuin.ac.jp
(3) sin53freedom@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., Urban Renaissance Agency, Japan

Abstract

At present in Japan, a simplified method is yet to be established for designing horizontal drainage pipes (with relevance of lengths and elbow fittings in mind), the method that considers the carrying performance as well as the drainability of horizontal drainage pipe systems, with water-saving toilets connected thereto, for detached houses. Therefore, plumbing is currently carried out using subjective methods, including determining pipe lengths and the number of elbow fittings, while concerns about stagnation of or blockage by waste and toilet paper in pipes are not addressed.
Considering this background, this study ultimately aims to propose a simplified yet practical method for predicting carrying performance. In this paper, first, two systems; one comprising a 6m straight pipe, and one comprising a 6m pipe with five horizontal elbow fittings arranged at equal intervals, were used to clarify the basic flow characteristics of wastewater, and necessary data about discharge characteristics and carrying performance were collected to be used in calculations. The calculation results were then used for quantitatively measuring the degradation of drainage performance affected by the total pipe length and the elbow shape, and a simplified method for predicting discharge characteristics and carrying performance was examined.

Keywords

Plumbing Design, Evaluation of Drainage Performance, Carrying Performance, Average Fixture Discharge Flow Rate, Horizontal Drainage Pipe

1. Background and study objectives

The design and layout of horizontal drainage pipes for detached houses relies much on the experience of engineers. In particular, the installation of water-saving type toilets can entail a problem, such as pipe blockage, due to pipe length and the number of horizontal elbow fittings. Such a problem needs to be taken seriously by local constructors and builders.

There are methods for identifying the carrying performance of horizontal drainage pipes for houses, and these include verification methods by actually constructing pipework models[1)], numerical simulation methods[2)] and the Moving Particle Semi-implicit (MPS) method[3)]. The problem is, these methods require a lot of effort in terms of construction and implementation of experiments and involve rather complicated calculations, and therefore are not widely used.

With this background in mind, the authors have been proposing a calculation method[4)] which enables realistic calculation of carrying performance from numerical values of resistance in straight and bent pipes. This paper reports further development of the concept of this method, in which "average discharge flow rate of drainage pipe-connected fixture" is collated with "average discharge flow rate of drainage pipe-connected fixture for carrying limit", with the aim of proposing a practical method for checking pipework, which is capable of determining the feasibility of pipework design. Furthermore, to provide an example, this paper reports the verification results of the method, which were obtained by applying said method to an experimental water-saving toilet and a basic pipework model.

2. Proposal of the simplified evaluation method of carrying performance and the overview thereof

Fig. 1 is a calculation flow chart of the simplified carrying performance check method which is discussed and proposed in this paper. The overview of the method is illustrated in Fig. 2, and the calculation procedure is as follows:

Step 1. Measure and calculate the fixture discharge characteristics value (the average fixture discharge flow rate q_d [L/s]) of the experimental toilet in accordance with SHASE-S 220[5)]. Use formula (1) to calculate q_d .

Step 2. Calculate, using formula (2) from q_d as reference data, the lowering rate γ of the average fixture discharge flow rate q_d' of the experimental toilet when connected to the horizontal drainage pipe (straight).

Step 3. Set conditions of the design pipework
(①Total length of horizontal drainage pipe reaching the drainage basin: Lt(m), ② the type of horizontal elbow fitting: DL, LL or 45L (see Photo 1), ③ the number of elbow fittings: n, and ④ gradient)

Step 4. Using the conditions set in Step 3 and $\Delta q_d'_L$ [L/(s·n)] representing a reduction in q_d' /horizontal elbow fitting/type, which was identified by the experiment, calculate $q_d'_c$ by formula (3) from the reduction in q_d' in the case of the straight pipe.

Step 5. Compare $q_d'_c$ calculated in Step 4 against the practical "average discharge flow rate of drainage pipe-connected fixture for carrying limit" per type of waste substitute, which was proposed in the previous paper. Determine if $q_d{'}_c$ satisfies formula (4).

Incidentally, this paper describes basic drainage experiments employing an experimental horizontal drainage pipe system, which were carried out in order to calculate $\Delta\, q_d{'}_L$(L/(s·n) representing a reduction in $q_d{'}$ / horizontal elbow fitting / type, which is required in Step 4. Numerical values in an applicable range, with consideration of the influence of installation locations of fittings, etc., were obtained from the experiment results, and were applied to the pipework model in two different configurations to carry out the calculations. The practicality of the simplified prediction method of carrying performance was subsequently examined.

Formula (1) $q_d = 0.6\, w ／ t_d$

Formula (2) $\gamma = q_d' / q_d$

Formula (3) $q_d{'}_c = q_d{'} - n \cdot \Delta\, q_d{'}_L$

Formula (4) $q_d{'}_c > q_d{'}_{cp}$

[Reference symbols]

q_d: average fixture discharge flow rate [L/s]
w: fixture discharge volume [L]
t_d: average draining time [sec]
γ : the lowering rate of $q_d{'}$
$q_d{'}$: average discharge flow rate of drainage pipe-connected fixture [L/s]
Lt: total length of design horizontal drainage pipe [m]
n: No. of fitting installation locations [n]
$\Delta q_d{'}_L$: reduction in $q_d{'}$/fitting [L/(s・n)]
$q_d{'}_c$: average discharge flow rate of drainage pipe-connected fixture at horizontal drainage pipe end under design conditions [L/s]
$q_d{'}_{cp}$: average discharge flow rate of drainage pipe-connected fixture for carrying limit [L/s]

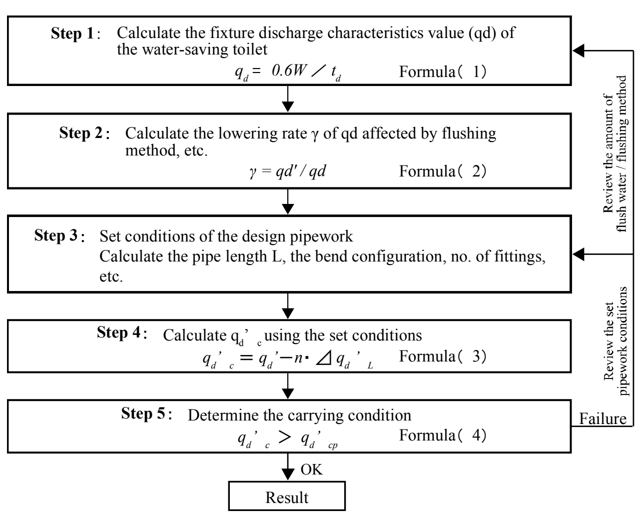


Fig. 1 Flow of calculations

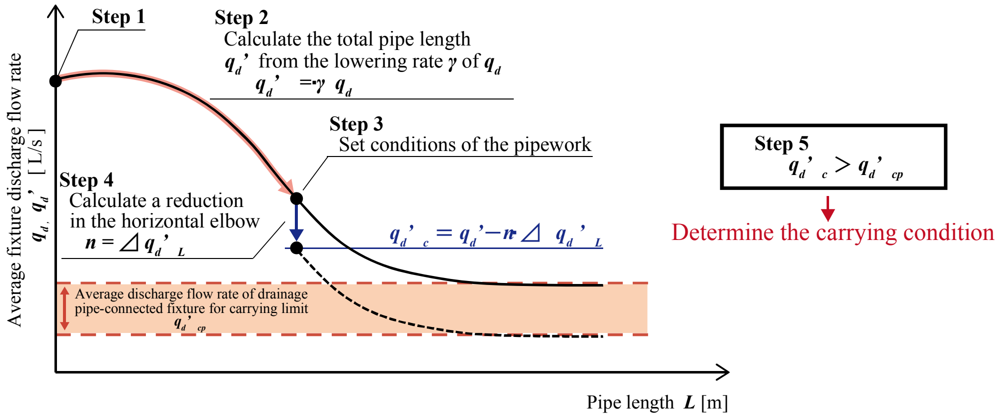


Fig. 2 Carrying performance calculation check method - overview

(1) DL fitting (90° elbow) **(2) LL fitting (Long radius 90° elbow)** **(3) 45L fitting (45° elbow)**

Photo 1 Horizontal elbow fittings

3. Experiment overview

In order to collect data as a basis for carrying performance prediction, two experiments were carried out; a "drainage pipe-connected fixture discharge characteristics experiment" to identify decreases of discharge characteristics values in connection with the total pipe length and the number of horizontal elbow fittings, and an "experimental waste substitutes carrying performance experiment" to identify the performance of the experimental horizontal drainage pipe system in carrying waste.

3.1 Experimental horizontal drainage pipe system

Fig. 3 and 4 are plane views of the experimental horizontal drainage pipe system (pipe length: 6m at most). Fig. 3 illustrates a configuration with straight pipe and Fig. 4 illustrates a configuration with elbows arranged at equal intervals. Both pipe configurations were used for the fixture discharge characteristics experiment and the experimental waste substitutes carrying performance experiment. With regard to the pipe configuration with elbows, three types of horizontal elbow fittings; DL, LL and 45L, to identify variations of discharge characteristics in relation to the type of horizontal elbow fitting used. Incidentally, the horizontal drainage pipe has a diameter of 75A (actual inner diameter 78mm) and a gradient of 1/100. A DT fitting (75A×150A) is connected to the downstream end of the system. Waste water drains down into the drainage basin.

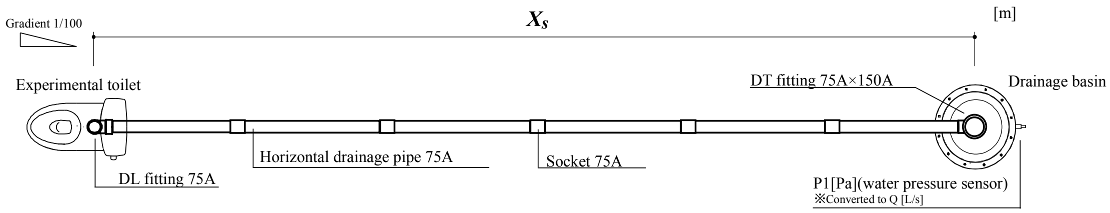


Fig. 3 Experimental horizontal drainage pipe system (with a straight pipe)

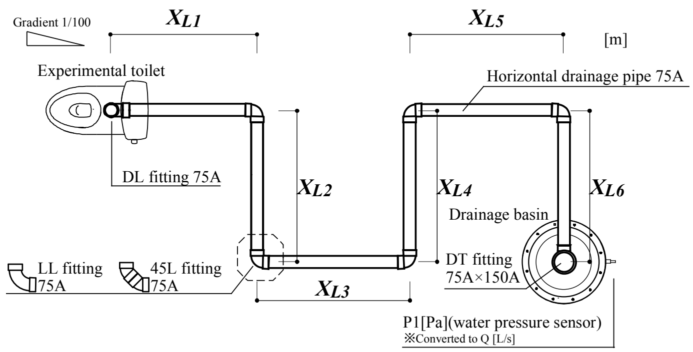
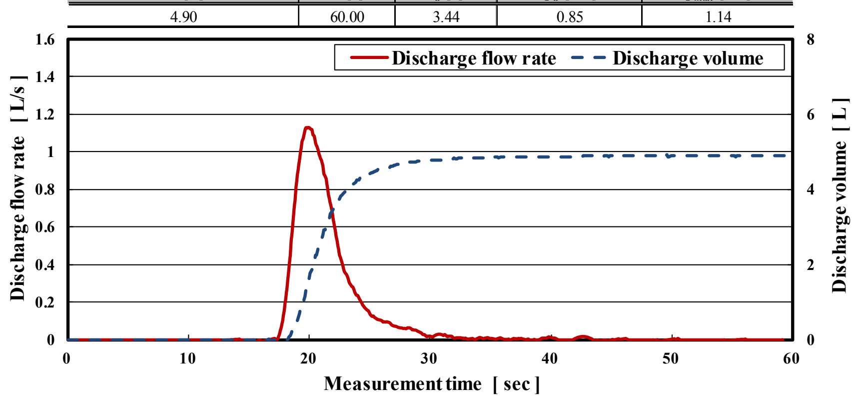


Fig. 4 Experimental horizontal drainage pipe system (with elbows at equal intervals)

3.2 Experimental toilet

Fig. 5 shows the discharge flow rate curve and discharge characteristics values of the experimental toilet. Said toilet is of a wash-out type which is commonly used in detached houses and uses 4.8L of flush water (JIS A 5207: water-saving type II). The average fixture discharge flow rate q_d of said toilet is 0.85L/s.

Fixture discharge volume	Required draining time	Draining time	Average fixture discharge flow rate	Max. fixture discharge flow rate
W [L]	T [s]	t_d [s]	q_d [L/s]	q_{max} [L/s]
4.90	60.00	3.44	0.85	1.14



*Measurements in accordance with SHASE-S 220[5)]

Fig. 5 Characteristics values and discharge flow rate curve of experimental toilet

3.3 Load application method

(1) Drainage pipe-connected fixture discharge characteristics experiment
Table 1 shows the drainage load patterns which were applied to the experimental horizontal drainage pipe system illustrated in Fig. 3 and 4. Drainage load patterns No. 1 to No. 7 were applied as the length of the straight pipe was increased by 1m at a time, and drainage load patterns No. 8 to No. 17 were applied as the length of the pipe with equally spaced elbows was also increased by 1m at a time, or as the number of horizontal elbow fittings was increased by one at a time.

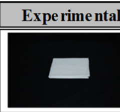
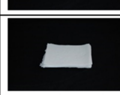
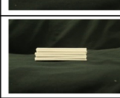
(2) Experimental waste substitutes carrying performance experiment
This experiment involved a system having a straight pipe with a length of 6m (a piping condition corresponding to No. 7 in Table 1) and a system having a 6m-long pipe and five equally spaced horizontal elbow fittings (a piping condition corresponding to No. 17 in Table 1). Three kinds of experimental waste substitutes; D, D' and BL shown in Table 2, were also used for this experiment. Each experimental waste substitute was immersed in the water seal of the toilet trap for 15 seconds before the toilet was flushed. Moreover, in order to identify a drop in the flow speed, when each experimental waste substitute passed the horizontal elbow fittings, high-speed cameras were used for capturing images of the flow in the drainage pipe for later analysis. Such images were captured at three locations; 1m, 2m and 3m from the upstream side of each experimental horizontal drainage pipe system (see Fig. 6).

Table 1 Drainage load patterns

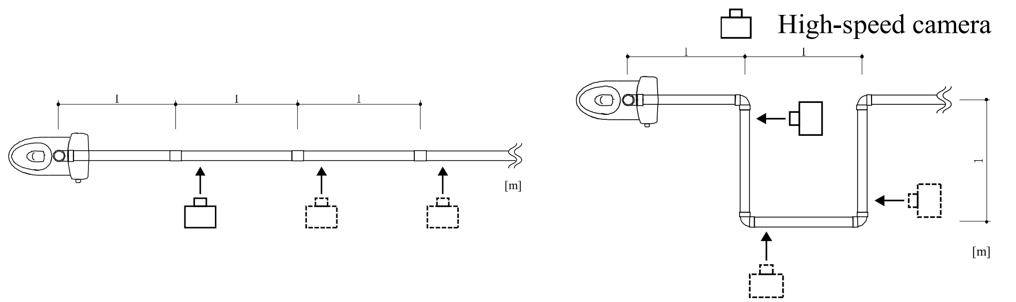
Pattern No.	Pipe configuration	Piping condition						
		X_S [m]						
No.1	Straight pipe	0.5						
No.2		1						
No.3		2						
No.4		3						
No.5		4						
No.6		5						
No.7		6						
		X_{L1} [m]	X_{L2} [m]	X_{L3} [m]	X_{L4} [m]	X_{L5} [m]	X_{L6} [m]	No. of horizontal elbows
No.8	Pipe with equally spaced elbows	1	-	-	-	-	-	1
No.9		1	1	-	-	-	-	1
No.10		1	1	-	-	-	-	2
No.11		1	1	1	-	-	-	2
No.12		1	1	1	-	-	-	3
No.13		1	1	1	1	-	-	3
No.14		1	1	1	1	-	-	4
No.15		1	1	1	1	1	-	4
No.16		1	1	1	1	1	-	5
No.17		1	1	1	1	1	1	5

※For X_S and X_L, see Fig. 3 and 4.

Table 2 Experimental waste substitutes

Type	Experimental waste substitute		Description	Definition
BL※			Toilet paper 0.9m × 4 pieces laid flat (1 ply)	A common load condition defined as standard by Better Living Standard
D			Toilet paper 1m × 6 pieces laid flat (1 ply)	A load condition approx. 1.7 times harsher than the condition defined by Better Living Standard
D'			Toilet paper 1m × 6 pieces laid flat (2 ply)	A load condition twice as severe as the condition using D in order to cause stagnation

※In accordance with Better Living Standard BLT WC: 2018[6)]



(1) Straight pipe **(2) Pipe with equally spaced elbows**

Fig. 6 Locations of high-speed cameras

3.4 Measurement items

(1) Drainage pipe-connected fixture discharge characteristics
Water pressure variations P[Pa] in the drainage basin were measured at points indicated as P in Fig. 3 and 4. Incidentally, measured water pressure values were converted so as to determine fixture discharge characteristics including fixture discharge volume W [L] and discharge flow rate fluctuation Q[L/s].

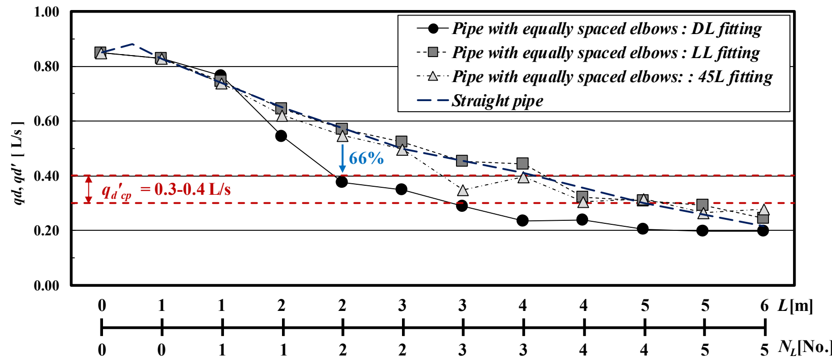
(2) Experimental waste substitutes carrying distance
Once each experimental waste substitute was flushed down the experimental toilet, the carrying distance, from the centre of the drainage pipe that connects the toilet and the horizontal drainage pipe to the tail end of the waste substitute that became stationary, was visually measured.

(3) Flow speeds of experimental waste substitutes
High-speed cameras were used to capture images of experimental waste substitute flowing down the pipe. The images were then analysed using PIV (Particle Image Velocimetry) and the flow speeds of the waste substitutes were estimated.

4. Experiment results and observations

4.1 Drainage pipe-connected fixture discharge characteristics experiment

Fig. 7 compares average drainage pipe-connected fixture discharge flow rates q_d' in relation to the pipe configuration and the fitting shape. When comparing with the q_d' values in the straight pipe, the q_d' values per pipe length in the piping system with equally spaced LL fittings and the piping system with equally spaced 45L fittings change in a similar manner regardless of the increase in the pipe length and in the number of horizontal elbow fittings. In contrast, in the piping system with DL fittings, there is a significant decline in q_d', compared to the other piping systems, as the pipe length increases from 2m to 5m and the number of horizontal elbow fittings increase from one to five along with the pipe length, and when the DL fitting system has a 2m long pipe and one horizontal elbow fitting, q_d' is 66% of q_d' in the LL fitting system. This suggests that compared to the other fittings, the DL fitting generates more resistance in the horizontal elbow and therefore, preventing smooth drainage.



※The carrying limit *qd'cp* (*qd'* for carrying performance) is 0.30-0.40L/s in the piping systems with equally spaced elbows, according to the previous study[7], and is used as a reference value in this study for determining carrying limits of fixture discharge characteristics.

Fig. 7 Comparison of average drainage pipe-connected fixture discharge flow rates *qd'* in relation to the pipe configuration and the fitting shape

4.2 Experimental waste substitutes carrying performance experiment

Fig. 8 compares the carrying distances of the experimental waste substitutes in relation to the pipe configuration and the fitting shape. The waste substitutes, regardless of the type thereof, were carried over distances of 5.5m or more in the straight pipe, whereas the waste substitutes were carried over shorter distances in the pipe with equally-spaced elbows, the shortest of which is 3.7m indicating a decline of the carrying performance by approximately 67%. Here, the carrying limit $q_d{'}_{cp}$ of each waste substitute in the experimental horizontal drainage pipe system used in this study was calculated by collating the position at which the waste substitute became stationary with a $q_d{'}$ value of 4.1. Table 3 lists the carrying limits $q_d{'}_{cp}$ (average values) of the waste substitutes, which are in the range of 0.24-0.28L/s, and these values more or less correspond to the results that were obtained by the previous study[7]. the $q_d{'}_{cp}$ obtained in this study, which is 0.28L/s in the case of experimental waste substitute D', will be used as a reference value in further study, with safety in mind.
Fig. 9 compares the flow speeds of the experimental waste substitutes in relation to the pipe configuration and the fitting shape. The range defined by the broken lines refers to the allowable range of drainage pipe flow speeds of 0.6-1.5m/s specified by SHASE-S 206[8]. According to the graph, the flow speeds of the waste substitutes decrease as the image capturing position becomes lower. In particular, all the waste substitutes have lower flow speeds in the piping system with DL fittings than in the piping systems with the other types of fittings, which are roughly in the range of 0.4-1.0m/s. Accordingly, it is inferred that in a piping system with DL fittings installed thereto, resistance is generated where waste passes, and the resistance affects the flow speed of the waste to such an extent that it creates a disadvantageous effect to the carrying performance of the piping system.

Pipe configuration	Fitting shape	Waste substitute	Carrying distance [m]
Straight pipe		BL	6.00
		D	5.40
		D'	5.96
Pipe with equally spaced elbows	DL	BL	5.36
		D	4.02
		D'	4.10
	LL	BL	6.00
		D	5.19
		D'	4.15
	45L	BL	6.00
		D	5.94
		D'	3.70

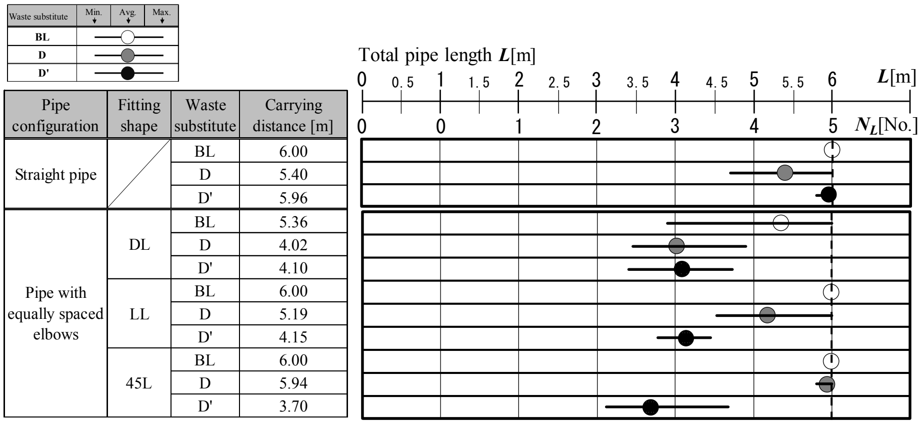


Fig. 8 Comparison of carrying distances of experimental waste substitutes

Table 3 Comparison of carrying limits $q_d{}'_{cp}$ in relation to the pipe configuration and the fitting shape

	Straight pipe			Pipe with equally spaced elbows									qd'cp[L/s] (avg.)/waste substitute		
Fitting shape				DL fitting			LL fitting			45L fitting					
Waste substitutes	BL	D	D'	BL	D	D'	BL	D	D'	BL	D	D'	BL	D	D'
$q_d{}'_{cp}$ [L/s]	0.21	0.30	0.21	0.20	0.23	0.23	0.25	0.29	0.32	0.28	0.27	0.35	0.24	0.27	0.28

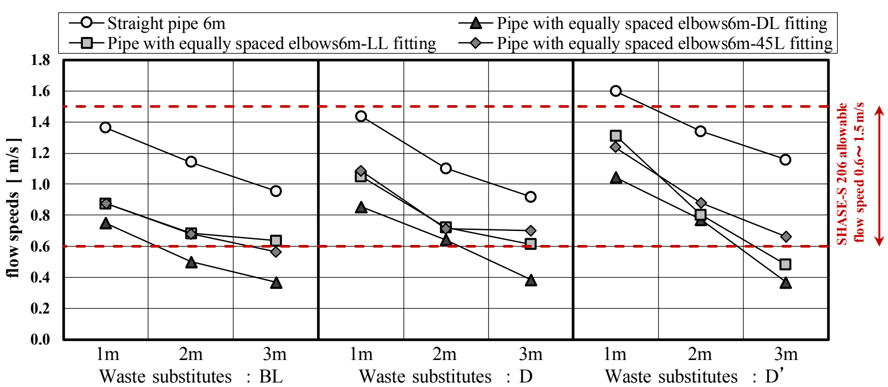


Fig. 9 Comparison of flow speeds of experimental waste substitutes in relation to the pipe configuration and the fitting shape

5. Consideration of simplified carrying performance prediction methods

5.1 Prediction method of q_d' by the horizontal drainage pipe length

The average fixture discharge flow rate q_d' obtained using the straight pipe (see 4.1) was used as an initial value, and a decrease in the q_d' value obtained as an average drainage pipe-connected fixture discharge flow rate was calculated in relation to the increase of the pipe length. Formula (4) was used for calculating the lowering rate γ of q_d'. Fig. 10 shows lowering rates γ corresponding respectively to pipe lengths, which were calculated from the straight pipe q_d' values shown in Fig. 7. This makes it possible to predict an average drainage pipe-connected fixture discharge flow rate q_d' by multiplying the average fixture discharge flow rate q_d of a toilet by γ that corresponds to the pipe length of a horizontal drainage pipe system to be designed.

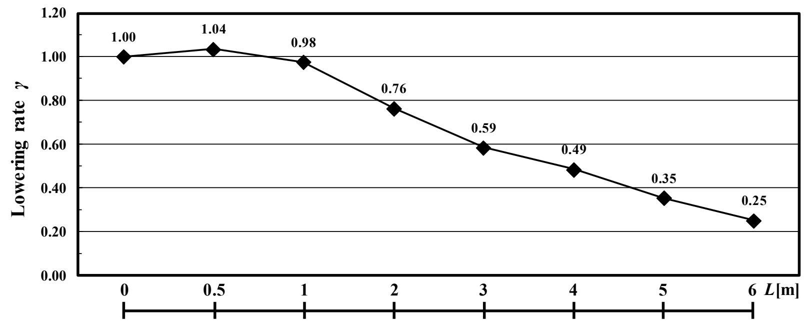
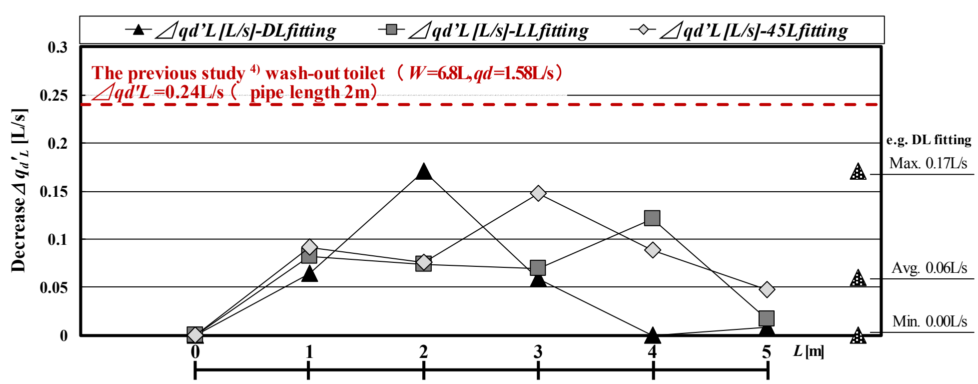


Fig. 10 Lowering rate γ per pipe length

5.2 Prediction method of q_d' by the horizontal drainage pipe length and the number of horizontal elbow fittings

A decrease amount $\Delta q_d'_L$ in q_d' per horizontal elbow per type was calculated from the average drainage pipe-connected fixture discharge flow rate obtained by the drainage pipe-connected fixture discharge characteristics experiment using the pipe with equally spaced elbows (see 4.1). Fig. 11 shows $\Delta q_d'_L$ per horizontal elbow per type in relation to each pipe section. There is a likelihood that the loss in q_d' becomes significant at the insertion positions of the second and the third elbows which are further away from the toilet than the first elbow. This suggests that the variation of the pipe flow speed (see Fig. 9) caused said significant loss around said insertion positions. Here, Table 4 lists the minimum, maximum and average $\Delta q_d'_L$ values of each type of fitting system, which were obtained from Fig. 11. A set value of $\Delta q_d'_L$ is determined from the numerical values in the table.



※In the DL fitting system, $\Delta qd'L$ at the 4m point is treated as 0; there is hardly any variation in qd'.

Fig. 11 $q_d'_L$ per horizontal elbow per type

Table 4 List of min. max. and avg. $\Delta q_d'_L$ values

Fitting shape	□ $q_d'_c$ [L/s] (Min. $\Delta q_d'_L$)	◇ $q_d'_c$ [L/s] (Max. $\Delta q_d'_L$)	▲ $q_d'_c$ [L/s] (Avg. $\Delta q_d'_L$)
DL fitting	0.00	0.17	0.06
LL fitting	0.02	0.12	0.07
45L fitting	0.05	0.15	0.09

5.3 Observations by using the actual piping model

The values in Table 4 are substituted in formula (3), and calculated values $q_d{'}_c$ were compared with the experimental values $q_d{'}$ that were obtained by using an actual piping model. The actual piping model was used in two different configurations as shown in Table 5. The minimum, maximum and average $\Delta q_d{'}_L$ values of each fitting type were substituted in formula (3) to obtain $q_d{'}_c$. The calculated $q_d{'}_c$ values are shown in Fig. 12. In the case of using the minimum and average values, the calculated $q_d{'}_c$ values are close to the experimental values. Here, as Fig. 13 shows the correlation of $q_d{'}$ and $q_d{'}_c$, in the case of using the minimum $\Delta q_d{'}_L$ value, the error against the experimental value is approximately 4%. Moreover, an error of 60% between the maximum values and an error of 30% between the average values were quantitatively identified.
Accordingly, it is considered that the prediction of $q_d{'}$ according to the proposed method is realistically applicable provided that $\Delta q_d{'}_L$ is set to minimum. Moreover, in Fig. 12, the actual measured $q_d{'}$ values exceed 0.28L/s which is a $q_d{'}_{cp}$ value, and Fig. 14, which compares carrying distances (using the experimental waste substitute D') in two different actual pipe configurations, indicates that the waste substitute is carried along more or less the entire length of the horizontal drainage pipe. Therefore, it is considered possible to predict the carrying distance of waste by collating $q_d{'}_c$ with $q_d{'}_{cp}$.

Table 5 Actual piping model

Pattern No.	Pipe configuration	Piping condition						
		X_{L1} [m]	X_{L2} [m]	X_{L3} [m]	X_{L4} [m]	X_{L5} [m]	X_{L6} [m]	No. of horizontal elbows
No.18	Actual piping 1	4	1	-	-	-	-	1
No.19	Actual piping 2	1	1	2	-	-	-	2

※X_L: see Fig. 4

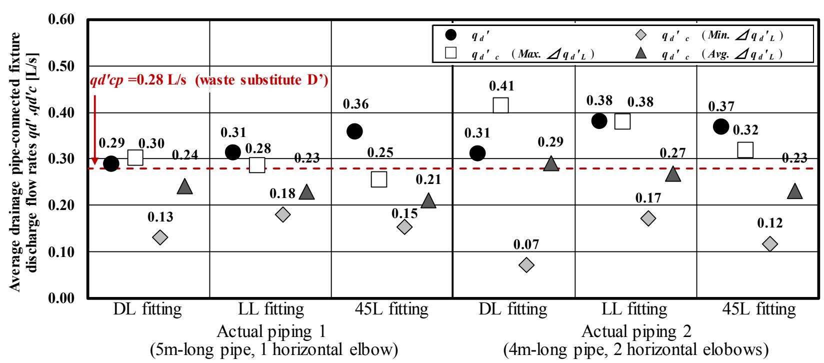


Fig. 12 Comparison between $q_d{'}$ and $q_d{'}_c$

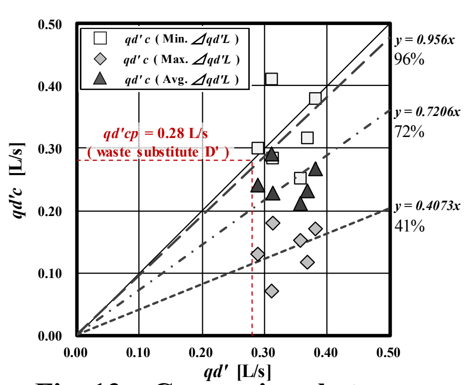


Fig. 13 Comparison between $q_d{'}$ and $q_d{'}_c$

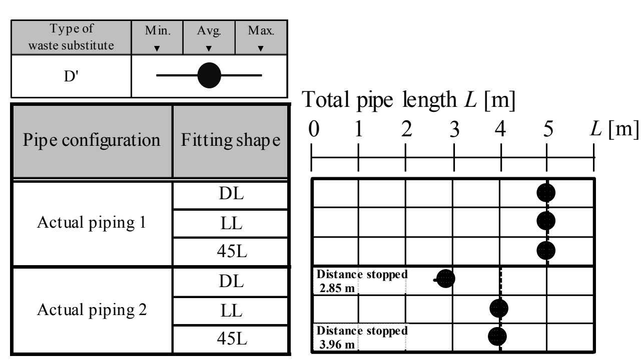


Fig. 14 Carrying distance of experimental waste substitute D'

6. Conclusions

A method for predicting the carrying performance of water-saving toilets was proposed based on experimental data obtained by using a 6m-long straight pipe and a pipe with equally spaced elbows. The practical application of said method was also examined. Subsequently, the following has been established.

(1) It is possible to roughly predict a decrease in average fixture discharge flow rate by subtracting an experimentally obtained decrease in the discharge flow rate affected by the horizontal elbow type from a decrease in the average fixture discharge flow rate of a water-saving toilet relative to the length of a drainage pipe.

(2) It is possible to roughly estimate a carrying distance by collating (1) with an experimentally obtained average discharge flow rate of drainage pipe-connected fixture for carrying limit.

(3) At this stage of the study, observations were made using an actual but simple piping model with one or two elbows. In further study, the collation of experimental data and calculated data on a more intricate piping model will be required..

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8. Presentations of Authors

Ryota Oba is a graduate student of the Otsuka 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 latest 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 a 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 interests are the hybrid drainage system that uses both force feed type and gravity type drainage methods compatible with commercial building conversion.

Shintaro Gomi works at the Urban Renaissance Agency. 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 repair of waste pipe systems including bathrooms in existing high-rise apartment houses.

The new European Unified Label for water and energy efficiency of products

A. Silva-Afonso (1), C. Pimentel-Rodrigues (2)
(1,2) anqip@anqip.pt
(1,2) RISCO (University of Aveiro, Portugal), Portuguese Association for Quality in Building Installations (ANQIP), Portugal, and European Bathroom Forum (EBF), Brussels

Abstract

Introduction and aims: Hydric stress and security of water supply are important concerns across the world. Climate change and the increasing need for environmental protection, natural resources preservation and efficient use, have made water availability and the existence of sustainable standards in water consumption a concern for all. In Europe, European Commission drivers for the efficiency of water-using products (WuP) include Eco design approaches, Ecolabel and Green Public Procurement (GPP) but these criteria are focused on the energy efficiency of taps and showers and have had limited acceptance by consumers. **Method:** Many national initiatives have been developed over the past 10 to 15 years to address the efficiency of water-using products, of which the Swiss and Swedish energy labels together with the European Water Label and the Portuguese ANQIP label decided to join together to form a unified label for water-using products. **Results and conclusion**: Taking the view that the EU consumer today lacks consistent information on the performance and water consumption of these basic products, European and National Trade Bodies and existing National Schemes, representing many hundreds of manufacturers, have developed a simple and harmonized water labelling Scheme – the Unified Water Label. This Scheme applies to products that use water and consider also the associated energy for water heating. According to the European Commission, encouraging the replacement of all standard household appliances (taps, toilets, showers, bathtubs, washing machines, dishwashers, products for external use, etc.) with efficient water products will result in an overall reduction of annual domestic water consumption up to 35% for taps, 11% for showers and associated energy up to 30% by 2030. **Contributions:** This paper presents the new European unified label for WuP, describing the classification criteria and associated tests

Keywords Water-using products, water efficiency, energy efficiency, efficiency labels.

1 Introduction

Hydric stress and security of water supply are important concerns across the world. Climate change and the increasing need for environmental protection, natural resources preservation and efficient use, have made water availability and the existence of sustainable standards in water consumption a concern for all. In Europe, water stress is beginning to significantly affect a number of countries, especially in the Mediterranean basin, but the European Commission drivers for water efficiency in buildings, that includes Eco design approaches, Ecolabel and Green Public Procurement (GPP) [1], are focused on the energy efficiency of taps and showers and have had limited acceptance by consumers.

As a result of the lack of a strong policy by the European Commission to objectively promote water efficiency in buildings, a number of efficiency labels for water using products (WuP) have appeared in Europe in recent years, usually for voluntary use, on the initiative of industry or civil society associations [2,3]. The importance of these labels has been emphasized not only in relation to water efficiency, but also in relation to energy efficiency.

Indeed, a study carried out in a Portuguese municipality showed that reducing water consumption by only 1 m^3 through water efficiency measures in buildings may result in a reduction about 7.2 kWh in energy consumption. The study took into account the energy consumed to produce sanitary hot water and the reduction of energy consumed by mains water supply and drainage networks and by treatment plants (by decreasing flows abstracted, treated and pumped) [4].

According to the European Commission, encouraging the replacement of all standard household appliances (taps, toilets, showers, bathtubs, washing machines, dishwashers, products for external use, etc.) with efficient water products will result in an overall reduction of annual domestic water consumption up to 35% for taps, 11% for showers and associated energy up to 30% by 2030.

In the European Union (EU), total water abstraction for use in taps and shower systems has been estimated to be about 25000 Mm^3 in 2010 and the total primary energy requirement in the EU associated with the use of taps and shower systems has been estimated to be about 3000 PJ^3/year [5]. Total emissions of CO_2eq related to the EU annual demand of primary energy in taps and showers has been estimated to be about 160 Mton in 2010.

The European Commission had only in its forecasts the creation of a mandatory energy label for taps and showers, since these products are included in the Energy Efficiency Directive (Directive 2012/27/EU of the European Parliament and of the Council, of 25 October 2012, on energy efficiency). However, the European Commission (EC) has shown willingness to accept alternatively a proposal from industry representatives for a new water efficiency label within the scope of a Voluntary Agreement (VA).

The Voluntary Agreement is a tool that results from the Ecodesign Directive 2009/125/EC (European Commission 2009), meaning that manufacturers agree to self-regulate their products under the supervision of the EC. For taps and showers, a VA could include a mandatory requirement for the provision of information about the performance of taps and showers, for example via a label sufficiently different from the Energy Label. The information provided could focus on the water flow rates under nominal conditions of use, and the associated energy consumption.

However, rating approaches based on the measurement of water flows do not take product functionality into full account. A mere reduction of flow rates could in fact have an impact on users and lead to increased time of use, potential dissatisfactions and lower savings than expected (e.g. more time to shower) [6]. This means that complementary requirements are needed in case of Voluntary Agreement, as described for the mandatory label, to avoid that a good rating (i.e. a low flow rate) comes at the expense of a poor performance or the comfort of users.

So, a Voluntary Agreement was considered as a possible alternative to a mandatory label if the following conditions are met, according to the Commission Recommendation (EU) 2016/2015 of 30 November 2015:

a) The market coverage is significant (i.e. above 80%);
b) Similar effects can be achieved;
c) The performance of products and the comfort of users are not compromised.

The advantages of that particular agreement would be that:

a) Labelling schemes focusing on water flow rates or volumes are already popular in Europe and can be used as a basis for the development of a unified label following the same approaches;
b) It would be simpler to enforce and easy-to-understand;
c) It would be more flexible for modifications and adaptations, if needed.

2 The journey

Many initiatives have been developed in Europe over the past 10 to 15 years to address the efficiency of water-using products. In the case of taps and showers, the main European schemes and labels include:

a) The ANQIP label [7];
b) The Swedish Energy Efficiency Labelling [8];
c) The Swiss Energy Label for Sanitary Fittings [9];
d) The WELL Label [10];
e) The Water Label (EWL) [11].

It is now widely understood that parallel schemes on the market may cause confusion to consumers and can make products that want to enter the market in different countries more expensive. So, in the perspective of a Voluntary Agreement, main European label management entities have begun to join forces on a new platform, the European Bathroom Forum (EBF), with headquarters in Brussels, aiming to develop a Unified Water Label (UWL) based on a "best of all" approach.

In March 2018, the EBF managed to reach an agreement with representatives from Water Label, ANQIP, Swedish Energy Efficiency Labelling, and Swiss Energy Label in order to work towards the development of a single label for all the water using products in buildings. The WELL scheme did not participate in this early stage of label development. Figure 1 shows the new European unified label.

The majority of industry stakeholders agree that a single label that covers water and energy aspects is the best option for the market. So, the Scheme and label are concentrated on the water and associated energy savings and respect National legal requirements where the product is marketed, as well as the European and/or National standards when applied.

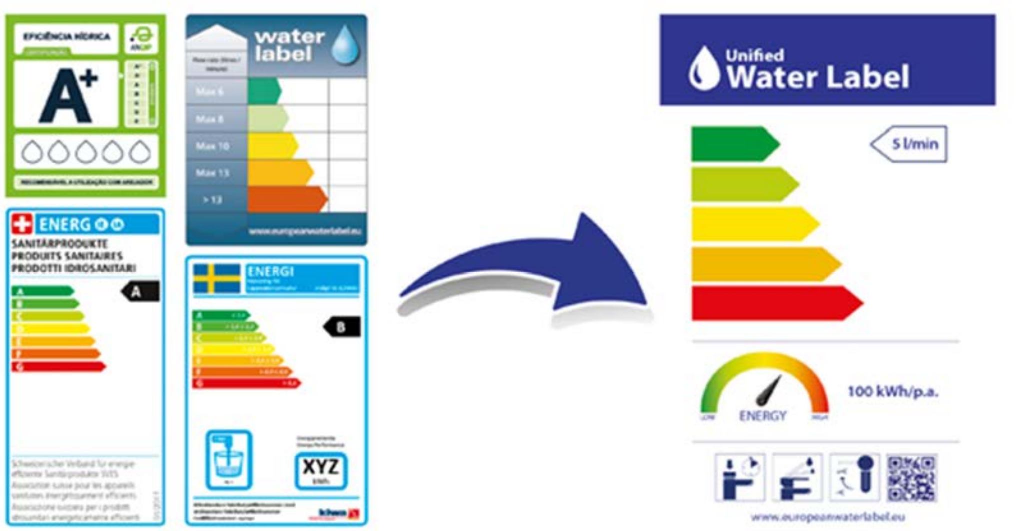

Figure 1 – European Unified Water Label [11]

The UWL Scheme sets the main principles which all signatories agree to follow while supplying products and accessories on countries of the European Union (EU), European Free Trade Association (EFTA), European Economic Area (EEA) and bordering countries. The manufacturers and signatories of this Scheme recognise that:

a) Water is an essential natural resource which must be preserved;
b) Water 'efficient' using products can help mitigate water and energy consumption while maintaining safety and comfort;
c) Minimum harmonised products criteria should be set to guarantee fair and simple information of the user.

3 Summary description of the UWL Scheme

3.1. General

The label will present performance brands of different colors (green, sage, yellow, orange and red), corresponding to the possible range of flows or volumes for the product covered, as shown in Figure 1. When a specific rating is to be shown, a blue panel can be added to the right side of the chart with the appropriate flow rate. Flow rate or volume figures should usually have one decimal place (baths no require decimal points).

In some cases, it is possible to use special labels ("reduced size labels" when space is restricted, "one-line labels" when space in a document is restricted and "extra-small one-line labels" in printed catalogues/brochures). In electric showers, urinal controllers, greywater systems and in replacement flushing devices a recommended "efficient" label can also be used (Figure 2). There are also other special labels for shower handsets supplied with a flow regulator, a neck leaflet for shower handsets and taps, etc.

Figure 2 – Recommended Water Label [11]

The Scheme applies to showers (mixer showers, shower outlets and electric showers), taps, water closets (WC suites, independent WC bowls, independent WC flushing cisterns and replacement WC flush mechanisms), urinals (urinal bowls, independent urinal flushing cisterns, urinal controllers), bath tubs and other miscellaneous products (supply line flow regulators, grey water recycling units and flush-free urinals).

For showers, the lowermost performance brand (green) corresponds to "≤ 6 L/min" and the uppermost (red) to "> 13 L/min". For water closets (WCs), the correspondent values are "≤ 3.5 L/min" and "> 6.0 L/min". In the case of taps, the minimum and maximum performance brand corresponds to "≤ 1.0 L/min" and "> 4.0 L/min" respectively. There are also specific categories for other products, such as baths.

To enhance the label and to highlight to consumers technical features present, manufacturers are able to add a maximum of three technical icons (in addition to the energy icon) to the label. Figure 3 shows some examples of technical icons for taps.

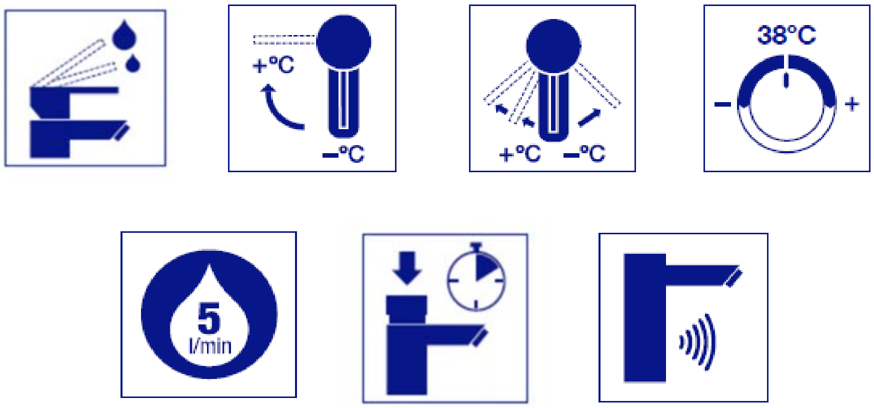

Figure 3 – Examples of icons for taps (volume break, cold start, temperature break, thermostat, pressure-independent flow rate, time-controlled/mechanical self-closing and electronic /sensor) [11]

3.2. Energy associated

The energy use associated with water flow rates is not considered in EN standards, so the Scheme established a calculation based on basic principles of physics:

$$E = M \text{ x } C \text{ x } \Delta T \qquad (1)$$

where:
E = Energy (kWh)
M = Mass (kg)
C = Specific heat of water [kWh/(kg.K)] = 0.00116 kWh/(kg.K)
ΔT = Temperature difference (K)[1]

This basic calculation coupled with average use times can easily be used to calculate expected annual energy consumption. Average use times to be used for the following products are:

a) Basin (and bidet) taps: 1 minute per event, 5 events per person per day;
b) Kitchen taps: 1 minute per event, 5 events per person per day
c) Showers (handsets and mixer controls): 7 minutes per event, 1 event per person per day

For basin (& bidet) taps and showers the average outlet temperature is always regarded as 38°C while for kitchen taps the average outlet temperature is 45°C. In all cases the average seasonally adjusted inlet temperature is regarded as 15°C. Core assumptions have

[1] Given that this is a difference, °C can be used instead of K in ΔT

been taken directly from the European Commission study into taps and showers task 3 report: users [8]. For Bath tubs, the same core calculation can be used to help users understand, in energy terms the cost of filling the bath tub for each bathing event.

The energy icon can be added to the base of the Unified Water Label to depict to the consumer the expected annual energy cost of using the product. It is required that all basin taps, kitchen taps, showers (handsets and mixer controls) and bath tubs shall carry the energy icon. The energy icon shall in all cases be placed under the main water rating and to the far left of the space provided for all technical icons (for the applicable categories). An example of the energy icons can be seen in Figure 4.

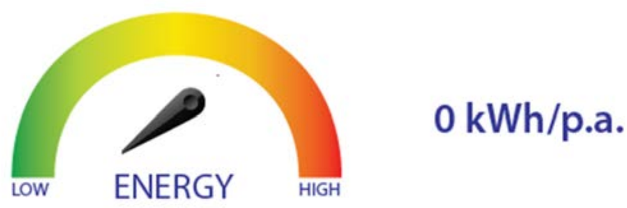

Figure 4 – Energy icon [11]

3.3. Tests

It is a prerequisite of the Scheme that all products shall satisfy all National Regulatory requirements of the intended country of destination. Products shall comply with all relevant European Norms, including, obviously, compliance with the tests provided for in these standards.

Third party accreditation is not required in the Scheme. It is expected that the manufacturer will retain internal documentation to verify any claims made. Internal documentation may also be subject to audit as part of the normal requirements of ratification of manufacturer's claims. The product, when verified shall comply with the supplied Declaration of Conformity from the Manufacturer that accompanied the original product applications to the listing company.

According to JRC and European Commission, functional testing for showers is also required (as in the case of mandatory EU Energy Labels). For this test, the UWL will adopt a procedure similar to that used in the spray coverage test of the WaterSense scheme of the U.S. Environmental Protection Agency (EPA).

It is possible that the European Committee for Standardization (CEN) will develop specific EN standards for the determination of flow rates or volumes in appliances or plumbing products in view of the rating of efficient products. If this happens, the UWL will naturally incorporate these procedures. Given that an ISO Standard in this field (ISO/31600) is also in development, it will be desirable (and probable) that the EN standards are in line with the ISO standard.

3.4. Website and Audits

The Scheme is supported by an extensive website [11] and audit process. The audits are coordinated by the Scheme and label administrator and are performed regularly by selected test houses on products selected randomly. The cost and arrangement of testing is the responsibility of the listing company.

The label administrator will arrange for 5% of the products (and accompanying literature, point of sale material and advertisements in relationship to the listed products) on the Scheme database to undergo an audit for compliance with the Scheme's requirements on an annual basis. The 5% will be selected, across the qualifying product ranges.

3.5. Transition period

The Scheme was presented to the industry and the public in March 2019 in the ISH (International Frankfurt Trade Fair). Until 31st December 2020, there will be a transition period with cohabitation of existing schemes with UWL. During this period transition labels may be used for the products integrated into one of the four schemes that have joined the UWL through a reference in the new label of the original scheme.

This indication will be translated by including the symbol of the current scheme in which the product is still integrated as an icon in the UWL. Figure 5 shows, for example, the label of a flushing cistern originally labelled by ANQIP and which will integrate the new scheme.

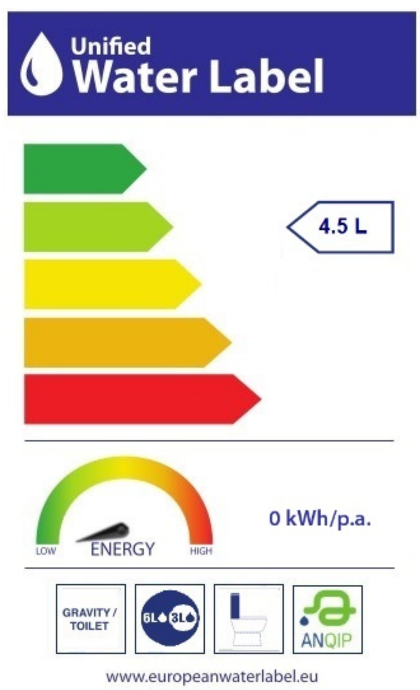

Figure 5- Transition label of a product originally labeled by ANQIP

4 Conclusions

Many initiatives have been developed in the past 10-15 years to address the efficiency of water-using products at national and international levels. In the European Union (EU), concerns over water efficiency of water-using products have recently been highlighted in the context of water scarcity and droughts and Eco design approaches.

In Europe, WuP performance in terms of water consumption and comfort for users has been constantly improved by the industry while respecting the essential national and European health and safety requirements. In this way, it seeks to respond to increasingly important demands of environmental preservation and to the needs of adaptation in face of growing water stress in many countries, respecting the minimum comfort of users.

Taking the view that, in general, the consumers today lack consistent information on the performance and water consumption of these basic products, European Associations representing many hundreds of manufacturers and existing National Schemes for product efficiency, have developed a simple and harmonised water labelling Scheme – the Unified Water Label.

It is hoped that this new unified scheme will contribute to a more efficient use of resources and energy in buildings, not only in Europe, but in all countries that use these labeled products. It is also intended to contribute to the desirable international harmonization at this level, which will allow consumers to become more aware of the importance of efficient resource management, while also offering them solutions without loss of comfort and to reduce production costs.

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6 Presentation of Authors

Armando Silva-Afonso is a retired Full Professor at the University of Aveiro (Portugal), Department of Civil Engineering, where he collaborates as Visiting Professor. His specializations are urban and building hydraulics and water efficiency in buildings, and he is President of the Board of ANQIP – the National Association for Quality in Building Installations, in Portugal. He is also an invited expert on the European Commission for water efficiency in buildings.

Carla Pimentel Rodrigues holds a PhD from the University of Aveiro (Portugal) in Civil Engineering (water efficiency). She is Technical Director at ANQIP – the National Association for Quality in Building Installations and is also a of the Research Centre RISCO at the University of Aveiro. She he has published 2 books in the field of water efficinecy in buildings and one chapter in an international book.

Examination of "Net Zero Water Building" Evaluation Method in Japan

H. Kose (1), T. Nakano (2), T. Nishikawa (3)

(1) hkose@toyo.jp, (2) t-naka@suac.ac.jp, (3) t-nskw@cc.kogakuin.ac.jp

(1) Professor, 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

Water Environment Management Committee of the Architectural Institute of Japan has developed the results of the activities of the Subcommittee on the quantitative evaluation of resources and energy saving in the water environment, which was active from FY 2015 to FY 2018. We will establish the "Zero Water Evaluation Methodology Subcommittee" with a plan for four years and examine the applicability of Net Zero Water Building promoted by the US Department of Energy in Japan.

This study reports the results of the previous subcommittee and discusses the issues to be considered for the "Net Zero Water Building" evaluation method that will lead in the future. The US Net Zero Water Building Strategy consists of water conservation and efficiency improvement, alternative water (rainwater and reclaimed) use, water returned (treated wastewater on-site returned to original water source, and stormwater infiltrated to the original water source through green infrastructure).

In Japan, too, these factors are being promoted as elements, and while laws are being developed, there are fundamental restrictions on the use of alternative water and the infiltration of on-site drainage. On the other hand, in addition to very severe conditions such as typhoons, heavy rains, snowfalls and intense heat in weather conditions, geotechnical disasters such as earthquakes and eruptions are often encountered, and there is a high possibility that water supply and sewerage as infrastructure will cease for a long time. In such an emergency, it is necessary to secure water at the building or district level, and it is also necessary to evaluate the system that can cope with these.

In order to consider these methods, it is necessary to consider from both aspects of performance evaluation such as ZEB (Net Zero Water Building) defined by the Society of Air Conditioning and Sanitary Engineering of Japan parallel with the arrangement and scoring of the conditions found in LEED in the United States. These problems are shown in this study.

Keywords

Net Zero Water Building, SDGs, BCP, ZEB

1. Introduction

Japan has a lot of rainfall, and there are many storms and floods such as typhoons, floods and storm surges. In addition, the spread of water infrastructure has reached almost 100%, and since there is less need to secure water sources on their own, citizens are strongly aware that water is abundant.

On the other hand, the amount of existing water resources relative to precipitation is small due to the steep topography of the riverbed, urbanization, and the increase in abandoned land for forest management, and the amount of water resources per capita is considered to be the smallest in the world. In addition, due to natural disasters, there is a high risk of disruption of water and sewer infrastructure.

About 25 typhoons occur annually and land several times a year. Recently, the risk of torrential rain has increased further due to the occurrence of linear precipitation zones. Coupled with the occurrence of “guerrilla thunderstorms” accompanying the rise in the temperature of the ground surface such as heat island, the risk of infrastructure disruption, such as power outages and overflowing sewers, is increasing.

Furthermore, earthquakes are occurring throughout Japan. In addition to the effects of seismic waves, there is a possibility of disruption of water and sewage infrastructure due to the occurrence of tsunamis in coastal areas and landslides in mountainous areas. Therefore, there is a risk that these facilities cannot be operated.

In this way, Japan has been required to secure independent resources and energy from the viewpoint of BCP and LCP. In addition, the SDGs (Sustainable Development Goals) adopted by the United Nations in 2015 require the strengthening of infrastructure and simultaneous resolution of climate change. Against this background, we thought that securing resources and energy at the time of disaster should be considered from the viewpoint of the water environment as well as saving resources and energy in normal times.

In the United States, the Ministry of Energy has established “Net Zero Water Building Strategy”. When this concept was applied to Japan, we decided to consider what viewpoints should be considered.

This study is based on the results of the “Subcommittee on Quantitative Evaluation Methods for Resource and Energy Conservation in the Water Environment of the Architectural Institute of Japan” that was active from FY 2015 to FY 2018, and it includes the contents being examined by the “Zero Water Evaluation Method Study Subcommittee of the Architectural Institute of Japan”.

2. Methodology

In addition to ascertaining the status of disaster risk in Japan through literature surveys, the current status of Net Zero Water Buildings by the US Department of Energy will be assessed through information from public institutions and literature surveys. We will also consider what elements need to be incorporated when the water use program devised in the research submitted to the CIB W062 International Symposium in 2017 is applied in an emergency.

3. Trends in disaster risk and resource / energy conservation in Japan

3.1 Precipitation and flood damage

Japan is a country located at 20-45 degrees north latitude, and the capital Tokyo is located at 35 degrees north latitude. The average annual rainfall in Tokyo from 1981 to 2010 is 1528.8mm, and the maximum daily precipitation over the last 30 years is 259.5mm on September 22, 1996 (Figure 1). There are about 25 typhoons on average from 1981 to 2010, and they develop and approach Japan or land. Also, a heavy rain occurs due to the occurrence of a front due to the typhoon (Figure 2).

In 2018, the largest flood damage occurred in the last 30 years, which was called "The Heavy Rain Event of July 2018". Damages such as floods and landslides occurred in various places, resulting in 224 deaths. Disruptions in water and sewage infrastructure due to floods also occurred in various places (Figure 3).

Also, in Japan, septic tanks for merging treatment are installed in each house and village in places where sewerage is not widespread, but if it goes down, wastewater is not purified, and water pollution occurs.

Furthermore, due to the occurrence of the heat island phenomenon accompanying urbanization, there are frequent showers and thunderstorms, and it is called "guerrilla heavy rain". These may cause inundation, causing inundation damage such as inundation of buildings and underground submergence in urban areas (Figure 4).

3.2 Disaster caused by earthquake

Japan is at risk of earthquakes across the country. The probability of an earthquake has been announced, and in Tokyo, the probability of being affected by a shake with a seismic intensity of less than 6 is over 26% in the next 30 years (Figure 5). The Great East Japan Earthquake that occurred in 2011 was M9.0, the largest earthquake in Japan's observation history, and the coastal area from Tohoku to Kanto was devastated by the tsunami. In other areas, it was difficult to return home, planned blackouts, long-term stays at evacuation shelters, long-term residences for temporary housing, etc. in various parts of eastern Japan. Recently, large-scale earthquakes such as the 2016 Kumamoto earthquake have occurred frequently (Figure 6).

In Japan, securing 3L a day of drinking water for 3 days (1 week recommended) is shown as a guideline for stockpiled items (Figure 7). However, there are problems related to non-potable water and drainage, such as inadequate evacuation toilet environment and inability to drain the building infrastructure.

We think that there is a possibility that the problem can be solved if the self-sustained building can be considered by utilizing the evaluation of the Net Zero Water Building.

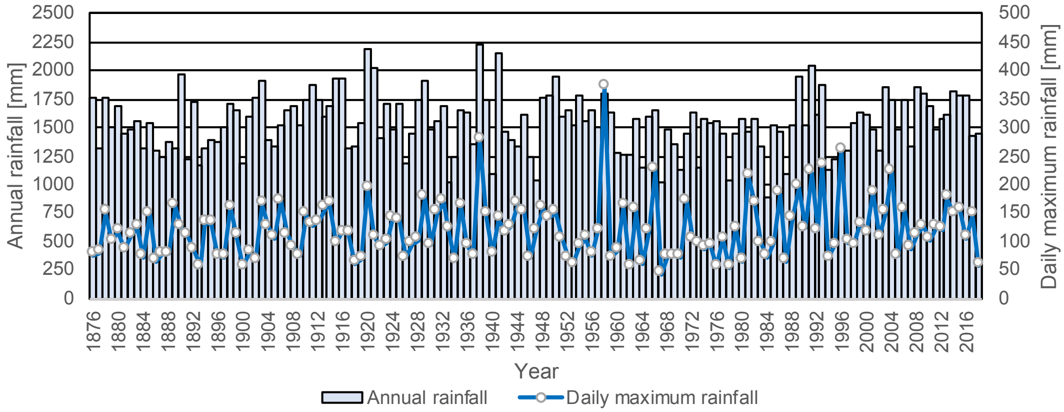

Figure 1 – Annual and daily maximum rainfall in Tokyo (1876-2018) from 1)

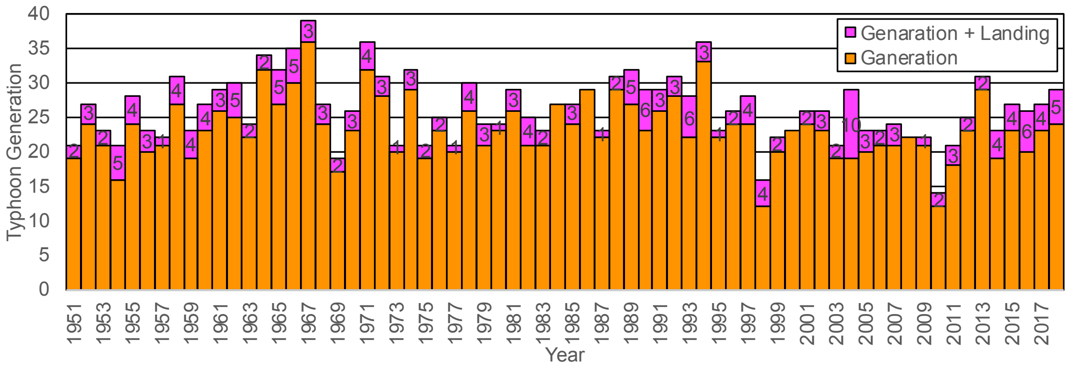

Figure 2 – Typhoon generation and landing in Japan (1951-2018) from 2),3)

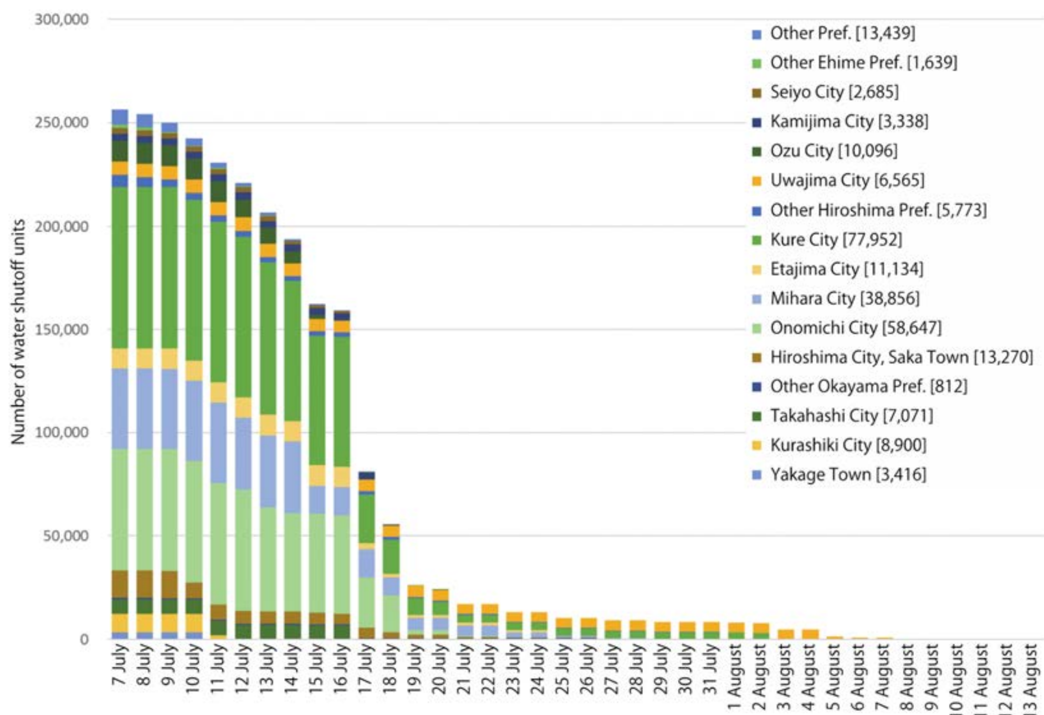

Figure 3 - Recovery status of water supply due to heavy rain in July 2018 from 4)

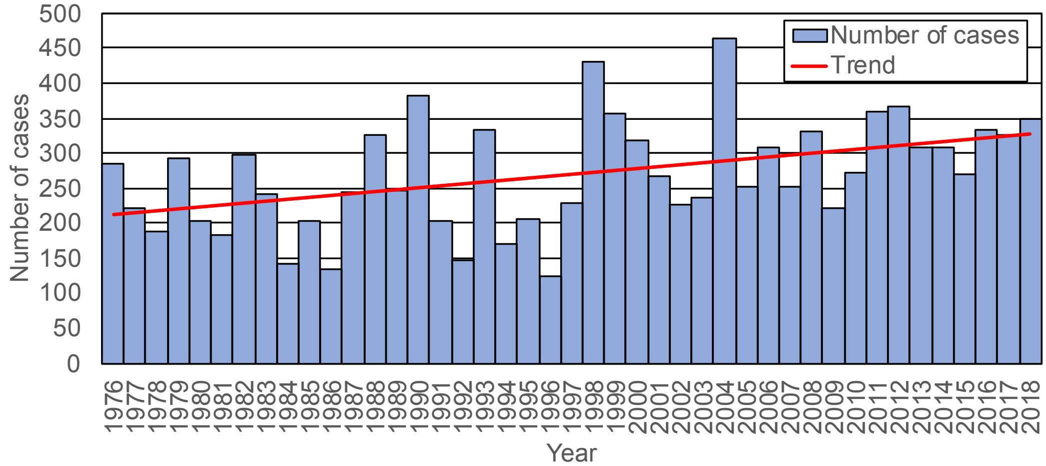

Figure 4 - Number of annual occurrences of hourly precipitation over 50mm in Japan (1976-2018) from 5)

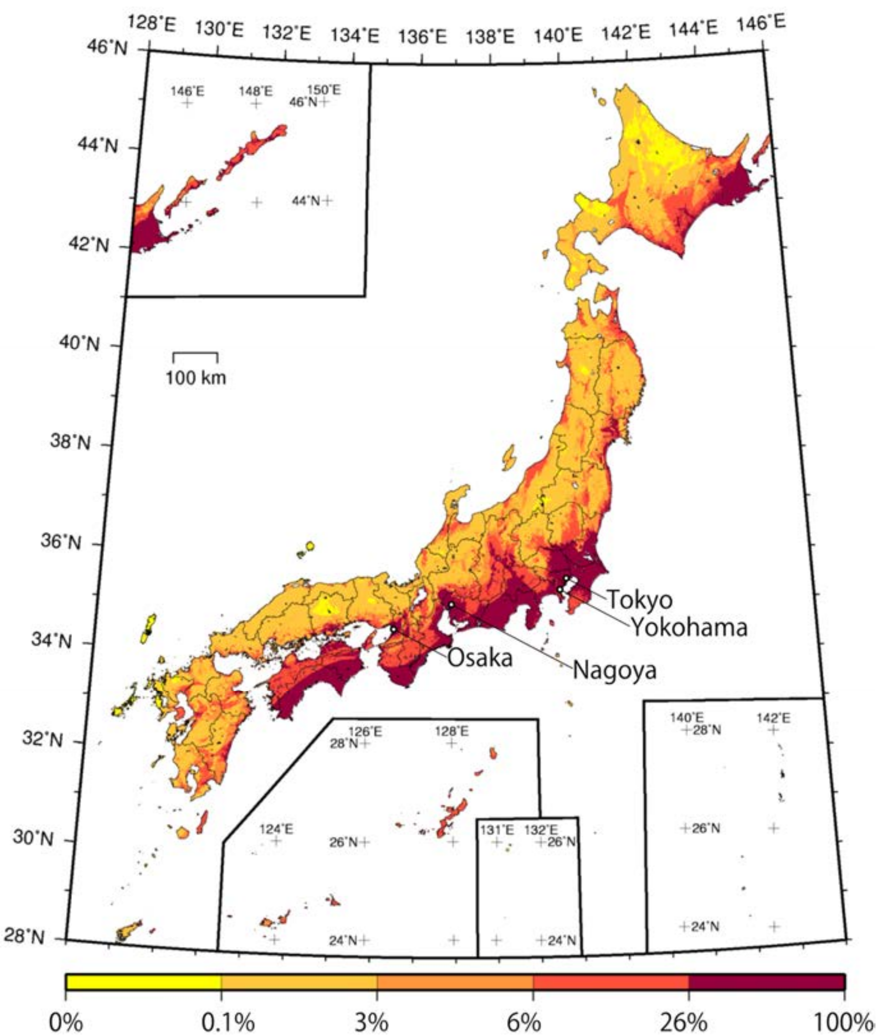

Figure 5 - Probability of experiencing seismic intensity of less than 6 in the next 30 years (2018) from 6)

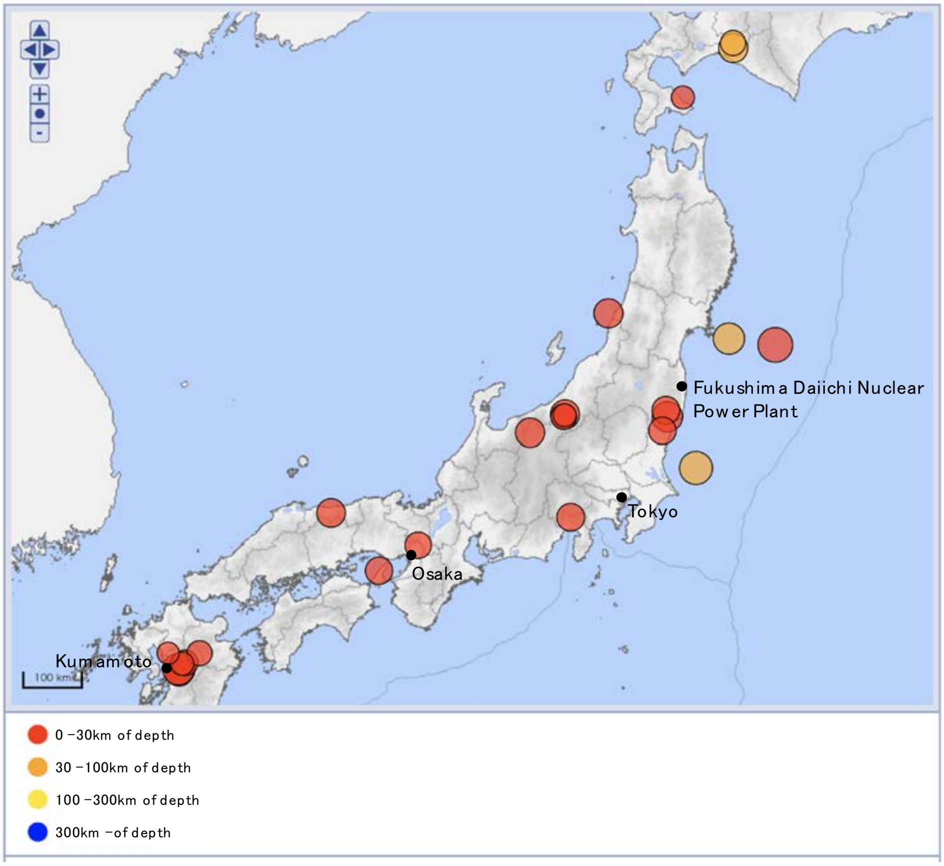

Figure 6 - Epicenter distribution of earthquakes with seismic intensity of less than 6 in Japan over the past 10 years (26 earthquakes, 18 August 2009-17 August 2019)
from 7)

Figure 7 – Video about disaster preparation by Government of Japan [8)]

3.3 Trends in resource and energy conservation

Two-thirds water use of Japan is agricultural water, less than 20% is domestic water, and over 10% is industrial water. Domestic water consumption per person has been decreasing since 2000 (Figure 8), and in office buildings, water supply unit will be changed from the past 60 - 100 L [10)] to 40 - 60 L.

On the other hand, toilet flushing, washing machine and cooking water are generally on the water-saving trend, but in Japan there is a custom of bathing in the bath, so the proportion of water used for bathing tends to increase. As a result, water consumption is higher than in other countries (Figure 9). But used bathtub water is reused as cloth washing for washing machines at home.

Concerning energy saving of energy related to water, for example, pump design in buildings is said to be in a situation where energy saving is not achieved due to the situation where many safety factors are estimated. [12)]

The energy around the water is increasing in households where hot water is used, such as the spread of the domestic hot water supply system and a bidet toilet seat. Also, in these devices, energy saving is progressing in each device such as a high-efficiency water heater, solar water heater, and a bidet toilet seat with instant water heating systems (Figure 10).

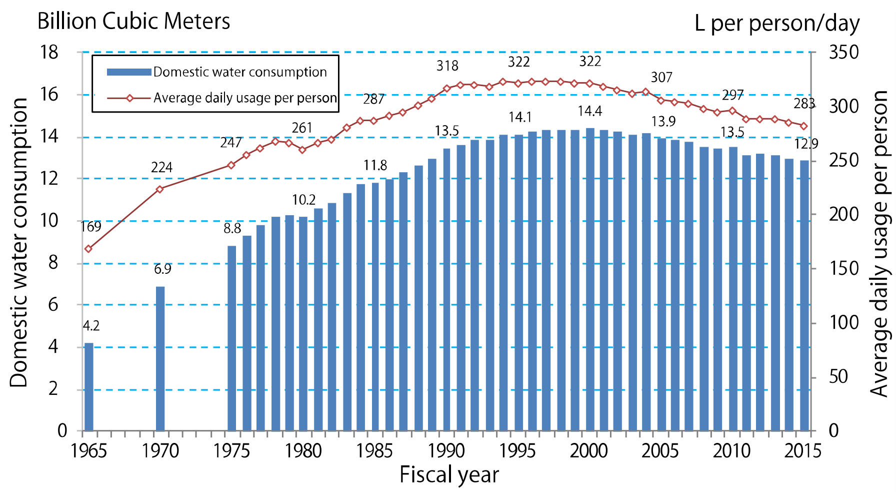

Figure 8 - Trends in domestic water usage in Japan [from 9)]

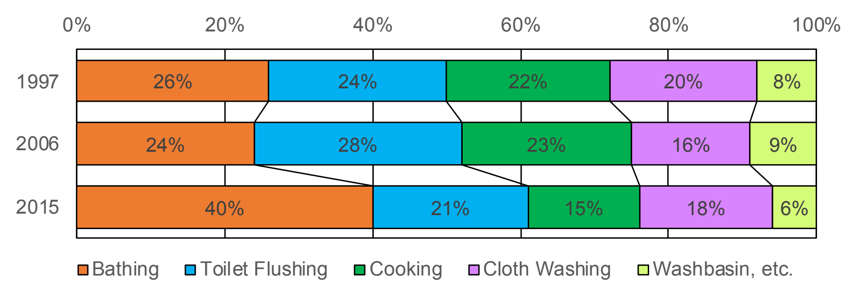

Figure 9 - Water consumption rate at home [from 11), etc.]

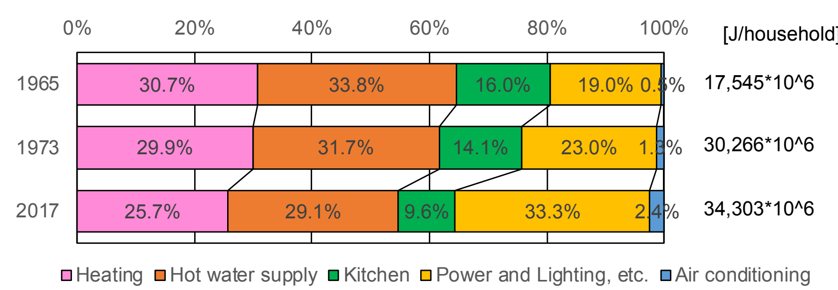

Figure 10 - Trends in energy consumption per household and energy consumption by application [from 13)]

4. Evaluation of "Net Zero Water"

4.1 "Net Zero Water Building Strategy" and examples in the United States

"Net Zero Water Building Strategy" by the US Department of Energy includes four concepts: water saving and water efficiency, rainwater and alternative water use, on-site drainage penetration, and green infrastructure. As an ideal form, it is supposed to fulfill the water circulation within the site. This is thought to be due to the fact that in the western part of the United States, there is not enough precipitation, it is in an arid region, and there is a lack of green space (Figure 11).

Microsoft Silicon Valley Campus has obtained zero water building certification. This is the first time for the company. This means that 100 percent of the building's non-potable water will come from rainwater or recycled water. Beyond drinking fountains and sinks and showers, not a drop will come from municipal reservoirs. This involves a lot of work – from design and construction to the actual operation of a wastewater treatment facility on site. [16)]

The Bullitt Center is a tenant building in Seattle. In this building, water from sinks and showers is stored in a greywater tank and cleaned in a constructed wetland, which can filter about 1900L per day. And clean greywater is infiltrated back into the soil to recharge the local aquifer. The building will restore the historical relationship of water to the land by collecting rain, returning it to the earth and the atmosphere. And 61% of the water in a Douglas fir forest evaporates or infiltrates into the ground, similar to the grey-water treatment in the Bullitt Center. [17)]

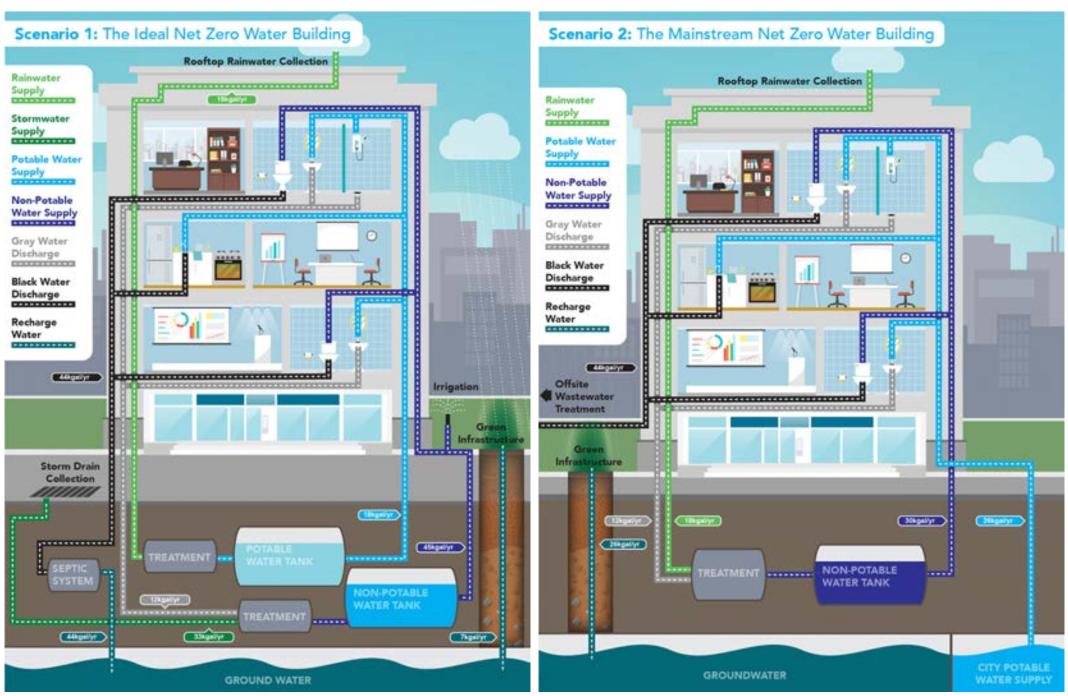

Figure 11 – Net Zero Water Building strategy by US government [14), 15)]
(Left) Scenario 1: The Ideal Net Zero Water Building
(Right) Scenario 2: The Mainstream Net Zero Water Building

4.2 Net Zero Water Building Framework in Japan

Net Zero Water Building in Japan extends the concept of Net Zero Water Building from the viewpoint of water conservation in the event of disasters, in addition to water saving and energy saving, rainwater and reclaimed water use, and construction of green infrastructure. As a result, it is thought that the water supply and drainage can be secured in an emergency, and the interest in the in-building water environment system can be raised for citizens, businesses and government.

The framework under consideration is shown in the form added to the flow diagram of the water calculation program created in 2017 [18] (Figure 12). When considering as an evaluation method, it is possible to express the numerical value that Net Zero Water Building can be achieved when the necessary facilities are secured by calculating the water usage situation when the water source and drainage destination is disrupted according to a unified standard. In this way, it is desirable to be able to utilize BCP and LCP.

However, the current water calculation program calculates the annual water consumption assuming normal times. In an emergency, for example, it is necessary to re-evaluate the evaluation in a week or in a form that restricts the use of water.

In addition, even if the infrastructure is disrupted, it is assumed that the building is functioning. However, there are various disaster cases, and the power level in the premises cannot be secured, or the pipeline is damaged. Therefore, it may be necessary to consider the level that cannot be used. Considering everything, the condition becomes complicated, so it may be necessary to consider a few limited cases.

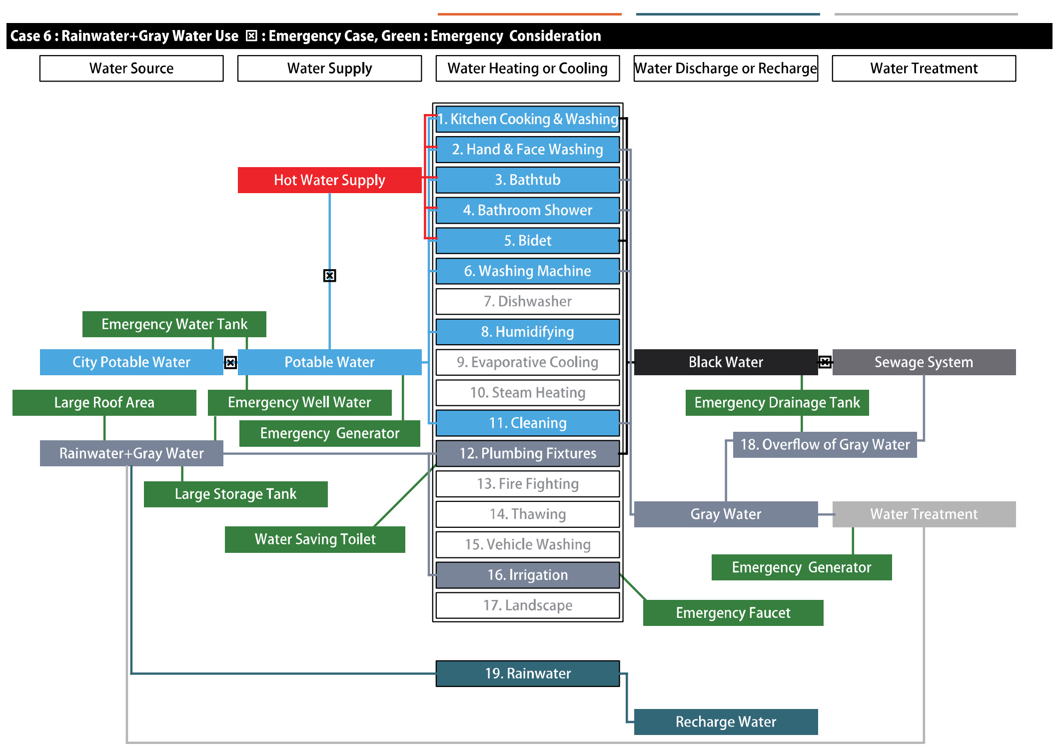

Figure 12 - Flow diagram of the water calculation program 2017 with an emergency consideration (green boxes) from 18)

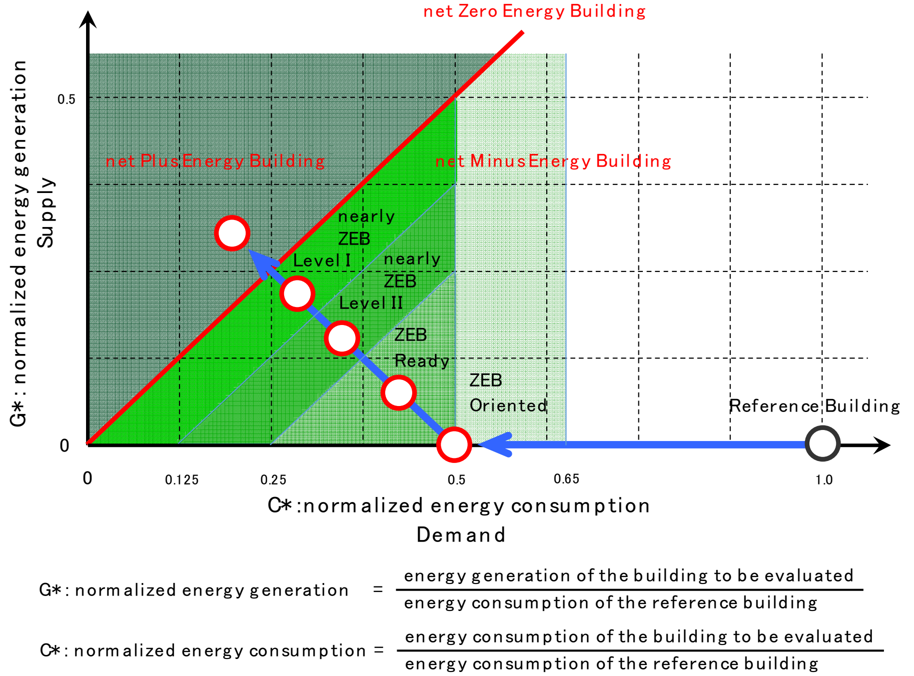

Figure 13 - Staged evaluation of ZEB (Net Zero Energy Building) from 19)

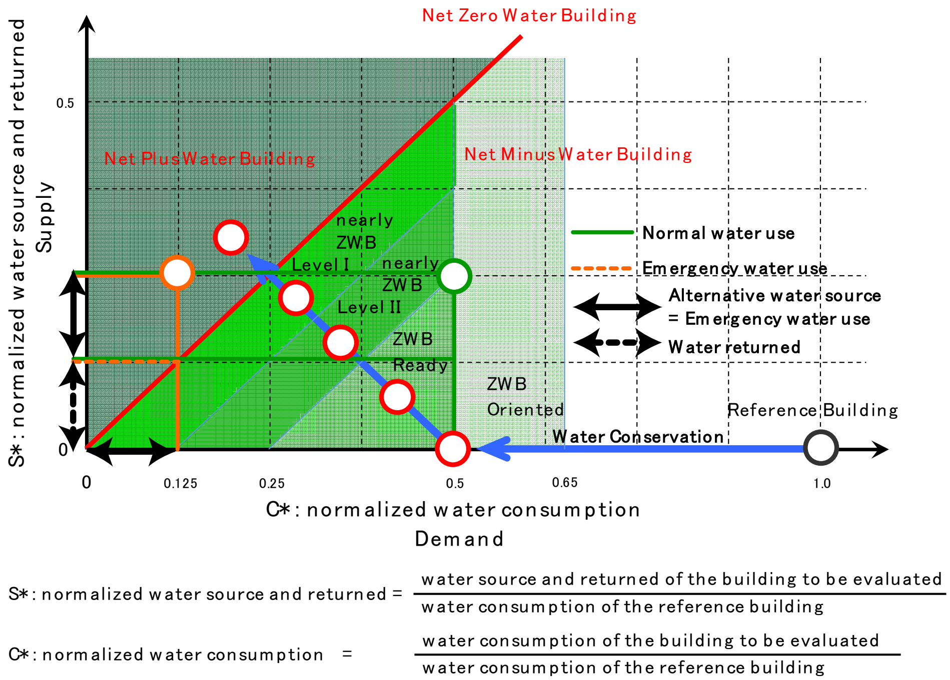

Figure 14 – Evaluation of Net Zero Energy Building (proposal)

4.3 Considering the evaluation of zero water building from the evaluation method of ZEB in Japan

Japanese Basic Energy Plan plans to convert new public buildings into ZEBs by 2020 and average all new buildings by 2030. In Japan, the concept of ZEB is organized and shown. The energy saving rate for the standard energy consumption is at least 50%, and ZEB is defined by these XY judgment lines based on the energy created by renewable energy such as solar power generation (Figure 13).

When this definition is applied in consideration of the definition of Zero Water Building in the United States, the water conservation rate relative to the water consumption of the standard building is on the X axis, and the sum of alternative water use (rainwater and reclaimed water) and recharge water is on the Y axis. Furthermore, it is necessary to evaluate the Net Zero Water in the building from various perspectives by calculating considering both normal water use and emergency water use (Figure 14). For the evaluation of Net Zero Energy related to water, the same evaluation method as that for Net Zero Energy Buildings in Japan can be applied.

5. Conclusion

In this study, we conducted a basic study on the evaluation method of net water buildings in Japan and could sort out the evaluation method from the viewpoint of securing water supply and drainage at the time of disaster and saving resources and energy.

In the future, we would like to show this idea with easy-to-understand charts in the three-year committee activities and improve the calculation program to continue the activities with the aim of putting the evaluation method into practical use.

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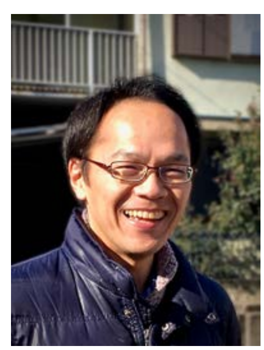

Hiroyuki Kose is the Professor at Toyo University, Faculty of Information sciences and arts from 2009. Special fields of study are plumbing engineering, water environment, reproduction of the agricultural and forestry industries by collaboration of citizens and an organization and community design for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

Water And Energy Facilities Management System For Hotel-Type Buildings Using IDEF0

A. Sewell (1), J. de Souza(2), L. Helena(3)

(1)alec.sewell@usp.br

(2)jorge.leon.souza@usp.br

(3)lucia.helena@usp.br

(1) Escola Politécnica da Universidade de São Paulo, Brazil

(2) Escola Politécnica da Universidade de São Paulo, Brazil

(3) Escola Politécnica da Universidade de São Paulo, Brazil

Abstract

Humans use the natural resources of the planet, both for their survival and for their comfort. However, the heavy use of these resources results in their scarcity, generating social and economic problems and compromising society's development. The management of facilities is a critical issue, especially water and energy in hotel-type buildings. In this case, there is usually not as much concern by the users about the consumption of resources compared to their place of residence. On that basis, the aim of this paper is the use of the IDEF-0 tool to develop a sustainable facility management system for hotel-type buildings in operation. The development process was made through a bibliographic survey; data collection of water and energy consumption tendencies; definition of the system's scope application; and the proposition of a management system distinguished in processes. The end result consists of a facility management system that discusses, from a qualitative and quantitative point of view, environmental, social, and technological aspects; promoting systemic and continuous action on building systems through the structured and didactic IDEF-0 graphical representations. It is concluded that once integrated with the current operation through the application of detailed processes, specific actions, with the goal of increasing the system's efficiency, also raises the potential for resource conservation, resulting in significant economic, social and environmental impacts. The effective contribution of this paper is the creation of a tool for the management of facilities focused on water and energy with a wide application range, capable of reducing excessive consumption and expenses, improving the performance of building systems, educating users towards the good use of available resources, and promoting a more sustainable operation without diminishing the quality of the final product.

Keywords

Facilities; utilities; management; hotel; water; energy; IDEF0.

1 Introduction

Sustainable development is an increasingly recurring issue in society. In order to satisfy a predatory development model and a growing demand for resources such as energy and potable water, there have been consequences such as environmental degradation, air and water pollution and depletion of natural resources. These impacts create irreparable losses to the environment, thus compromising the development of society as a whole.

The construction industry plays a fundamental role in achieving the overall objectives of a more sustainable development. According to the International Council for Building (CIB, 2002), this sector of activities is the one that consumes the most natural resources, in addition to using energy intensively, which causes considerable environmental impacts.

In the challenge of promoting the incorporation of sustainability principles into the civil construction sector, it is clear that despite the growing demand for sustainable construction, the vast majority of existing buildings were not conceived on the basis of these fundamentals. According to former ASHRAE chairman, Holness (2009), about 80% of buildings that will exist in urban areas by 2030 are already part of the mass stock of buildings. Therefore, it is evident that these buildings should be included among the priorities in initiatives for sustainable development.

In this context, the reality of hotel-type buildings is expressive due to their unique characteristics of processes inserted within the facilities management. In these ventures, the issue arises of consumption habits and unsustainable guest behaviour (NISA et al., 2017), operation, maintenance, leisure and aesthetic policies; and the compliance of equipment and services framework to sustainable strategies. These elements illustrate the potential for recurrence of water and energy waste and excessive consumption in the building operation, aggravating factors that can generate extra costs.

The implementation of a facilities management system is a strategy with a broad application perspective to address these issues. The facilities management according to ISO 41.011 (2017) is the process of organizing and integrating processes, human and material resources within a space built for the purpose of improving users' quality of life and core business productivity.

Thus, the objective of this article is to conceive a water and energy facilities management system for hotel-type buildings in operation by means of integrated processes using the IDEF-0 tool. With the system, it is possible to make feasible the introduction of technologies, procedures, principles and behaviours in order to increase the efficiency of building operations in a lasting way.

2 Methodology

For the development of this article, the concepts of facilities management were used and applied in the development of a system.

First, the characteristics of hotel-type buildings were analysed, including data on water and energy consumption trends through bibliographic research. Once the study was completed, a series of technical and managerial recommendations were made, based on the central theme, to increase the efficiency of processes and the long-term use of utilities, aimed at reducing costs and the need for maintenance, as well as the mitigation of waste and negative impacts to the environment, without abdicating the quality and comfort of users.

Next, the proposed scope of action was characterized and the guidelines, organized in processes, were elaborated. Once defined, to consolidate the proposed system, the processes were structured in a logical, comprehensive and didactic sequencing with the use of the IDEF0 (Integration Definition for Function Modeling) tool.

3 IDEF0

IDEF0 is a function modeling technique based on combined graphics and text that are presented in an organized and systematic way (FIPSPUB 183). Developed by the Integrated Computer-Aided Manufacturing (ICAM) program created by the United States Air Force, with the goal of providing understanding; support analysis; and to structure the design of functions and integration activities of system components. An IDEF0 model has a software approach and is composed of glossaries, texts and hierarchical diagrams cross-referenced to each other that describe the functions and their interfaces within the context of a system.

IDEF0 models provide a blueprint of functions and their interfaces, and as such, it reflects how system functions interrelate and operate through ICOM (Inputs, Controls, Output, and Mechanism respectively). This configuration facilitates understanding and communication. The IDEF0 models are elaborated with three types of information that complement each other: graphic diagrams, text and glossary. The graph diagram is the main component of an IDEF0 model, which provides a format for depicting models both verbally and graphically. The two modeling elements present in the diagram are boxes and arrows. A representation of an activity and the basic structure of a box and the ICOM arrows can be seen in Figure 1.

As for its structure, The IDEF0 models can be considered three dimensional, because any two-dimensional IDEF0 function model diagram can be extended to child functions presented at different layers, or levels of the model (WAISSE G., et al). Thus, any desired level of specificity is achieved, as shown in Figure 2.

The structuring of processes by the IDEF0 tool allows both a comprehensive view of the system through broad outlines as well as a specific and detailed view of its components, which facilitates reviewing, analysis and identification of possible improvements and strategies.

4 Results and Discussion

This chapter presents the development of the water and energy facilities management system for hotel type buildings. Since the methodology of IDEF0 is appropriate for the development of strategic plans, as well as for operational and strategic management, it is ideal for the representation of a set of components of a water and energy facilities management system of a building in operation.

The system was developed for the understanding, analysis, improvement or replacement of the current operation. The system´s scope encompasses all elements of a hotel business, including people, information, software, processes, equipment, products and raw materials.

4.1 Guidelines

As a starting point for the system, a set of guidelines were established for hotel-type buildings in operation. In order to organize them in a coherent way, the guidelines were separated into two categories that serve as foundation for the system: process management and technical management, divided into water and energy. Within this framework, the guidelines promote action from demand to recovery of energy systems, prioritizing measures of minimum or no cost and simple execution.

For the visual representation of the guidelines, a flowchart was devised, illustrated in Figure 3, which follows a recommended chronological order, as in the case of process management, or that presents the natural progression of the use of resources, as in the case of water and energy.

4.2 Implement the facility management system (A-0)

Based on the flowchart and associated texts, the IDEF0 method was applied. Every guideline was transformed into a process by incorporating the ICOMS method and, whenever necessary, creating further layers of detail.

The A-0 (Figure 4) represents the general overview of the mechanism of the facilities management system for hotel-type buildings. The diagram summarizes the complete set of external and internal interfaces of the system, conveying a cyclical characteristic to the process of decision-making; planning; execution; operation and maintenance, while also establishing a flow of ideas, strategies and results.

The system prompts procedures that involve all the people who interact with its facilities and an operation and maintenance plan with a holistic vision of its subsystems that is organized to undergo revisions and updates if necessary. The end result comprises the whole set of materials, people, equipment and processes that interrelate, defining an integrated system.

4.3 A0

Diagram A0 (Figure 5) integrates the first level of the guideline flowchart and illustrates how the two main parts are structured and interact with each other.

It should be noted that the configuration is hierarchical because, despite both management types being simultaneous, it is necessary that the planning and preparation of the processes and framework of services anticipate and support the needs for execution and implementation of technical solutions.

4.4 Technical Management (A2)

The Technical Management category A2 (Figure 6) includes technical solutions that influence water and energy consumption. Submetering and automation are mechanisms to support the processes of both subsequent subcategories, giving greater control and knowledge to the parties involved.

The energy management subcategory not treated in detail in this paper approaches ways to reduce energy consumption with energy efficient design strategies, renewable energy production, monitoring and intelligent automated systems.

4.5 Manage Water (A22)

The focus of this paper, the subcategory of water management A22 (Figure 7) involves proposals to optimize the use of this resource. To achieve this goal, there are many more effective alternatives than a single, specific decrease in its use. Among the solutions proposed by the system, the following can be singled out: the exploration of new sources of water; optimization of essential subsystems; more efficient procedures and equipment, taking into account the use patterns; and the internal and external building energy waste management.

4.6 Optimize Landscaping (A223)

Natural landscaping (Figure 8) was chosen to exemplify the level of detail of the system developed within the scope of water consumption management. It is important to install a meter for the irrigation system, which facilitates the acquisition of data to evaluate the impacts of the solutions adopted.

Pursuing solutions that involve water supply should be the first to be regarded. Potentially feasible examples of alternatives to irrigation water include reclaimed wastewater, greywater, swimming pool backwash filter, refrigeration system condensate and captured rainwater.

According to the LEED O & M 2016 reference guide, the demand for water in irrigation can be controlled by modifying the layout in order to optimize water distribution in the event of rain. Among the strategies of sustainable layout, we can highlight: the segmentation of the area into hydro zones in order to group plants with similar water needs; the use of native or adaptable plants; and the positioning of species relative to water, sunlight or shade access.

To establish a more efficient irrigation system, waste and loss through evaporation should be minimized. Automated components can rely on timers, humidity sensors; and direct water application to the root zone of plants; among other techniques and technologies that utilize water in a more rational way.

5 Conclusion

Due to the clarity and simplicity of the standard established in the design and diagramming of processes through the IDEF0 method, the facilities management system allows a systemic and integrated approach, taking into account technical, environmental and social aspects, capable of promoting a more sustainable operation and to provide, besides the prevention of intercurrences, the systems feedback, with a view to improving it.

The implementation of the proposed system can generate knowledge, participation and a use culture. In addition, with due adaptations, the system can also be used in other types of buildings, promoting a scenario of great exploratory potential, through which the facilities management will contribute to sustainable development in society.

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7 Presentation of Authors

Alec Shoji Yamamoto Sewell is an undergraduate student in Civil Engineering at Escola Politécnica da Universidade de São Paulo. He graduated on the field in July 2019 and is currently pursuing a master´s degree in sustainable facility management.

Jorge Leon Cavalcante de Souza graduated in Civil Engineering at Escola Politécnica da Universidade de São Paulo with a complementary formation in Sustainable Buildings at ESTP Paris. He currently takes professional improvement courses, mainly in business and management.

Lúcia Helena de Oliveira is working at Escola Politécnica da Universidade de São Paulo in the department Department of Construction Engineering where she is currently an associate professor. She is specialized in Building Systems, acting mainly in water conservation, rational use of water and management of water use in buildings.

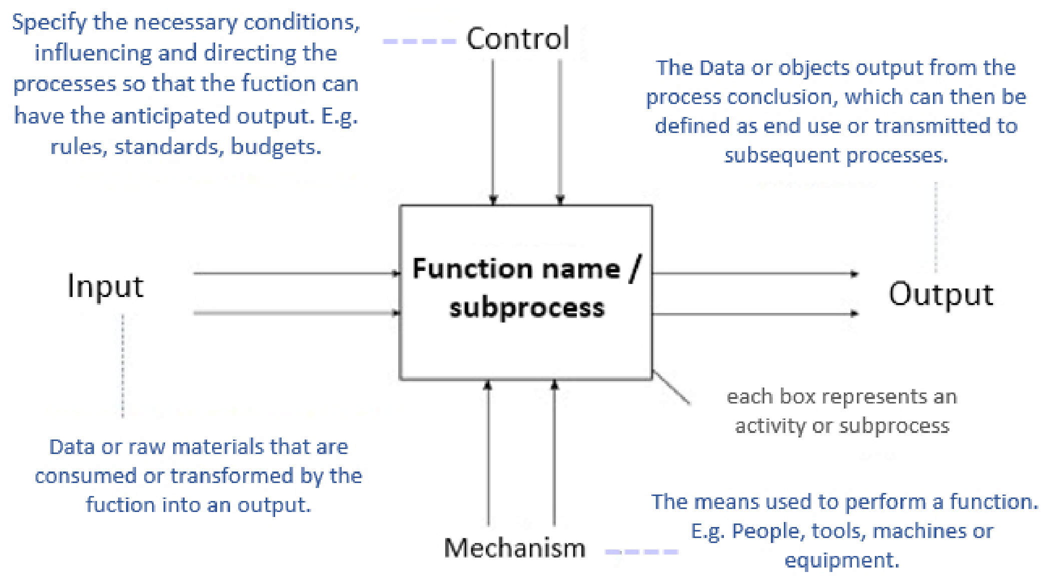

Figure 1 - Standard representation of an activity

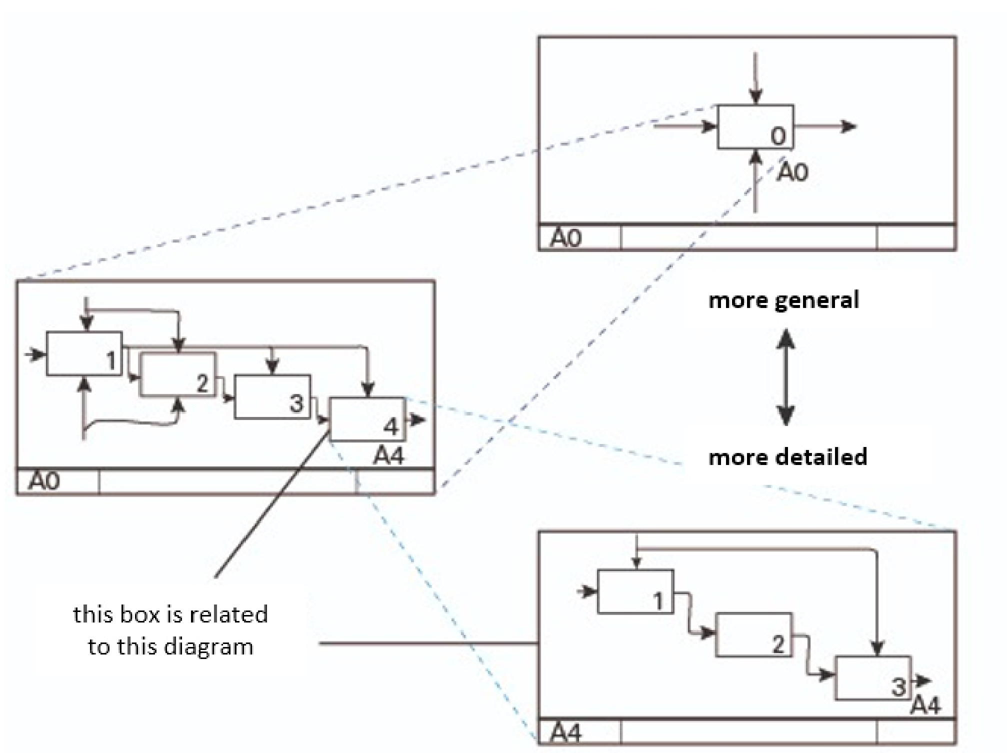

Figure 2 – Structure of the IDEF0 Decomposition

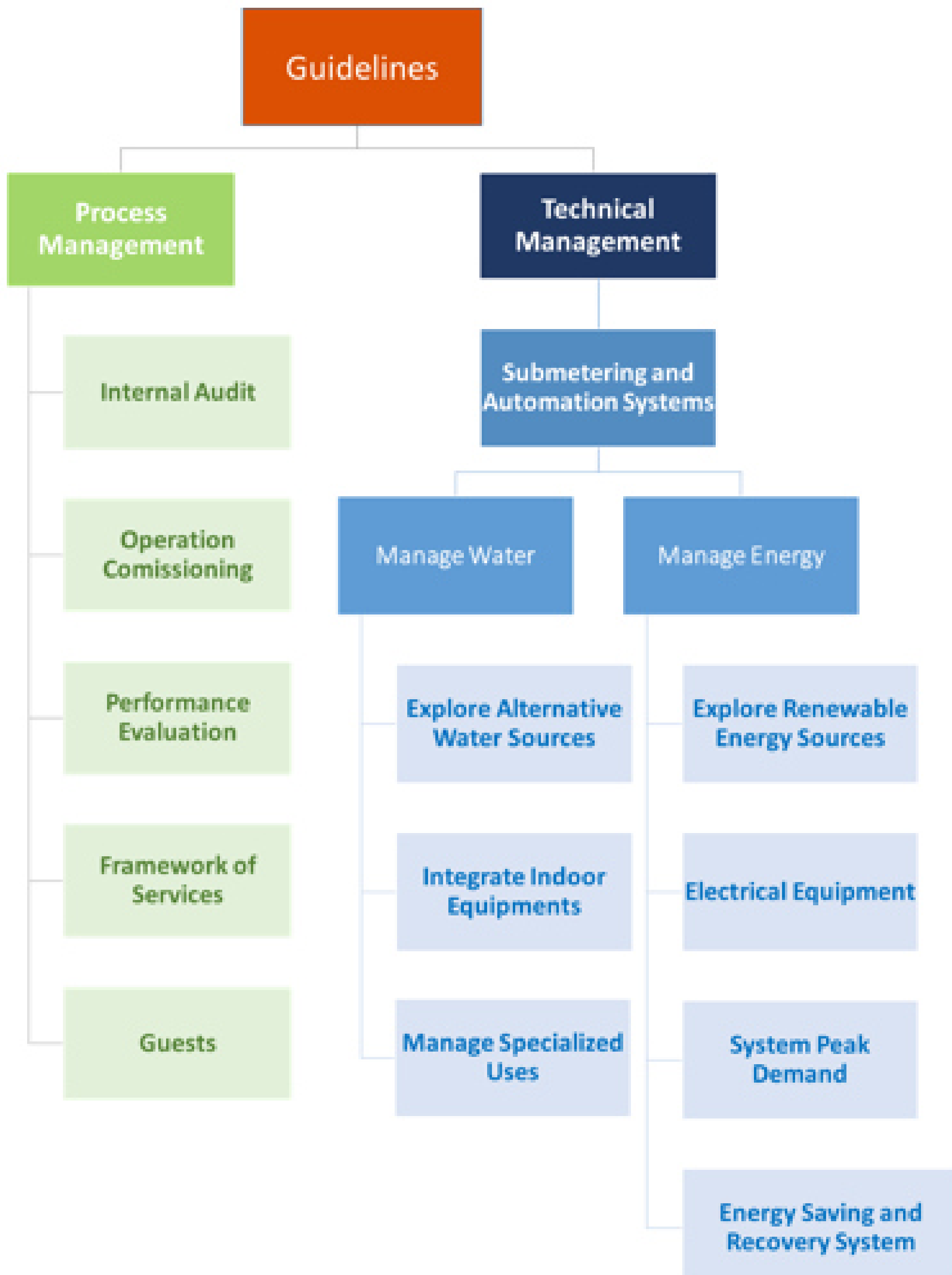

Figure 3 – Sustainable operation guideline flowchart

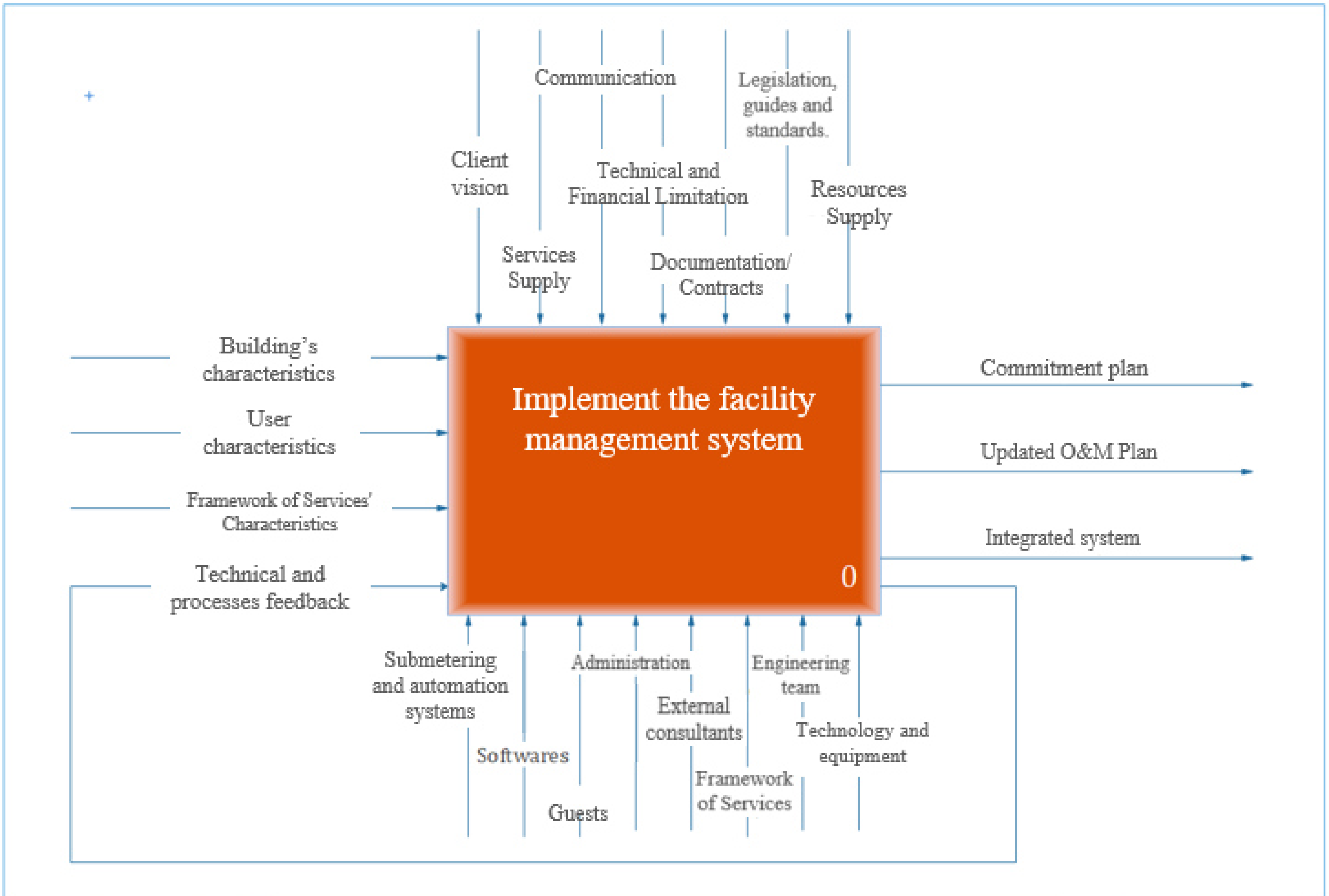

Figure 4 - Overview diagram of the water and energy facilities management system (A-0)

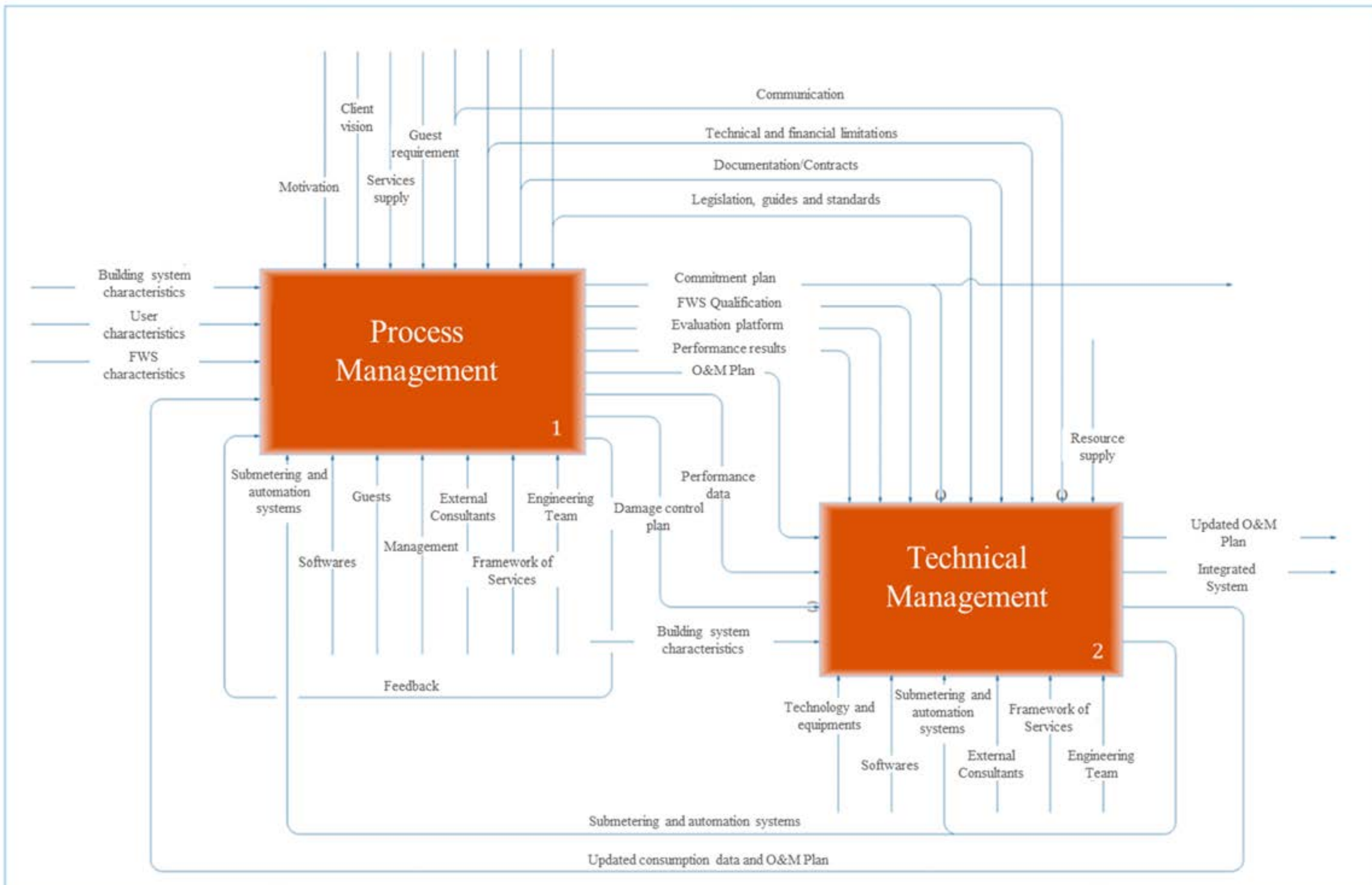

Figure 5. Process Management and Technical Management interaction diagram (A0)

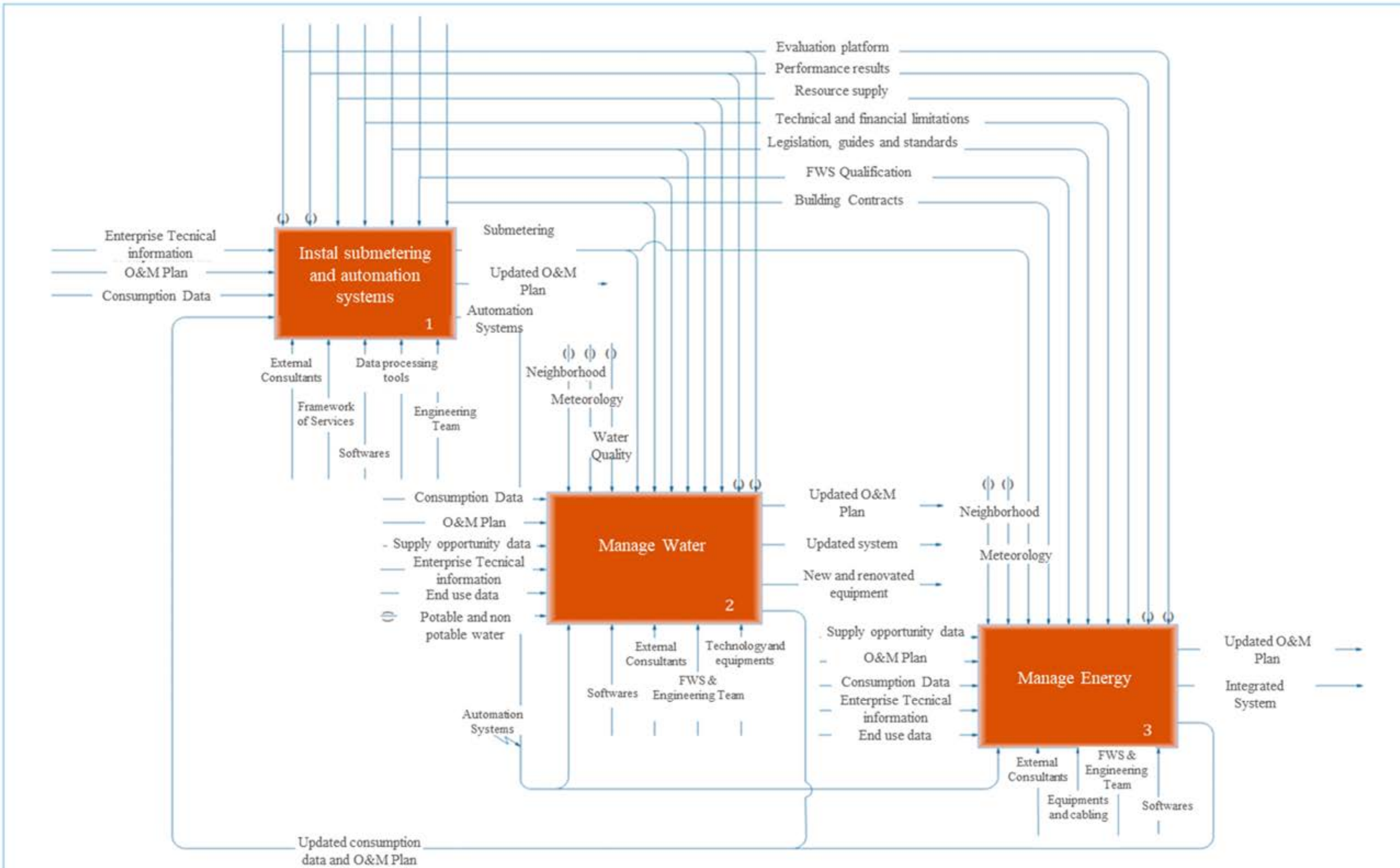

Figure 6. Technical Management diagram (A2)

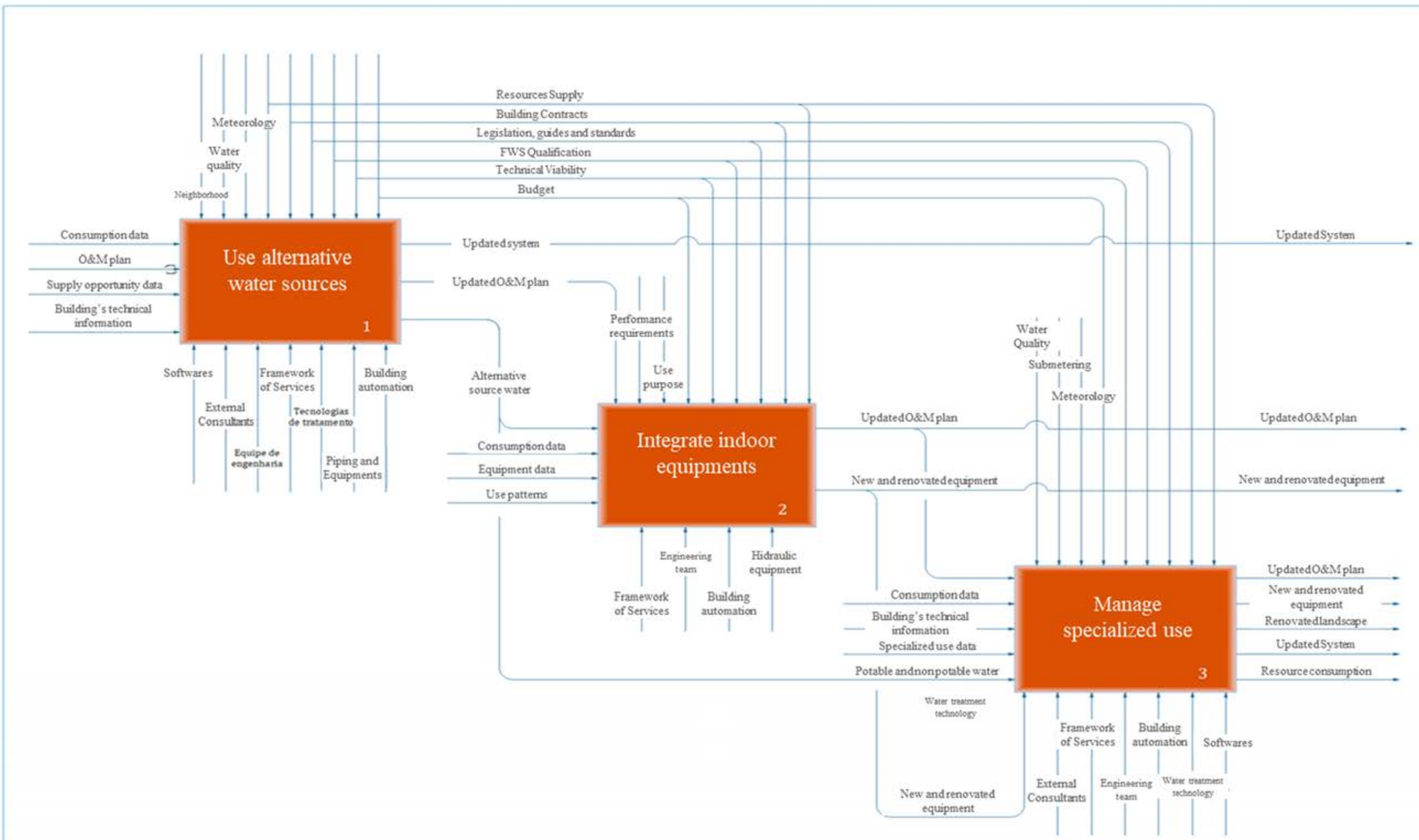

Figure 7. Manage Water (A22) process diagram

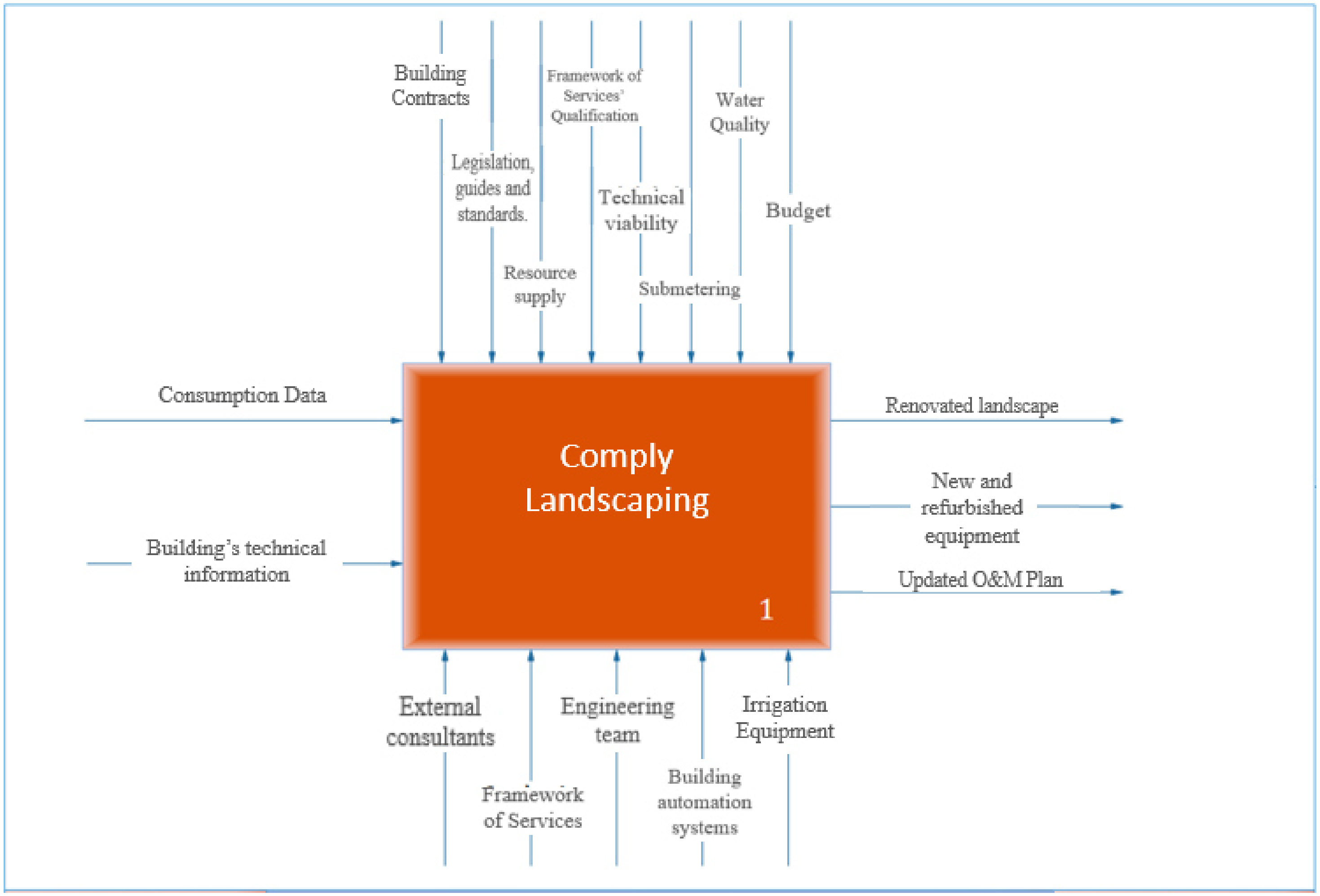

Figure 8. A223F (Optimize Landscaping) process diagram.

Fact-finding investigation of Toilet Usage in High-rise Office Buildings and Examination of Drainage Load Calculation Data

Yudai Motomura (1), Masayuki Otsuka (2), Shogo Sato (3), Sadahiro Koshiba (4)

(1) motomura.yuudai@takenaka.co.jp
(2) dmotsuka@kanto-gakuin.ac.jp
(3) m18J3004@kanto-gakuin.ac.jp
(4) koshiba.sadahiro@takenaka.co.jp
(1) Takenaka Corporation, Japan
(2) Prof. Dr. Eng, Department of Architecture and Environmental Design, College of Architecture and Environmental Design, Kanto Gakuin University, Japan
(3) Graduate Student, Graduate School of Engineering Kanto Gakuin University, Japan
(4) Takenaka Corporation, Japan

Abstract

Currently, in Japan, amounts of water for flushing toilets in newly-built and existing office buildings have been gradually reduced by more than half from 13.0 L to 6.0 L. Meanwhile, this has raised issues regarding the steady flow rate method and drainage load calculations, which are specified by the current SHASE-S206 Plumbing Code, because the unit data required for calculations, such as fixture discharge amounts and average fixture discharge amounts, are too large and no longer compatible with the current designs. In addition, the occupancy time of toilet booths and the interval of average fixture discharge are changing along with the change in usage of toilets, and this is considered to have some influence in appropriately determining the number of fixtures.

In this investigation, the optimal number of fixtures was first discussed by examining the occupancy time of toilet booths, the intervals of average fixture discharge, etc., which are important factors in carrying out a drainage load calculation made based on the appropriately determined number of fixtures and a drainage stack for a toilet system to be installed in an actual high-rise office building. The findings were then considered together with the reduction of amounts of flush water in order to identify how the drainage load in the stack is affected. The results of the investigation were eventually taken into account to review, from an international perspective, drainage load calculations that consider factors, such as the current usage trend of toilets and the adaptation of water-saving toilets, and were contributed to developing new suggestions.

Keywords

office building; drainage load; occupancy time; intervals of average fixture discharge

1. Background and objectives

In Japan, fixture-unit load calculations in accordance with the American Standard National Plumbing Code and the steady flow rate method stipulated by SHASE S-206 are used for determining drainage pipe diameters. The latter takes into account the discharge volume, discharge flow rate and average discharge intervals of a sanitary fixture, and drainage load calculations are made in a logical manner so that the results are used for determining drainage pipe diameters. Meanwhile, the reduction of water used in toilets, which generate the highest drainage loads among all sanitary fixtures, has been encouraged worldwide, and amounts of flush water has been reduced from the conventional volume of 13L to 4.8-6L. Moreover, toilet booths are individually installed nowadays as private spaces that provide security as well as a refreshing atmosphere, and the length of time used in a toilet booth (hereinafter referred to “occupancy time”) and the intervals of time between the flushes are changing. With this background in mind, this paper reports a long-term investigation which was carried out on toilet usage with the focus on changes in the usage of toilet booths in an actual office building. The investigation results were used in the steady flow rate method by SHASE-S 206 to obtain drainage load values and determine drainage pipe diameters. The calculated values were then compared with the results calculated by the same method but using conventional values, based on which design data for future reference were considered.

2. Experimental overview

Table 1 shows the brief description of the building where the investigation was conducted. The investigation was carried out for three months between Wed. 22 Aug. 2018 and Tue. 13 Nov. 2018. A survey on the number of workers on duty on the subject floor was carried out 13 times in total between Mon. 01 Oct. and Fri. 12 Oct., and according to the results, the average number of male workers per day was 206 (standard deviation: ±38.6) and the average number of female workers per day was 61 (standard deviation: ±8.1). Fig. 1 and 2 are the floor plans, including pipe layouts, of the male and female lavatories which were used as subjects for the investigation. In each lavatory, the horizontal fixture drain branch (pipe diameter 100[A]) has connected thereto 4-5 water-saving type toilets (flush cistern type[1)]), 5 urinals, 4-5 washbasins, 1 hand washer, and 1 mouth washer (the male toilet only). The end of the horizontal fixture drain branch is connected to the drainage stack (pipe diameter 125[A]). In addition, the numbers of toilets in the male and female lavatories of the building are both classified as level 1 (the upper limit: little waiting time) according to SHASE S-206 Plumbing Code, Determination of the Number of Sanitary Appliances Installed[2)].

Table 1 Building description

Basic information	Intendeduse	Office building	Sanitary fixture	Toilet	Male 4/female 5
	Location	Osaka City,Osaka,Japan		Urinal	Male 5
	Stracture/Scale	S type/9flrs.aboveground/ 4flrs.underground		Washbasin	Male 4/female 5
	Site area	4,420㎡		Hand washer	Male 1/female 1
	Building area	3,706㎡		Mouth washer	Male 1
	Floor area (subject Flor)	2,994㎡	Sanitary facility	Drainage system： combined drainage stack dia 125A Horizontal fixture drain branch dia 100A Vent stack dia 100A Loop vent pipe dia 50A	
	Total floor space	44,592㎡			
	Workera on duty	Male 206,female 61			
	Features	Office arranged around the Core section of the building			

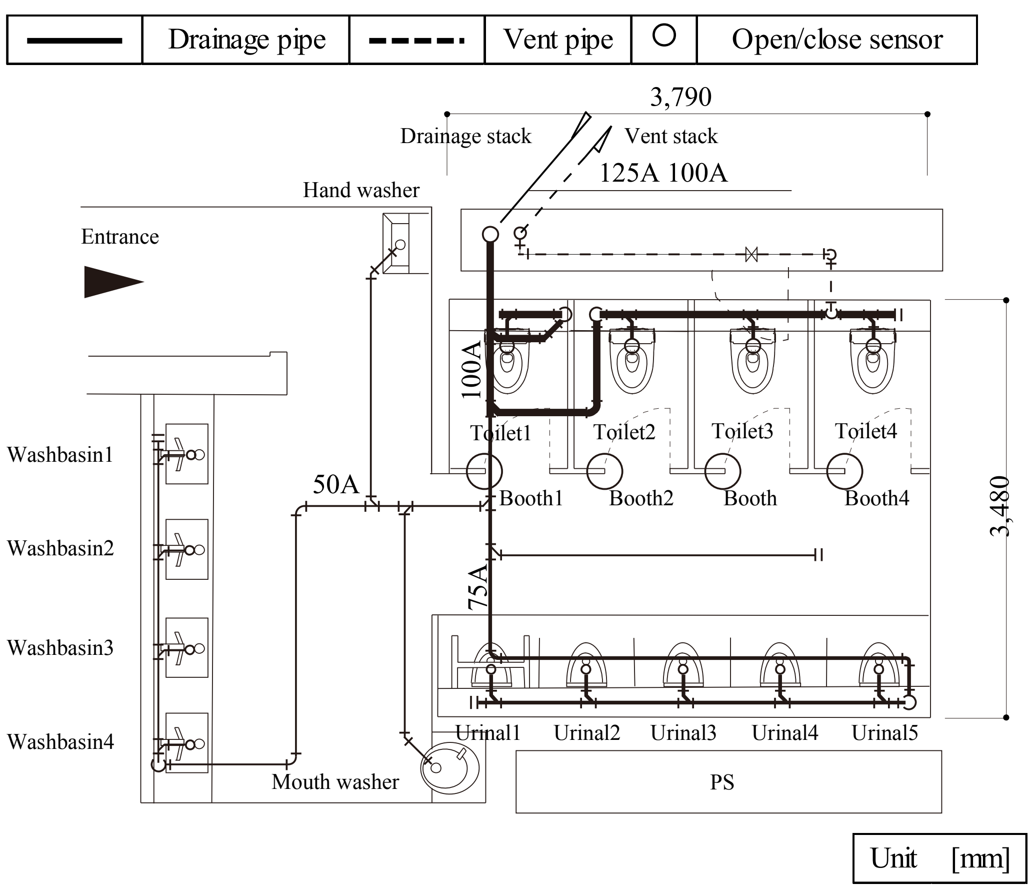

Fig. 1 Male lavatory floor plan

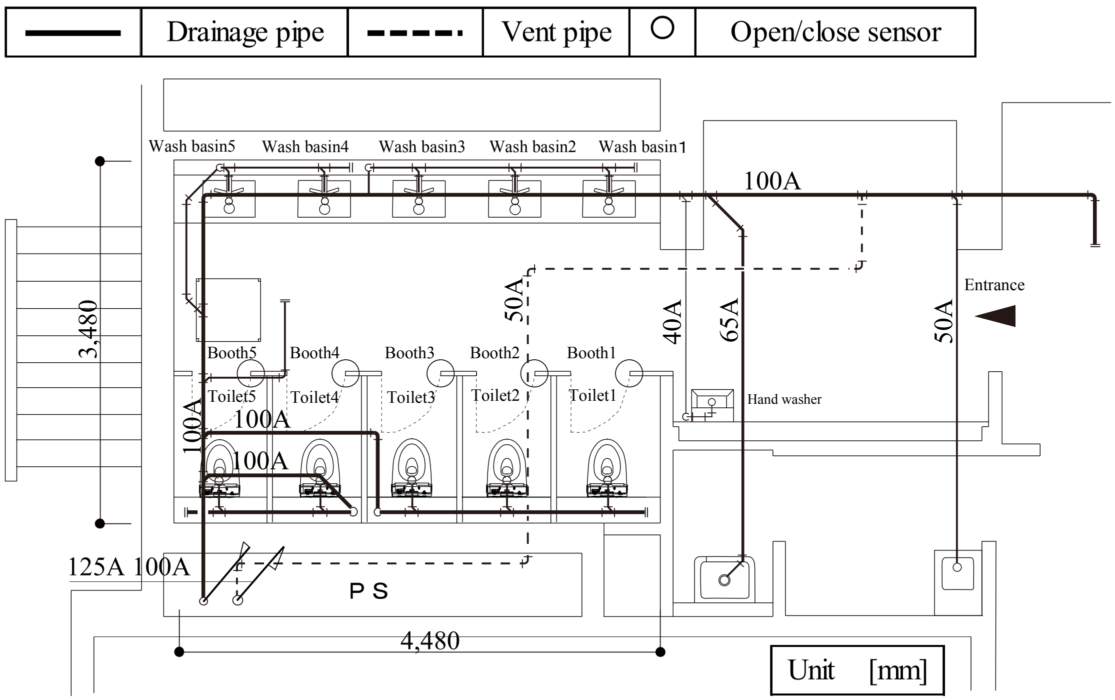

Fig. 2 Female lavatory floor plan

2.1 Measurement items and measurement methods

As shown in Fig. 1 and 2, the toilet booths were equipped with door open/close sensors. The time between opening and closing of each booth door was recorded to identify the occupancy time of each fixture, and the average fixture occupancy time τ[s] was subsequently calculated. Moreover, the flush valves of the toilets were provided with operation sensors. The time between operations of each flush valve was recorded to identify the intervals between discharges, and the average fixture discharge interval T□[s] was subsequently calculated.

2.2 How to calculate the average fixture occupancy time τ and the average fixture discharge interval T□

Fig. 3 shows an example of signals indicating the opening and closing of the booth door and the flush valve. The time between the opening and closing of the door, ($Open_1$ - $Close_1$), ($Open_2$ - $Close_2$)··· ()pen_n - $Close_n$), was obtained to calculate the average fixture occupancy time τ. Similarly, the time between the operations of the flush valve, ($Flush_2$ - $Flush_1$)··· ($Flush_n$ - $Flush_{n-1}$), was obtained to calculate the average fixture discharge interval T□.

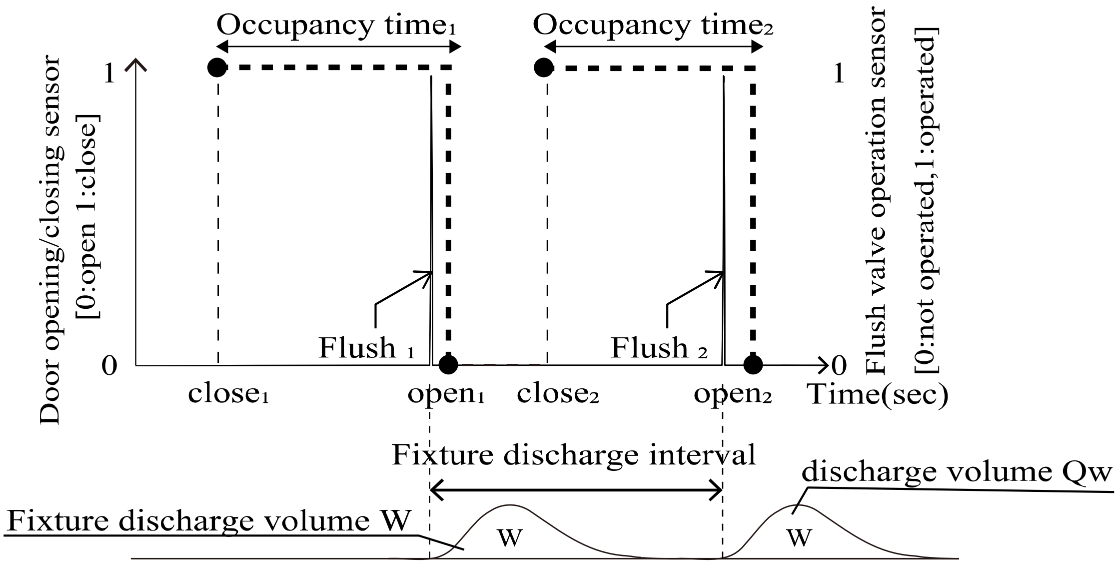

Fig. 3 Calculations of the average fixture occupancy time τ and the average fixture discharge interval T□

2.3 Drainage load calculation flow

Fig. 4 shows the calculation flow for estimating a drainage load and determining a pipe diameter in accordance with the steady flow rate method[3)] by SHASE-S206. The fixture discharge volume W was created using a water-saving siphon toilet: 13[L][3)] and a water-saving cistern toilet: 6.3[L][1)] in accordance with SHASE-S206. The average fixture discharge interval T□ was calculated from the values; 4 male toilets 600[s] and 5 female toilets 170[s], which are in accordance with SHASE-S206, and the values obtained from the investigations. Moreover, the average fixture discharge flow rate qd was calculated using a conventional toilet: 1.5[L/s], and the value of 0.72[L/s] (roughly 0.75[L/s]) that was used in the previous report[1)]. Incidentally, the average fixture discharge flow rate qd produced by the toilets is the highest among the sanitary fixtures, and therefore was used as a representative fixture value. Using the abovementioned values, the drainage load flow rate Q_L[L/s] was calculated according to the drainage pipe selection chart in Fig. 5 and the pipe diameter D was determined.

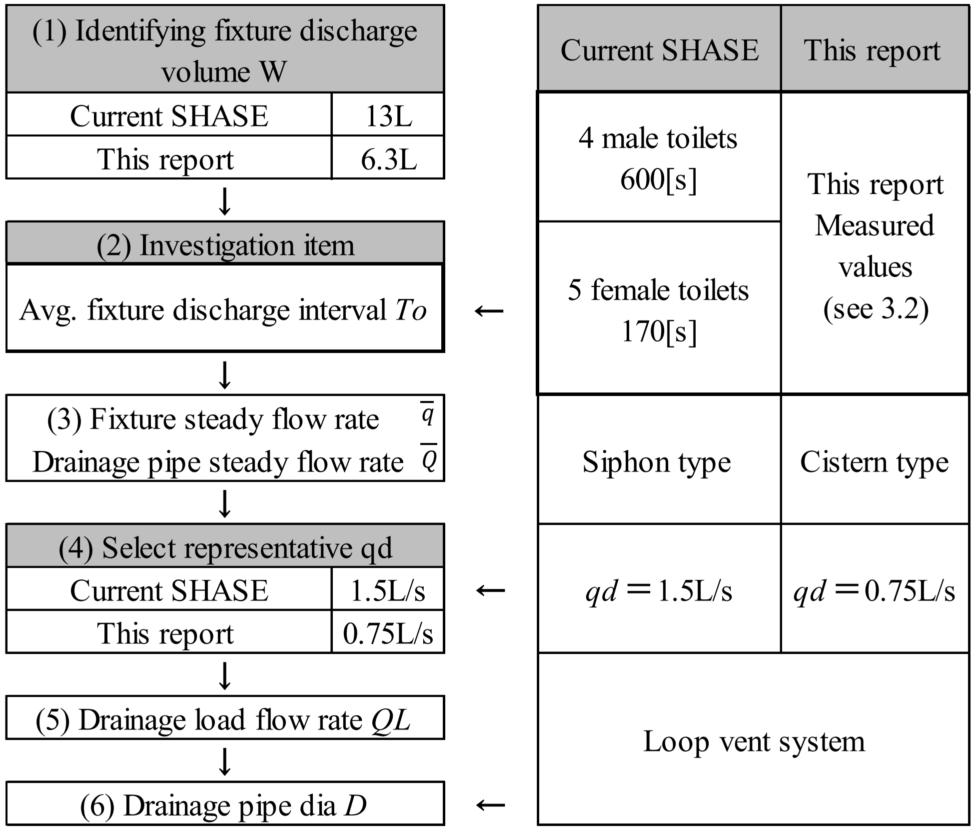

Fig. 4 Drainage load/pipe diameter calculation flow according to the steady

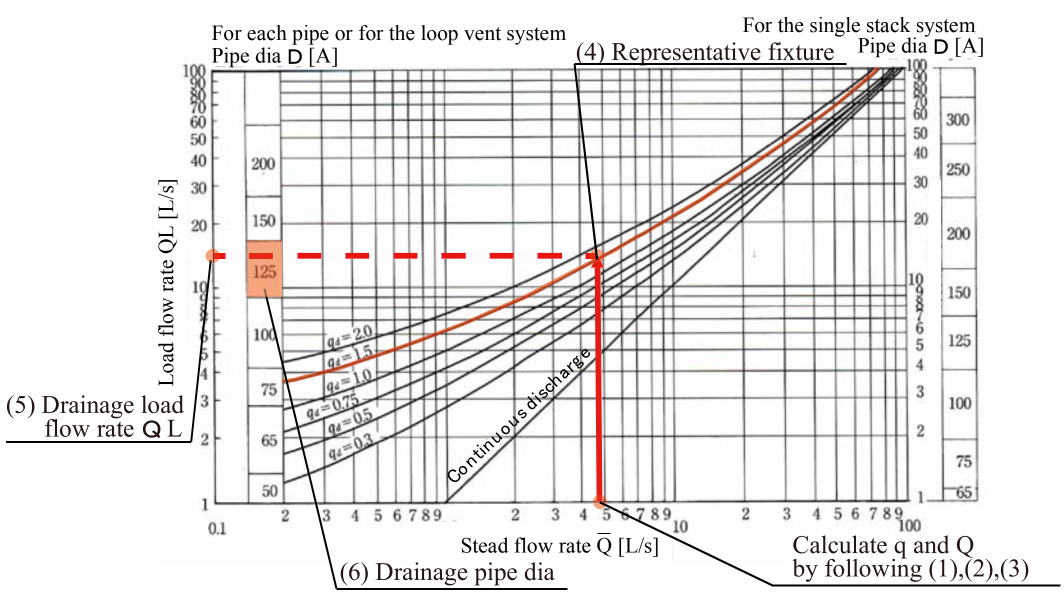

Fig. 5 Drainage pipe selection chart

3. Investigation results and observations

3.1 Investigation on the frequency of fixture occupancy and fixture occupancy time

Fig. 6 and 7 show the distributions of the frequency of fixture occupancy per hour and fixture occupancy time which were recorded during the entire period of the investigation carried out on the male and female toilets. The graphs show the average fixture occupancy frequency N_U and the average fixture occupancy time τ for each gender. Incidentally, in this report, the investigation period refers to 55 weekdays and excludes weekends when the frequency of toilet usage was very low. According to Fig. 6, the occupancy of male toilet booths is most frequent between 8 and 9 o'clock, and the average fixture occupancy frequency between these hours is 31.3[times/h]. This value was obtained by dividing the total occupancy frequency of 1,719 between 8 and 9 o'clock by 55 days. Meanwhile, the occupancy of female toilet booths is most frequent between 12 and 13 o'clock, and the average fixture occupancy frequency between these hours is 34.7[times/h]. The same calculation method was used to obtain this value as in the case of the male toilet booths. The peak hours of the male toilet usage and the female toilet usage are different, and this is mainly because men have a habit of going to the toilet before going to work, while women have a habit of going to the toilet and fixing their makeup after lunch.

In addition to the above, in contrast to the findings of the previous study [4)], where the average fixture occupancy time τ of male toilet booths was 434[s], Fig. 7 shows τ being 394[s] in this investigation, which is 40[s] shorter than 434[s]. However, approximately 30% of the total frequency of fixture occupancy exceeded the average fixture occupancy time τ of the previous study[4)]. Meanwhile, in contrast to the findings of the previous study[4)], where the average fixture occupancy time τ of female toilet booths was 134[s], Fig. 7 shows τ being 208[s] in this investigation, which is 74[s] longer than 134[s]. Moreover, approximately 38% of the total frequency of fixture occupancy exceeded the average fixture occupancy time τ of the previous study[4)]. This situation creates longer waiting times than the conventional situation.

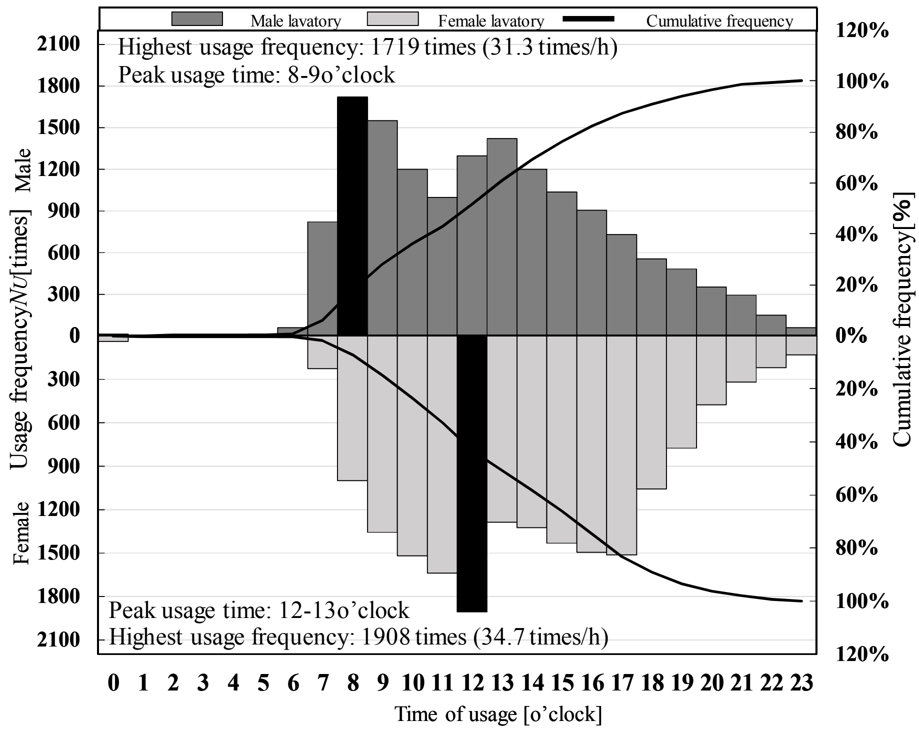

Fig. 6 Average fixture occupancy frequency N_U/gender (weekdays during the investigation period)

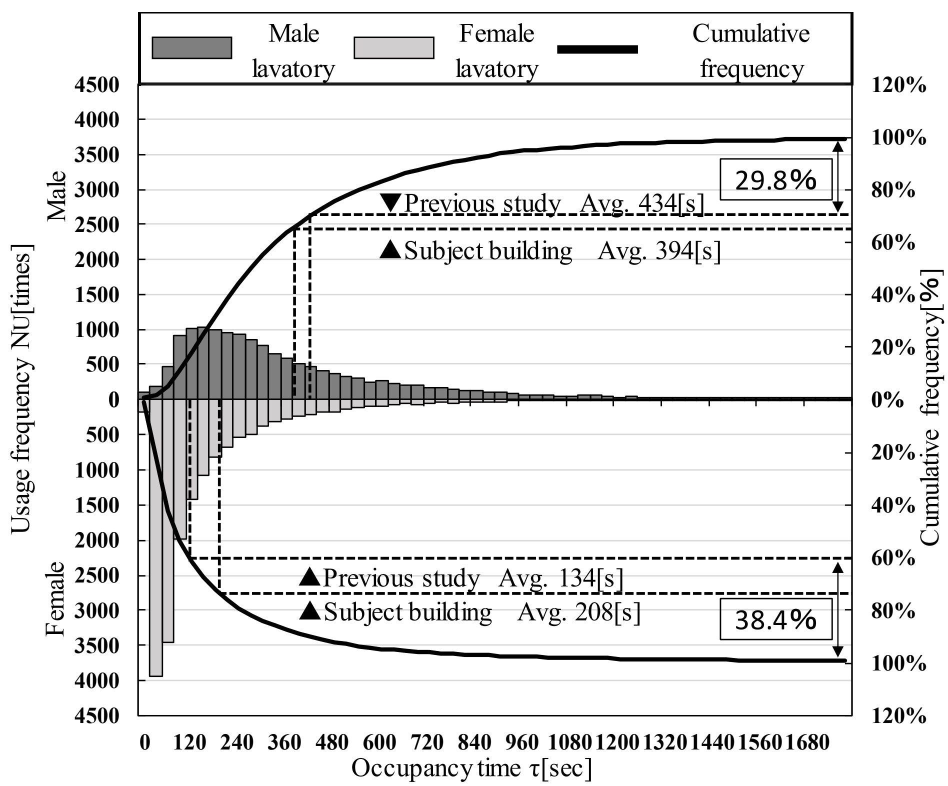

Fig. 7 Average fixture occupancy time τ/gender (weekdays during the investigation period)

Moreover, the average fixture occupancy time τ per booth per gender is shown in Table 2 and Fig. 8. According to Table 2, with regard to the male lavatory, there is a tendency that the further the booth is from the entrance, the longer the average fixture occupancy time τ becomes. With regard to the female lavatory, there is a maximum of 2-minute difference in average fixture occupancy time τ between booths. That is, there are variations in fixture occupancy time in both male and female cases. Meanwhile, Fig. 8 shows the τ values in comparison with the average fixture occupancy time τ[s] of male and female toilets (male: 300[s], female: 90[s][2)]), specified by the current SHASE S-206, when an appropriate number of toilets are used. The graph clearly indicates that in both male and female cases, the τ values obtained from the investigation results are longer than the τ values by SHASE S-206.

Table 2 Avg. max. and min. of the average fixture occupancy time τ per booth per gender

Gender	Booth No.	Occupancy time (min. sec.)					
		All booths	Booth 1	Booth 2	Booth 3	Booth 4	Booth 5
Male	Avg.	6,34	6,18	6,22	6,40	7,3	
	Max.	+46,28	50,2	53,2	44,44	45,11	
	Min.	-6,24	0,10	0,10	0,18	0,11	
Female	Avg.	3,38	3,11	2,49	4,53	3,29	3,46
	Max.	+54,29	56,40	46,10	57,57	35,52	50,44
	Min.	-3,28	0,12	0,15	0,10	0,10	0,12

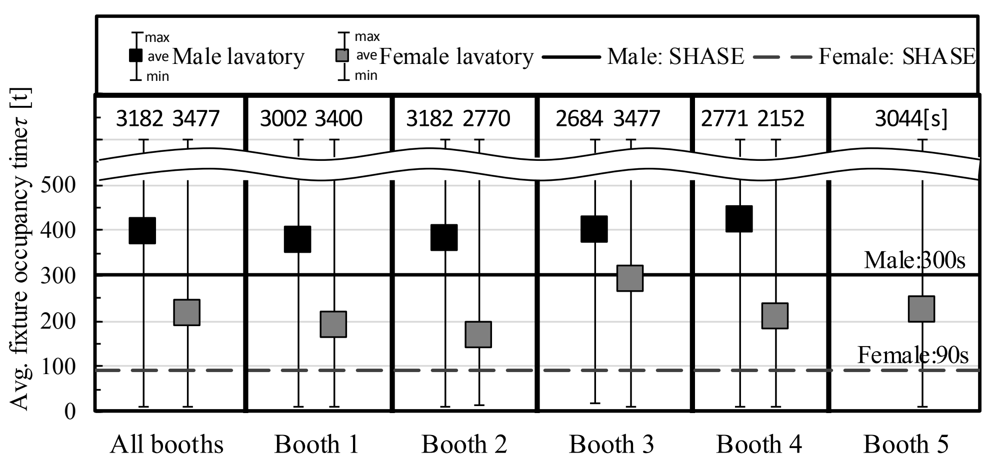

Fig. 8 Average fixture occupancy time τ values in comparison with SHASE specified values[2)] in both male and female cases

3.2 Investigation on flushing frequency and fixture discharge intervals

Fig. 9 and 10 are frequency distribution graphs each showing flushing frequency and fixture discharge intervals per hour per gender, which were obtained during the investigation period. The graphs also include the average flushing frequency N_F and the average fixture discharge interval T□ of all the toilets in each of the male and female lavatories. According to the current SHASE data, the average fixture discharge interval T□ is determined based on the time during which the usage frequency is the highest (hereinafter referred to as “rush hour”). Therefore, in this investigation, the hour between 8 and 9 o’clock in the male lavatory and the hour between 12 and 13 o’clock were regarded as rush hours, as shown in Fig. 9. These rush hours correspond respectively to the hours during which the male and female toilets were most frequently occupied according to Fig. 6. Fig. 10 indicates that the current SHASE S-206 specifies that the average fixture discharge interval T□ of 4 male toilets is 600[s], whereas the investigation ndicates that T□ is 305[s], which is roughly half of the SHASE-specified value. Meanwhile, the current SHASE S-206 specifies that the average fixture discharge interval T□ of 5 female toilets is 170[s], whereas the investigation indicates that T□ is 378[s], which is 208[s] longer than the SHASE-specified value. One of the causes is thought to be the increase in the average fixture occupancy time τ, and it is considered that a significant increase in the average fixture discharge interval T□ could greatly affect drainage load calculations.

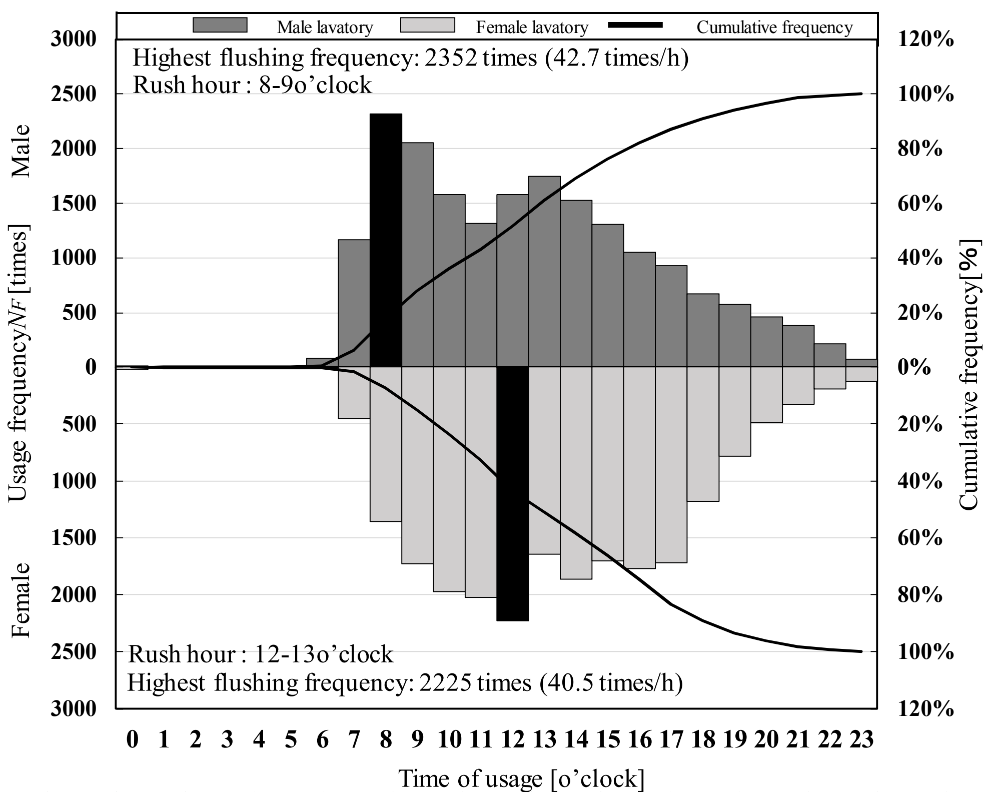

Fig. 9 Average flushing frequency N_F/gender (during the entire investigation period)

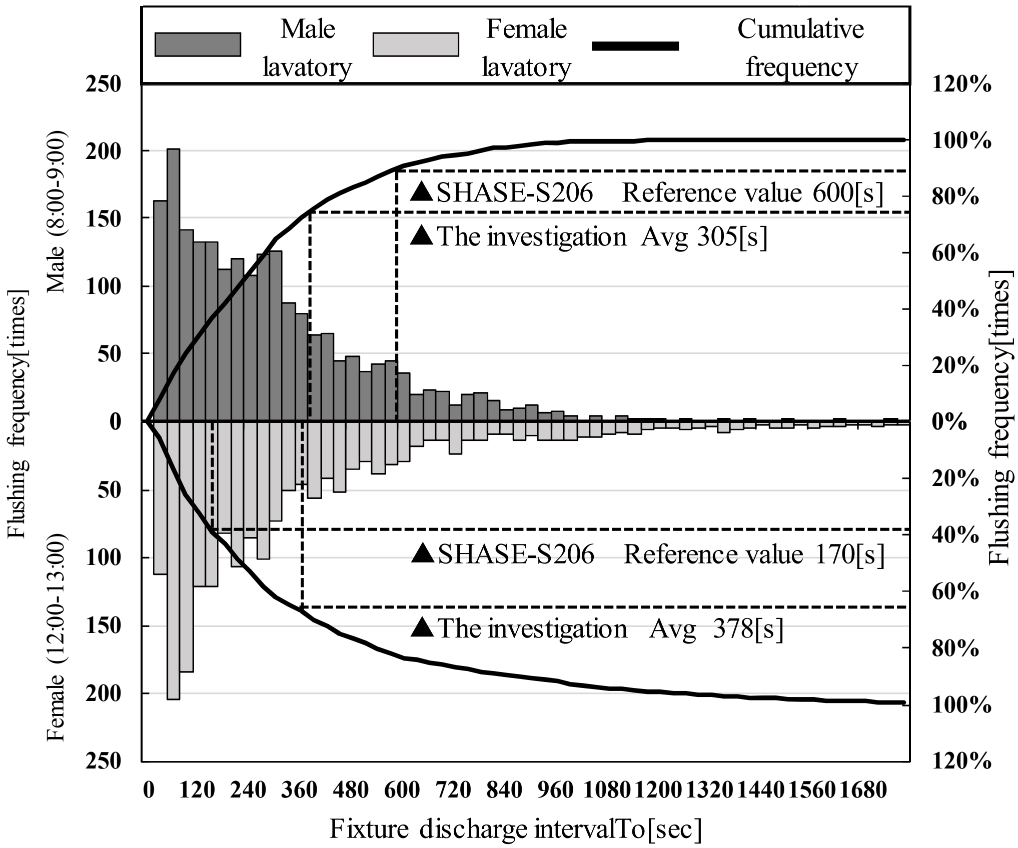

Fig. 10 Average fixture discharge interval T□/gender

3.3 Comparison of drainage load calculation results

Table 3 shows the numerical values specified by the current SHASE S-206 and the numerical values obtained from th e investigation, which were used for calculating drainage loads. As for the average fixture discharge interval T□, as described in 3.2, 600[s]; a SHASE-S206-specified value, and 305(≒300)[s]; a value obtained from the investigation, were used for the male lavatory, and 170[s], a SHASE-S206-specified value, and 378(≒380)[s], a value obtained from the investigation, were used for the female lavatory. The other factors, including the fixture discharge volume W, the average fixture discharge flow rate qd and the average fixture discharge interval T□, were also used according to the data by the current SHASE S-206. Moreover, the subject building having 9 floors was used, as described in Table 1, and each floor of said building was facilitated with the sanitary fixtures shown in Table 4. Using these numerical values, together with a calculated value $\overline{Q}$ and the drainage pipe selection chart in Fig. 5, the drainage load flow rate Q_L was calculated. Fig. 11 and 12 each show the relationship of the drainage load flow rate Q_L, calculated as above, and the floor number F. Incidentally, Fig. 11 and 12 provide calculation results by gender. Fig. 11 indicates that the drainage load flow rate Q_L of the male lavatory on the 9th floor is approximately 12.2[L/s] based on the current SHASE data and approximately 8.8[L/s] based on the investigation data, making a reduction of approximately

27.8%, and therefore, also making it possible to reduce the drainage attack diameter D from 125[A] to 100[A]. Meanwhile, Fig. 12 indicates that the drainage load flow rate Q_L of the female lavatory on the 9th floor is approximately 15.3[L/s] based on the current SHASE data and approximately 7.1[L/s] based on the investigation data, making a reduction of approximately 53.6%, and therefore, also making it possible to reduce the drainage stack diameter D of the loop vent system from 125[A] to 100[A]. Accordingly, in the case of the male lavatory, the fixture discharge volume W is reduced from 13[L] to 6.3[L], and the average fixture discharge interval T□ is shortened from 600[s] to 305[s]. Therefore, the pipe steady flow rate $\bar{q}$ changes from 13/600 (=0.021) to 6.3/305 (=0.020), barely making any difference. It should be noted, however, that the representative average fixture discharge flow rate qd decreased from 1.5[L/s] to 0.75[L/s][1)], and this caused the drainage load flow rate Q_L to decrease as a whole. In the case of the female lavatory, T□ increased from 170[s] to 378[s], indicating a considerable reduction in the drainage load flow rate Q_L.

Table 4 Reference numerical values used for drainage load calculations

Fixtures installed on the floor			Floor no.	Fixture discharge volume *W*	Avg. fixture discharge interval *To*		Avg. fixture discharge volume qd	
Fixture	Male	Female			SHASE	This report	SHASE	This report
Toilet	4	5	9	13L	Male : 600s	Male : 305s	1.5L/s	0.75L/s
				6.3L	Female : 170s	Female : 378s		
Urinal	5			6L	180s		0.5L/s	
Washbasin	4	5		3L	Male : 80s		0.3L/s	
					Female : 70s			
Hand washer	※2	1		3L	600s		0.3L/s	

* The mouth washer is counted as a hand washer.

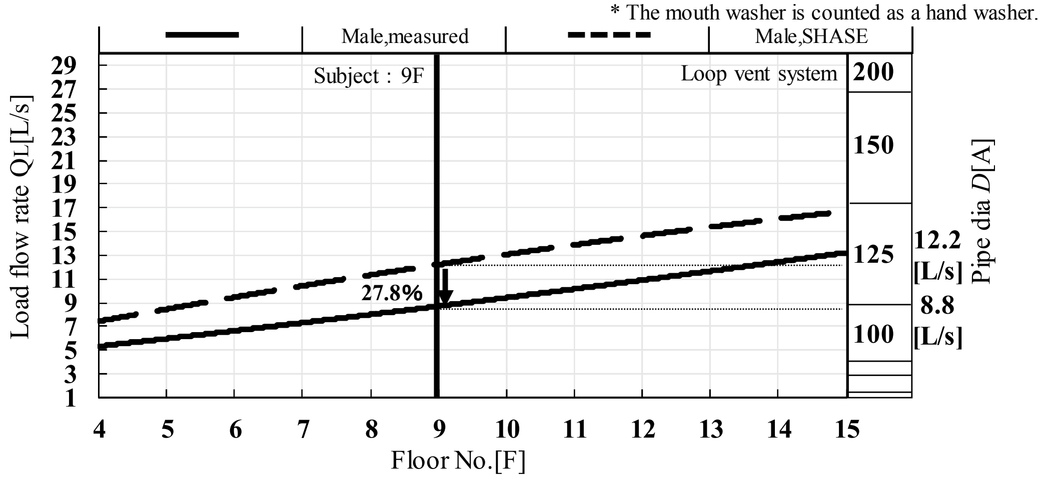

Fig. 11 Drainage pipe selection chart using the investigation results (male lavatory)

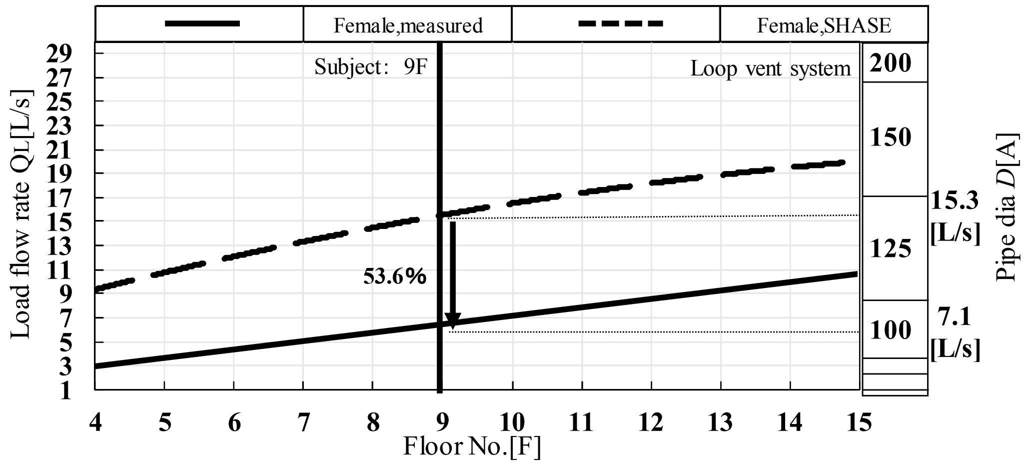

Fig. 12 Drainage pipe selection chart using the investigation results (female lavatory)

4. Conclusion

Using an actual high-rise building, an investigation was carried out on the usage of toilet booths, and the results of the investigation have clarified the following:

(1) The investigation results revealed that the average fixture occupancy time τ of male toilet booths was 394[s], and the average fixture occupancy time τ of female toilet booths was 208[s]. Moreover, the investigation results also revealed that said occupancy time values were greater than the data obtained in the previous report, i.e., male: by approximately 30%, and female: by approximately 38%. This clarified a change in the usage of toilet booths due to longer waiting times being incurred in the present situation than in the conventional situation.

(2) The investigation results revealed that the average fixture discharge interval T□ of 4 male toilets was 305[s] and the average fixture discharge interval T□ of 5 female toilets was 378[s]. Said values deviate from the values specified by the current SHASE S-206 though only slightly. This also indicates a change in the usage of toilet booths, as described in (1), and it is considered that a change in the average fixture discharge interval T□ could significantly affect drainage load calculations. Meanwhile, it was also revealed that the drainage load flow rate Q_L was reduced when calculated with consideration for water conservation, making it possible to reduce the drainage pipe diameter.

(3) Compared to the drainage load calculation results based on the conventional data by the current SHASE S-206, the drainage load calculation results based on the investigation results revealed the possibility of reducing drainage loads; the male lavatory by approximately 28% and the female lavatory by approximately 54% as well as reducing the drainage stack diameter.

In conclusion, the data provided by the SHASE S-206 needs reviewing with regard to the fixture discharge volume W, the average fixture discharge flow rate qd, and the average fixture discharge interval T□.

5. Reference literature

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6. Presentations of Authors

Yudai Motomura is a construction manager (MEP) at the Osaka Head Office of Takenaka Corporation.
He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating,Air-Conditioning and Sanitary Engineers of Japan). His latest interest is to acquire knowledge about the hybrid drainage system that uses both force feed type and gravity type drainage methods.

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 Interest is the hybrid drainage system that uses both force feed type and gravity type drainage methods compatible with commercial building conversion.

Shogo Sato is a graduate student of the Otsuka 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 study is a drainage experiment in high-rise building.

Sadahiro Koshiba is a design engineer at the Osaka Head Office of Takenaka Corporation and is currently the Head of Technology Group 3. He is a member of SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan).

Green walls: water consumption & quantity and quality of drain water

J. Van Herreweghe (1), K. Dinne (2), O. Gerin (3), B. Bleys (4)

(1) joris.van.herreweghe@bbri.be

(2) karla.dinne@bbri.be

(3) olivier.gerin@bbri.be

(4) bart.bleys@bbri.be

(1), (2), (3), (4) Belgian Building Research Institute, Belgium

Abstract

Nowadays, more and more buildings with green walls appear in the street scene. To allow plants to grow on a wall, essentially two different system types are used. Within the soil-bound system, the so-called **Green Facades**, plants root in het open ground at the base of the wall and grow on it whether or not supported by a climbing aid. Within wall-bound systems, so called **Living Wall Systems**, plants root in a substrate that is maintained on the wall in one way or another (flower box, geotextile, module,…). Most often, plants in living wall systems depend on an irrigation and fertilization system for their water and nutritional elements.

Although many manufactures are active on the market, each with their own system, still many questions remain on the actual successful and durable implementation of these systems. One of these questions is about their **real water consumption** and the **amount and quality of drain water** (excess of irrigation water coming out of the system) and what can still be done with it.

To answer this question, a **test setup, consisting of nine different living wall systems** available on the market, was built. It was equipped with an **irrigation and fertigation system** allowing an individual program for each wall. A flow logger allowed us to **monitor the water consumption** of each wall individually. Also, the **drain water** coming from each wall was collected for **quantification** and **quality analysis**. Within this analysis part, several parameters were looked at which each have their importance for either storage, reuse or evacuation to the sewer system of this drain water. Within this paper, the results of a first monitoring campaign will be presented.

Keywords

Green Walls, Water Quality, Water consumption, Drain water

1 Introduction

Making facades green is a study subject in full expansion in Europe. Numerous green wall systems, with multiple materials and characteristics, appear on the international and European market and, little by little, in Belgium and Flanders. This increasing interest stems from the many possible benefits that are attributed to green walls. Green walls have the potential to change the view of a building or city from gloomy and gray to lively and green. Besides, green walls might also contribute to the mitigation of the urban heat island effect by preventing the underlying structure from heating up. They also have an acoustic added value, the potency to improve air quality and a positive effect on psychological health. By using different plant species, they also might contribute to biodiversity.

As stated in the abstract, mainly two systems are used for the greening of facades: the soil-bound systems, so-called Green Facades and the wall bound systems, so-called **Living Wall Systems**. This paper only deals with Living Wall Systems. The different systems currently available on the market all display their strengths and weaknesses. Currently there is a lack of scientific information on many aspects of these systems which might hamper their successful and durable implementation. These aspects include proper choice of plants and suitable substrate, maintenance, sustainability (life cycle), influence on air quality,… Therefore, a collaborative research project dealing with these topics was conducted at the Belgian Building Research Institute together with several other research partners. One of the aspects looked at in this project is the **real water consumption** and the **amount and quality of drain water** (excess of irrigation water coming out of the system) and what can still be done with it.

2 Test setup

2.1 General description

To answer these questions a test setup was built including nine living wall systems (see Figure 1). Each wall has a surface of 4m² and are all oriented to the south. As stated before, living walls systems need and irrigation and most of them also a fertigation (injection of fertilizer) system. To allow sufficient flexibility in terms of individual adjustments on timing and duration of the irrigation and individual adaption of the fertigation for each wall, a self-designed and assembled irrigation and fertigation system was installed.

Figure 1 Picture of the test setup including nine Living Wall Systems

A schematic overview of the system is given by Figure 2. The whole test setup is supplied with tap water (A) which is stored in an underground water tank (B) in order to have no direct connection to the tap water system (legal obligation). From there the water is distributed over the system using a pump (C). A digital flow logger (D) allows us to monitor the water consumption of each wall. A digital water timer (E) per wall allows the programming of the start time and duration of in total 6 watering moments per 24 hours. Next, according to the preferences of the manufacture of the green wall, liquid fertilizer from a stock solution (F) can be dosed to the irrigation water using a volumetric dosing pump (G). Before the irrigation water reaches the wall (H), a sample is collected (I) to allow analysis of the initial quality of the water. The irrigation water is distributed within the green wall making use of the system provided by the manufacturer. Different systems are being used by the manufacturers. Some make use of sprinklers/drip lines, while others make use of a capillary system where water is stored in a gutter under the plant modules from where it is absorbed by a textile incorporated in the module. For every wall individually, the excess of irrigation water (so-called drain water) is collected underneath the wall using a gutter and evacuated towards a reservoir (J) allowing quantification of the collected water and sampling for quality analysis.

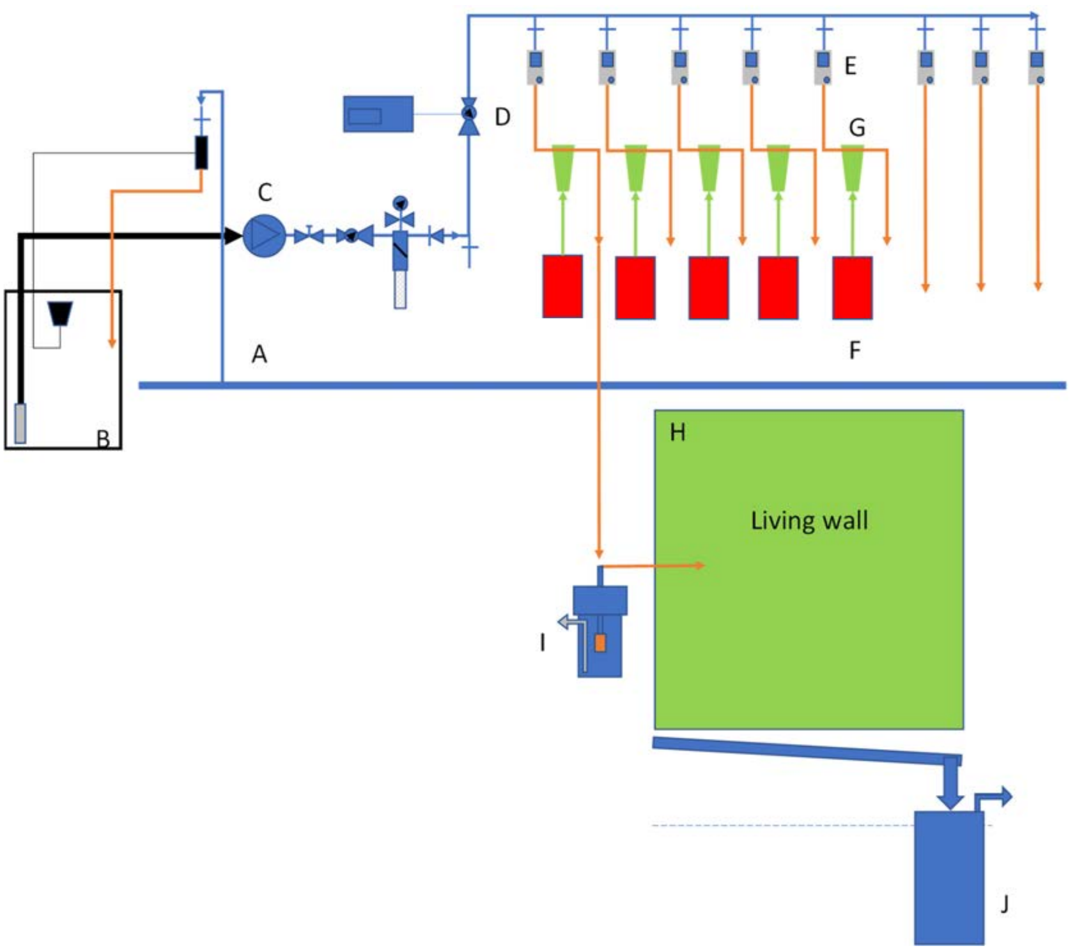

Figure 2 Schematic overview of the irrigation and fertigation system

2.2 Settings and sampling campaigns

The irrigation program for each wall is based upon recommendations of the manufacturer. We then optimized it to achieve a balance between sufficient humidity of the plant substrate on the one hand, and minimization of the amount of drain on the other hand.

Regarding fertigation, two main systems were applied based on the preferences of the manufactures. For some systems, once a year solid fertilizer was administered directly at the base of the plant (further called discontinuous fertigation). For the other systems, liquid fertilizer was administered continuously at low dose (0.5g/l final concentration) to the irrigation water. Two different types of fertilizer were used based upon the preferences of the manufacturers.

Determination of the water balance (in & out) and quality analysis was done during one-week lasting sampling campaigns. During this period the water consumption (flow logger), the amount of drain water (weighing of the collected drain water) and the water quality according to different analysis parameters were determined (see point 4). **Two sampling campaigns were launched before fertilization was applied** in order to have an idea about the influence of the wall itself on the water quality. Next, **two sampling campaigns** were launched **after the startup of fertilization** and having respected an equilibration period. These serve to have an idea about the influence of fertilization on the drain water quality.

4 Analysis parameters

As Figure 3 illustrates several water quality parameters have been analyzed on the collected water samples. These parameters were selected based on their importance for at least one of the final destinations of the drain water being either drainage to the sewer system, storage & reuse, and reuse for plant nutrition. The results for the parameters given in bold will be presented in this paper.

All chemical parameters, including Chemical and Biological Oxygen Demand (COD/BOD), were quantified using appropriate analysis kits from Hach and by making use of a DR6000 spectrophotometer.

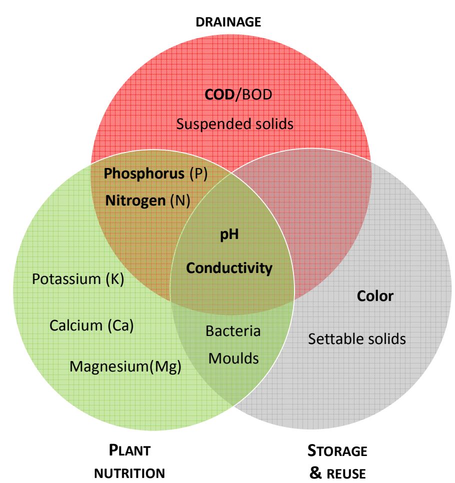

Figure 3 Overview of the water analysis parameters

3 Results

The following paragraphs will describe the results as far for the drain water quality, the water consumption and drain water quantity for seven green walls. Two additional walls were recently installed for which no results are yet available. For the drain water quality, the results of the campaigns before and after startup of the fertilization are described (see § 2.2).

Remark: The commercial names of the different systems are replaced by a code. Within this code the first letter is an O or I standing for the type of substrate, either ***O****rganic or* ***I****ntert. The second letter is a T or t standing for a* ***T****hick or a* ***t****hin system structure. The number of + signs behind are an indication of the quantity of substrate in the system.*

3.1 Drain water quality

Figure 4 contains a series of graphs showing the results of the analysis parameters for the drain water for seven living wall systems as discussed below. The light grey bars show the results without fertilization (influence of the system itself), while the dark grey bars show the results with fertilization (additional influence of fertilization). The shaded bars give the results for the reference samples including tap water and the irrigation water (with fertilizer) as supplied to the different walls. For systems with discontinuous fertilization (dc) the results for the drain water should be compared to the values of the tap water to have an idea about the influence of the green wall. For systems with continuous fertilization (c) the results for the drain water must be compared to the corresponding irrigation water.

pH and conductivity:

For the systems with **discontinuous fertilization** (dc): comparison of the **pH** values of the drain water with the pH of the tap water used to irrigate these systems indicate no major influence of the fertilization or the system on the pH of the drain water (see Figure 4 A).

For the systems with **continuous fertilization** (c): the addition of fertilizer to the tap water results in a pH decrease for the irrigation water (shaded bars Figure 4 A). However, this does not result in an obvious decrease of the pH of the drain water for these systems. This indicates that both systems with organic and inert substrate have a buffering capacity.

Regarding the **conductivity** (measure for dissolved ions), the systems themselves and **discontinuous fertilization** seem to have a limited effect on this parameter (see Figure 5 B). When fertilizer (soluble inorganic salts) is added to the tap water this obviously results in an increase of the conductivity of the irrigation water. This also results for systems with **continuous fertilization** in an increase of the conductivity of the drain water, indication that at least part of the fertilizer administered to the walls is not taken up by the wall and ends up in the drain water.

Color

Measurement of the color of the drain water indicates that most of the systems cause to a greater or lesser extent discoloration of the water. Addition of fertilizer does not result in a discoloration of the irrigation water, neither does the feeding of this fertilized irrigation water to the green walls cause an increased discoloration of the drain water (Figure 4 C). This means that the observed discoloration is mainly coming from the system itself. Especially green wall systems with a thick structure and a large quantity of organic substrate cause a clear discoloration of the drain water. Upon comparison of the apparent color (data not shown) and true color measurement results, it becomes clear that this discoloration largely results from dissolved impurities.

Chemical oxygen demand

In general, green wall systems and fertigation (= inorganic salts) are found to have a limited effect on the COD value of the drain water, except for the ticker systems with a large quantity of organic substrate (Figure 4 D). This might hamper stable storage of the drain water for later reuse.

Plant nutrition: nitrogen, phosphorus and potassium

The systems themselves and discontinuous fertilization do not have a clear influence on the nitrogen content of the drain water (see Figure 4 E). However, addition of fertilizer to the tap water results in an increased nitrogen content of the irrigation water, which in turn results in an increased concentration in the drain water. Since this concentration is lower than that of the corresponding irrigation water at least part of the nitrogen is taken up by the green wall. Anyhow, a considerable amount still flows out, which certainly makes reuse of the drain water from plant nutrition perspective worth considering.

Besides nitrogen, fertilizers also contain a source of phosphorus and potassium. As can be seen from Figure 4 F, the addition of fertilizer logically results in an increase in the phosphorus content of the irrigation water. Unlike with nitrogen, this does not result in a strong increase in the phosphorus content in the drain water. The findings for potassium (not shown) are quite similar to those of nitrogen.

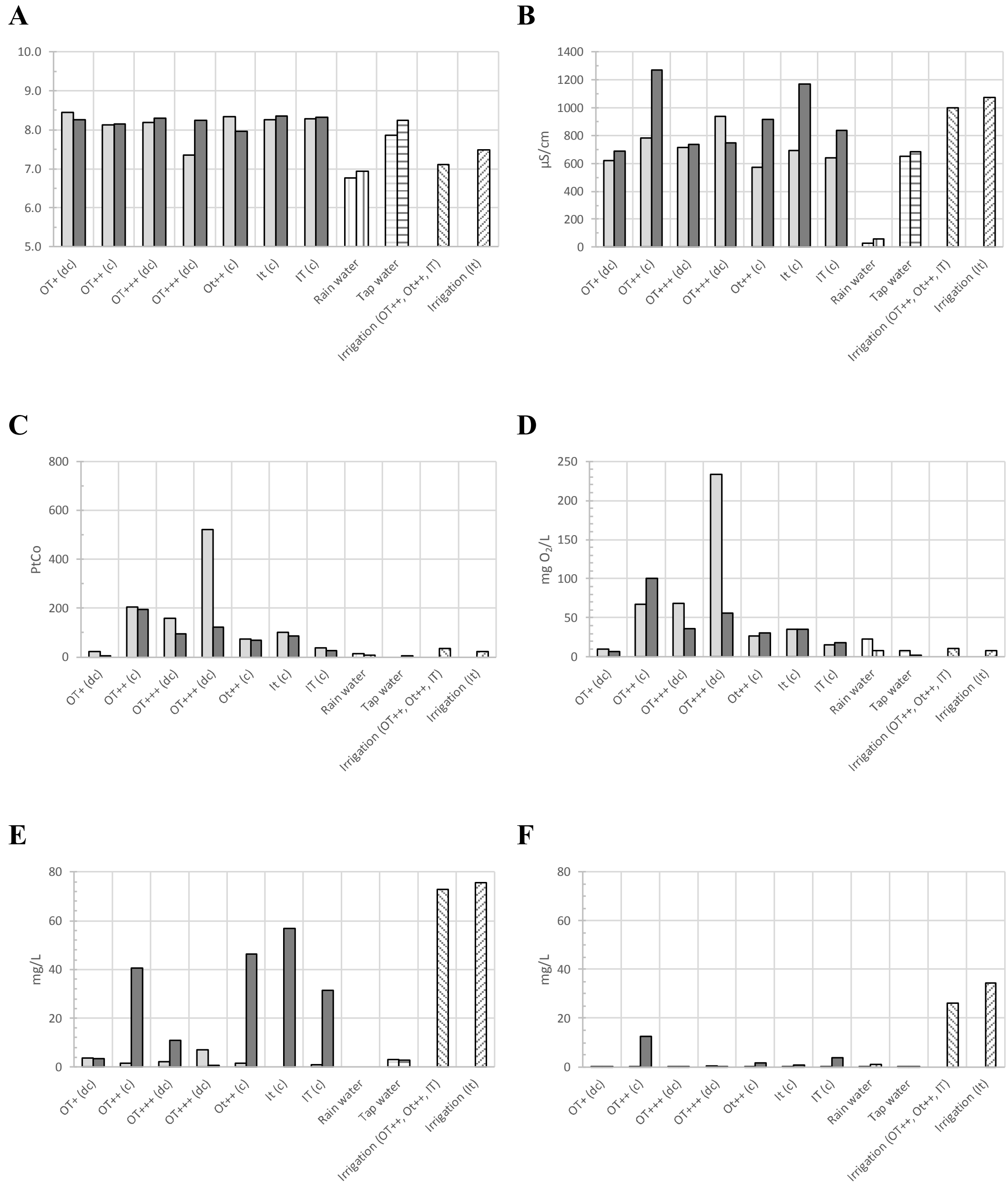

Figure 4 Graphs presenting the results for different analysis parameters including pH (A), Conductivity (B), True color (C), Chemical Oxygen Demand (COD) (D), Nitrogen (E) and Phosphorus (F) in the drain water, reference water samples (rain water and tap water) and the irrigation water (tap water including fertilizer) as supplied to the indicated walls. dc = discontinuous fertilization (compare to tap water), c = continuous fertilization (compare to appropriate irrigation water, shaded bars). Light grey: campaign without fertilization, Dark grey: campaign with fertilization.

3.2 Water consumption and drain water quantity

Regarding the water consumption and the amount of drain, strong differences are observed between the different systems. Some systems need a large water supply (drain + consumption), but also consume most of this supplied water (= have small quantity of drain water). These are typically the thicker systems with a large amount of organic substrate. Other systems are found to consume only a fraction of the water supplied (have relatively high drain water quantity). This includes the systems with an inert substrate or a thin structure with a moderate amount of organic substrate or systems with a small amount of organic substrate.

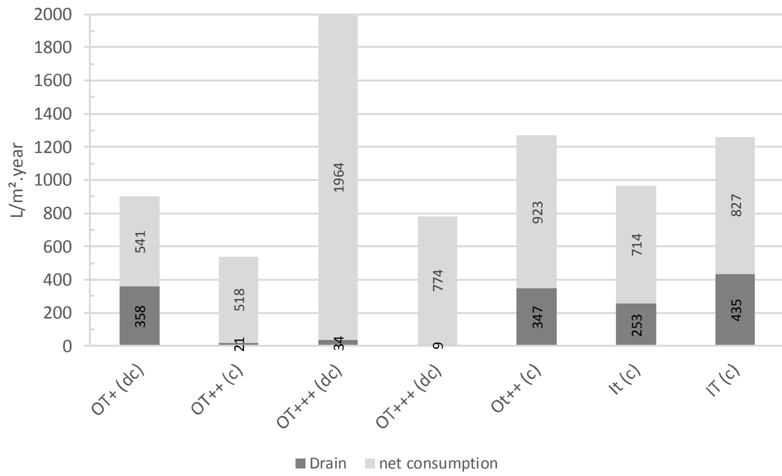

Figure 5 Water supply (drain + consumption), net water consumption (light grey) and drain water quantity (dark grey) in L/m².year

4 Conclusions

Based upon the above results, we can conclude that the systems themselves have an influence on several water quality parameters including pH, color and COD. Except for the influence on pH, this especially holds true for the thicker systems with a large quantity of organic substrate. Discontinuous fertilization has nearly no influence on the quality of the drain water. Continuous fertilization on the other hand, has a strong impact on the conductivity and the nitrogen & potassium content of the drain water. Regarding the amount of drain water and the water consumption a large variety can be observed between the different systems. Some of them have a great potential for optimization/improvement. Further research will have to confirm our observations and give insight in their evolution in time.

5 Presentation of Author(s)

Joris Van Herreweghe is a biochemical engineer and has a PhD in Bioscience Engineering. He is working as project leader for the laboratory of Microbiology and Microparticles of the Belgian Building Research Institute (BBRI).

Karla Dinne is biochemical engineer and head of the laboratory Microbiology and Microparticles 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).

Optimal operation model of rainwater reuse and detention mechanism for building raft foundation

C.L. Cheng. (1), Hsin-Yu Chen. (2), Yau-Cheng Huang(3)
1. CCL@mail.ntust.edu.tw
2. hsinchen14@gmail.com
3. M10413038@mail.ntust.edu.tw
(1) (2) (3) National Taiwan University of Science and Technology, Department of Architecture, Taiwan, R.O.C.

ABSTRACT

This study summarizes and classifies rainwater storage and detention pond merge design system, simulates the rainwater recycling system, calculates the cumulative amount of rainwater in the rainwater storage pool by using the cumulative formula, formulates the building raft foundation simulation operation mode according to the rainwater collecting area and the optimal rainwater storage volume. With regional changes in rainfall, achieves the effective use of the purpose of the detention pond and rainwater reuse, as well as assessing the water saving benefits of the various models for different building types. The optimal operation model, the effectiveness of rainwater replacement can be improved through the increase of rain collection area and storage volume. In addition, it can be effectively used of the rainwater recycling strategies for urban buildings by utilizing the raft foundation to store rainwater and flood detention, to reduce the urban water crisis due to floods and drought.

Keywords: Building raft foundation, rainwater utilization system, urban flood control, drought resistance, detention pool, building water saving design

1. Introduction

The global warming and climate change obviously increase the extreme weather and cause the disaster all over the world. United Nations Framework Convention on Climate Change (UNFCCC) warns that, not only will rainfall become more frequent and intense, the number of extreme rainfall events will increase overall[1][2]. Taiwan is located in the North Pacific subtropical monsoon region. During summer and fall, it is inevitably in the path of typhoons, and therefore each year a number of super typhoons would assault Taiwan. During typhoon season, the tributaries in the mountain regions surrounding the basin frequently flood over due to heavy rainfall, and threaten the urban area.

In order to mitigate the urban flood risk and water resource balance, Taiwan government improve the regulation for building rainwater use system and flood control capacity. The raft foundation is a type of building structure generally used in high-rise or large buildings. In order to maximize the flood control advantage of raft foundation space capacity, this study proposed the Raft Foundation (RF) as a solution of enhance flood control and rainwater use system. Namely, to increase rainwater retention, the rainwater collection area is expanded to water saving issues. This operation will reduce peak runoff in urban street block during storm and increase the capacity of rainwater usage. Due to the conflict of rainwater use and flood control in operation timing, the raining season and dry season should be considered for the operation model to increase the performance of water system in building. This research proposed operation model using the space capacity of idle raft foundation in existing buildings as retention pool and urban flood control facilities to reduce peak runoff during typhoon and typical storm periods and increase the rainwater usage in building.

2. Reviews and Methodology

Using the Raft Foundation of building as a solution of flood control and rainwater usage can mitigate the water shortage in dry season and reduce the flood run-off in typhoon season to increase the security of urban. The raft foundation space and initial function are shown as Figure 1.

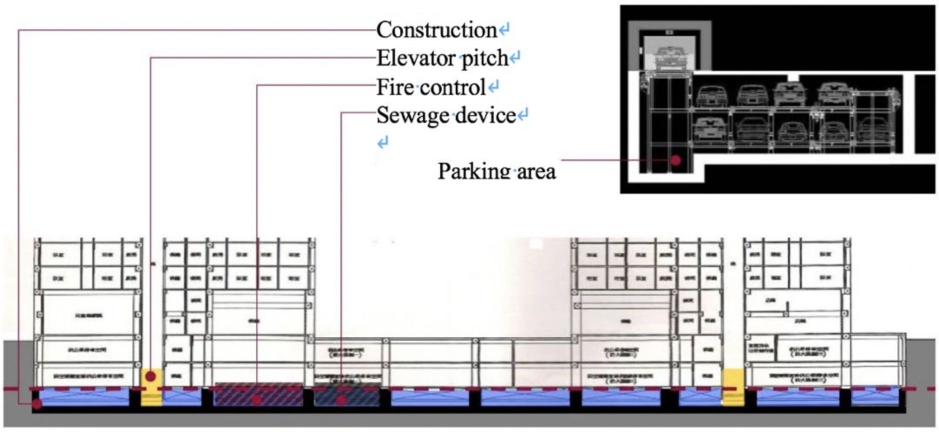

Figure 1- building raft foundation space and initial function

The urban area has high density of construction and impermeable pavement in general. It is necessary to recover the capacity of site water retention to the initial level before construction. The technical devices of water retention include rainwater storage, infiltration and instruction flood-stagnating. Due to the provision of current regulation, the capacity of building flood control is defined as the 0.045 of building site areas. The flood control of urban area should focus on the run-off reduce from building site. The concept of flood control use basement of building is shown as Figure 2.

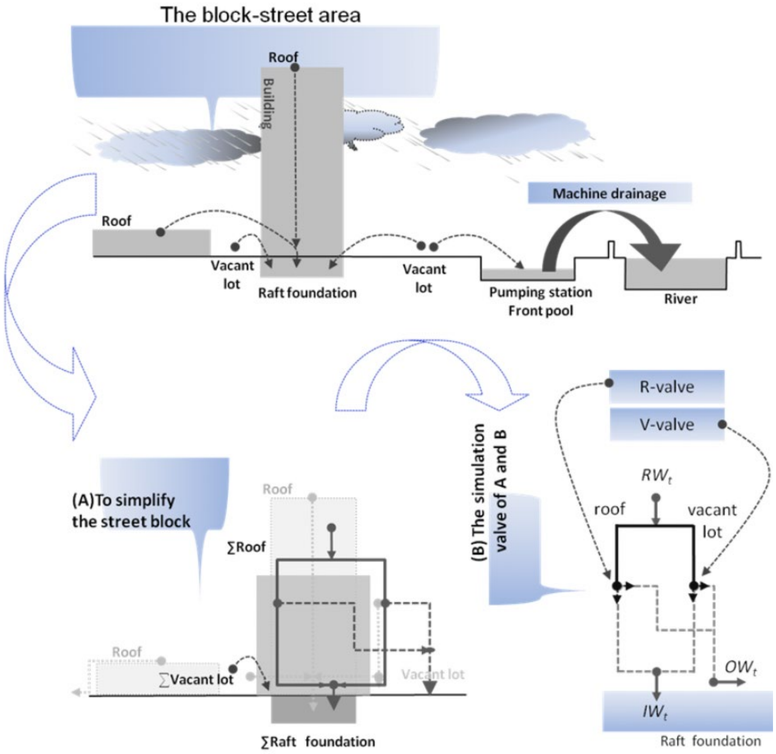

Figure 2- concept of flood control use basement of building

Rainwater storage capacity and the collection area dominate the performance of rainwater harvesting system. The collection area is part of building including roof area, and limited by the building scale and site. Thus, the volume of rainwater infill would directly affect the capacity of rainwater storage. The decision of rainwater infill would adopt the annual precipitation and evaluated by yearly data. The daily volume of infill water is calculated by run off coefficient and daily precipitation and collection area.

$$Q_t = 1/1{,}000 \times C \times I_t \times A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Q_t ： daily infill volume (m^3/day)

C ： run off coefficient

I_t ： daily precipitation (mm/day)

A ： rainwater collection area (m^2)

The capacity of rainwater storage of building is calculated by a continuous equations using the daily infill volume. The continuous equations are as follow：

$Z_{t+1} = Z_t + Q_t - D_t$，$Z_t \geqq 0$，$S \geqq Z_{t+1}$ …………………(2)

Z_{t+1}： volume of time t+1 time (m^3)
Z_t：storage volume of time t (m^3)
Q_t：infill volume of time t (m^3/day)
D_t：usage volume of time t (m^3/day)
S：storage volume (m^3)

The water use baselines for building category are determined by functional area and people numbers. According to the green building guideline for estimating the water usage, there is a reference guideline for all category as floor area. In order to validate the rainwater reuse efficiency, the category of buildings includes office building, commercial building, accommodation building, hospital building, dormitory, housing and others. The volume of total building water usage is calculated as following:

$W_t = W_f \times A_f$ ....(3)

W_t : uilding water usage volume (m^3day)
W_f :water usage for floor area (m^3 /(m^2・day))
A_f :functional floor area(m^2)

This study adopts the green building water resource index as the evaluation guideline for water saving rate. The water saving weighting factor RS8 is the indicator for water saving level. The calculation functions are as following:

$W_{ty} = Af \times WUI$..(4)

WUI：Water usage density baseline (m^3/m^2.year)

$W_{st} = W_{ty} \times (RS8 \div 8) \times S_{rc}$ ....(5)

W_{st} ：the annual water saving volume (m^3/year)
RS8：water saving indicator ($0.0 \leqq RS8 \leqq 8.0$)
S_{rc} ：the best water saving rate for building category

The adoption of building raft foundation in operation model must clarify the rainwater storage volume and the limitation of water usage for the simulation process. The combination of rainwater use system and flood control mechanism can improve the efficiency of water resource. However, the functional confliction of rainwater usage and flood control should be considered in the operation process.

3. Methodology and operational model

The building raft foundation space is initially existing for high-rise building and partial spaces are used for building functions such as parking, equipment, elevator pitch, fire control, sewage and etc.. The estimation of building raft foundation for rainwater can be defined as the remainder space except the all functional space. Figure 3 shows the frame work of raft foundation space for rainwater storage volume. The estimation equations are as following:

$$V_v = S_a \times R_c \times h_f \quad \text{………………………………}(6)$$

$$V_{fw} = S_a \times R_c \times h_f \times R_{rs} \quad \text{………………………………}(7)$$

$$R_{rs} = 1 - (h_f \times (A_e + A_p) + Q_s) \div V_v \quad \text{…………………………}(8)$$

$$Q_{ri} = q_{ri} \times f_{ra} \quad \text{………………………………}(9)$$

f_a: Floor area (m^2)
f_{ra}: rainwater collection area (m^2)
Q_{ri}: daily rainwater collection volume (m^3)
q_{ri}: daily precipitation (mm)
S_a: site area (m^2)
R_c: building basement area rate (%)
V_v: raft foundation volume (m^3)
V_{fw}: raft foundation water storage volume (m^3)
R_{rs}: Raft foundation rainwater usage rate (%)
h_f: raft foundation height (1.5 m)
A_e: raft foundation space for elevator pitch (m^2)
A_p: raft foundation space for parking area (m^2)
Q_s: raft foundation for sewage space (m^3)

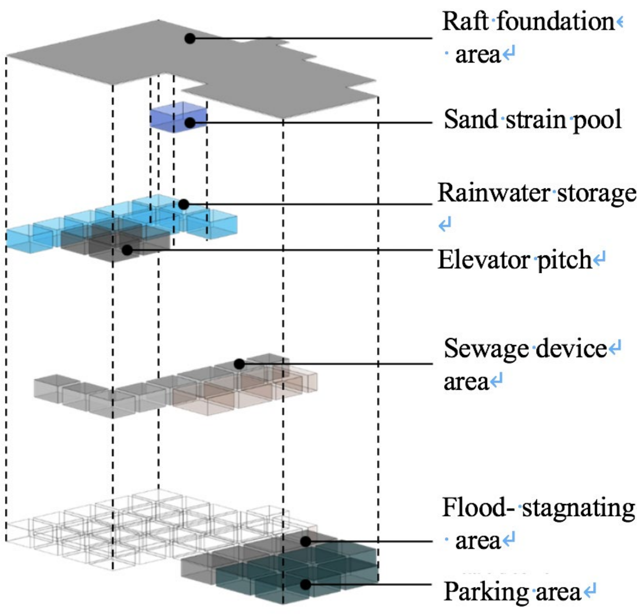

Figure 3- the frame work of raft foundation space for rainwater storage volume

According Taiwan building code, the necessary retain capacity for building floor control function depend on the building total area with the factor of 0.045. The minimum volume is as the following equation:

$$V_{fv} = A_1 \times 0.045\ (m^3/m^2) \ldots\ldots(10)$$

$$V_{fv} = A_2 \div S\ (\%) \times 0.045\ (m^3/m^2) \ldots\ldots(11)$$

V_{fv}: floor control minimum retain volume for building (m^3)

A_1: total building area for new construction (m^2)
A_2: renovation area (m^2)
S: regulation building cover rate on site (%)
The operation model based on the conditions of collection area and precipitation. In order to collect the optimized rainwater for building usage, the collection area include the rooftop, building wall and site. The simulation and evaluation set the storage volume as the object to process the infill rainwater, daily usage water, replenish water and overflow volume. The accumulation functions are set up as a loop calculation for the annual precipitation input. The functions of loop calculation are as following:

$$V_{fn} = V_{f\,n-1} + Q_{rin} - O_{wn} - Q_{rd} \ldots\ldots(12)$$

V_{fn} ：The storage volume of operation number n (m^3)
Q_{rin} ：The infill volume of operation n (m^3)
O_{wn} ：The over flow volume of operation number n (m^3)
Q_{rd} ：The replace water volume of raft foundation in operation number n (m^3)
The accumulation function has a condition for the combination operation of rainwater use system and flood control mechanism. The precipitation data adopted the Taiwan Central Bureau records in northern Taiwan.
Through the simulation and evaluation process, the optimal operation model would be defined by the minimum over flow volume of operation and maximum replace water volume of raft foundation in operation period. The conception of operation depend on the balance of 4 parameters included rainwater collection, water usage volume, overflow volume and replenish water. The simulation process is a loop calculation by Excel software and determine the optimal solution for the options of operation conditions.

4.Optimal operation model and validation

4.1 comparison of operation model

The operation models are assumed as the combination options of rainwater use and flood control. Two models are concluded as the optimal operation comparison. The one is the separated model for the rainwater use and flood control volume with independent space in raft foundation. The rainwater collection would be from rooftop and in site area to increase the maximum collect volume. The separated model of operation is shown as Figure 4.

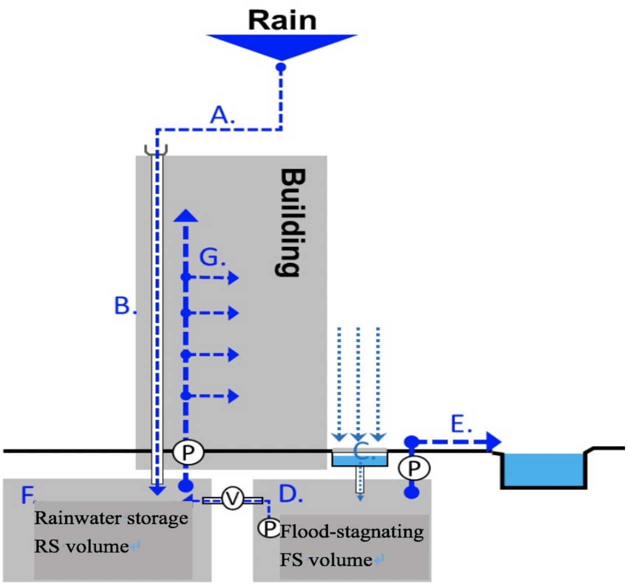

Figure 4- Separated model of operation

The combination model is assumed as the rainwater use and flood control space could be integrated as whole with operation proceeding to increase the optimal effects for both functions. The rainwater collection would be from rooftop, wall and in site area to increase the maximum collect volume. The separated model is shown as Figure 5.

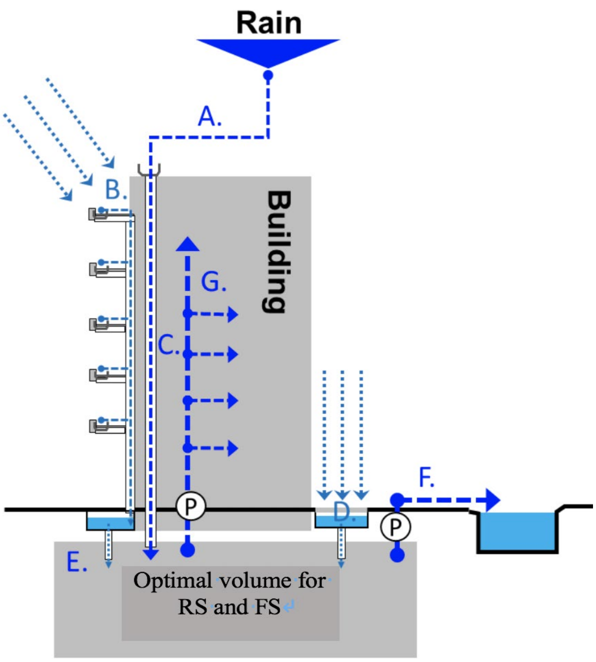

Figure 5- Combination model of operation

The operation model would follow the dry season from November to April and rainy season from May to October. The flood control space should be emptied in rainy season before the storm and rainwater use space should be full for reused system as possible. The both volumes should collect the maximum rainwater and minimum overflow in the dry season. The combination model would keep the both function work together in one volume for the operation.

4.2 Case study

In the roof collection mode, 5% alternative water / Rainfall of the day / Roof collection and 30% alternative water / Rainfall of the day / Roof collection are needed large amount of replenishment water in rainwater and detention storage and raft foundation water storage space, so the operation mode is adjusted, 10%, 15%, 20%, 25% of alternative water percent are added to the mode for roof and base collection rainwater, and the base area and the runoff water of the day are also added to be comprised.

The result of the comparison is in operation mode for roof and base collection rainwater, 15% alternative water / Rainfall and runoff of the day / Roof and base collection is the mode of minimum overflow/replenishment in raft foundation water storage space. So that after adjusting the alternative water percent and increasing the collection area, the best mechanism and mode of operation can be obtained in this case. The comparison for 15% alternative water / Rainfall and runoff of the day / Roof and base collection is shown in Figure 6.

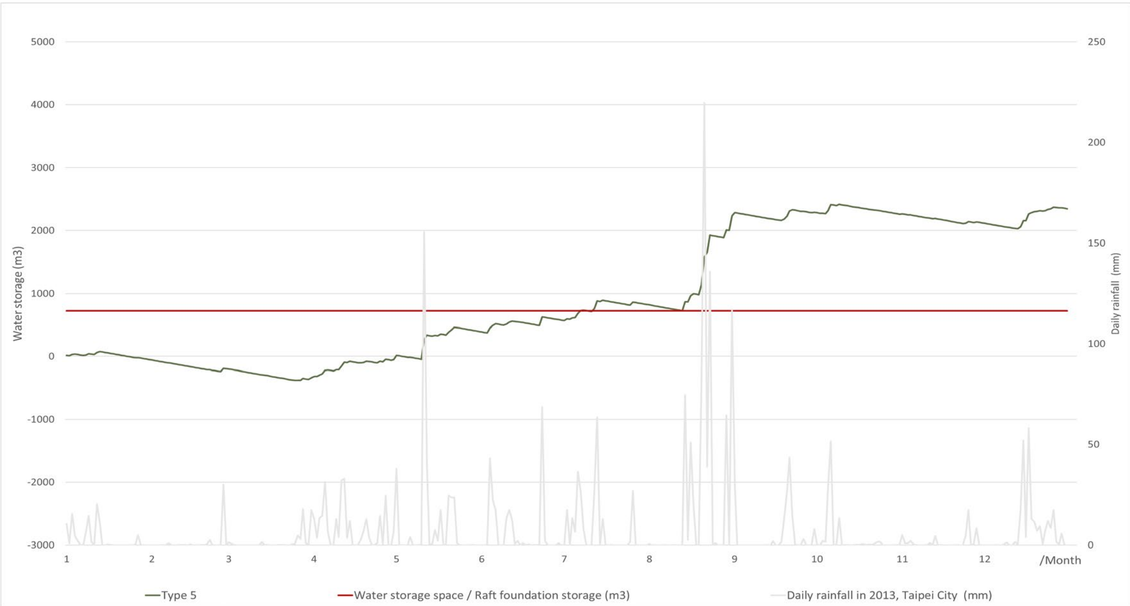

Figure 6- The raft foundation water intake for 15% alternative water / Rainfall and runoff of the day / Roof and base collection

4.3 Building Category Validation

The simulation results of separated model as practical cases study included 114 cases in northern Taiwan areas. The efficiency rates are category residential building of 64.5%, dormitory of 74.3%, commercial building of 31.1% and public buildings of 66.0%. The dormitory is the highest and commercial building is the lowest efficiency rate as shown as

Table1 and Figure 7.

Table 1 Building category and rainwater use efficiency rate by separated model

simulation results of separated model							
Building category		Collection area(m^2)	Floor area (m^2)	Rainwater storage volume (m^3)	Water use volume (day.m^3)	Replace water efficiency (%)	Average efficiency (%)
Residential building	Taipei city	49464.3	412356.7	10616.1	352.5	70.8%	64.6%
	New Taipei city	87705.6	581141.1	31183.6	1110.4	79.0%	
	Tauyuan city	46233.6	353289.0	4866.0	440.1	66.3%	
	Hsinchu city	13300.4	142742.2	782.1	125.7	42.4%	
Dormitory	Taipei city	22236.9	87905.2	5814.9	151.7	69.5%	74.3%
	New Taipei city	1887.5	5695.3	937.7	9.8	79.0%	
Commercial building	Taipei city	20051.2	68434.1	1470.5	261.3	35.3%	31.1%
	New Taipei city	2476.4	7703.2	208.2	29.4	47.1%	
	Hsinchu city	25724.1	214033.6	1975.0	817.4	11.0%	
Public building	Taipei city	67709.5	268469.9	33825.3	321.1	79.5%	66.0%
	New Taipei city	117124.5	124854.3	83376.7	213.1	100.0%	
	Tauyuan city	80350.6	88035.8	67832.6	156.9	52.3%	
	Hsinchu city	4038.0	50191.8	226.5	44.8	32.1%	

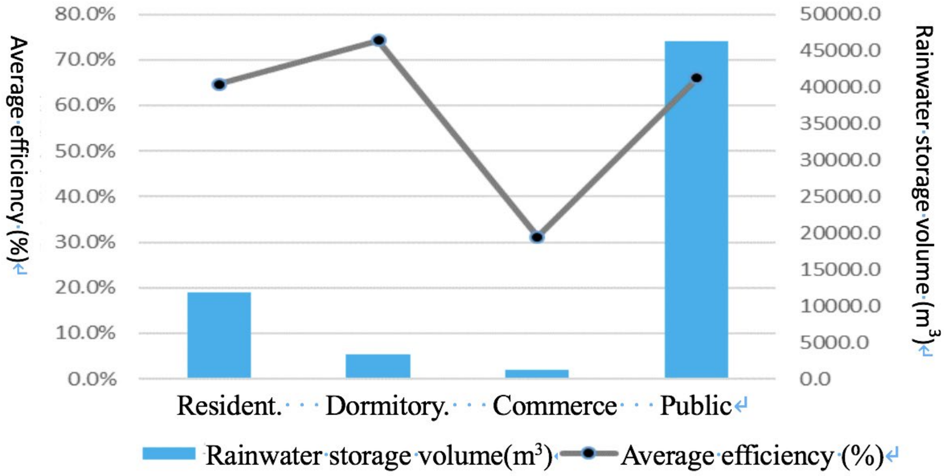

Figure 1 Rainwater storage and average efficiency for separated model

The simulation results of combination model as practical cases study with the same practical cases. The efficiency rates are category residential building of 95.0%, dormitory of 93.8%, commercial building of 48.8% and public buildings of 75.3%. The dormitory is the highest and commercial building is the lowest efficiency rate as well. The results are shown as Table 2 and Figure 8.

Table 2 Building category and rainwater use efficiency rate

simulation results of combination model							
Building category		Collection area (m^2)	Floor area (m^2)	Rainwater storage volume (m^3)	Water use volume (day.m^3)	Replace water efficiency (%)	Average efficency (%)
Residential building	Taipei city	78080.9	412356.7	35808.5	352.5	97.8%	95.0%
	New Taipei city	129155.6	581141.1	67719.5	1110.4	99.1%	
	Tauyuan city	62333.4	353289.0	34865.7	440.1	98.0%	
	Hsinchu city	20936.0	142742.2	8500.1	125.7	85.3%	
Dormitory	Taipei city	27884.6	87905.2	19949.1	151.7	87.7%	93.8%
	New Taipei city	2555.8	5695.3	1740.2	9.8	100.0%	
Commercial building	Taipei city	26258.4	68434.1	21761.6	261.3	57.9%	48.8%
	New Taipei city	3142.1	7703.2	2705.6	29.4	70.5%	
	Hsinchu city	35160.1	214033.6	23707.9	817.4	17.8%	
Public building	Taipei city	75851.9	268469.9	53830.5	321.1	93.5%	75.3%
	New Taipei city	123974.5	124854.3	87199.7	213.1	100.0%	
	Tauyuan city	84060.9	88035.8	78454.2	156.9	52.3%	
	Hsinchu city	5746.7	50191.8	2916.5	44.8	55.3%	

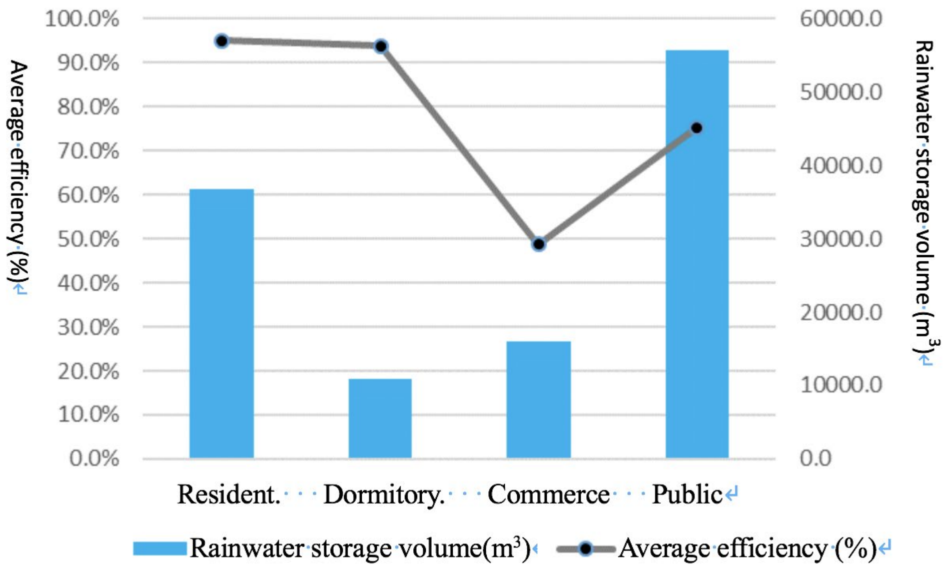

Figure 2 Rainwater storage and average efficiency for combination model

As the result, the combination model shows the average efficiency of rainwater use increases around 20% compare to the separated model. The optimal model is the combination operation with the seasonal operation for the rainwater collection and storage.

Thus, the efficiency and process are validated and confirmed. The optimal operation model applied to the building with raft foundation and proved the efficiency with well level for rainwater use system in building.

5. Conclusion

This study summarizes and classifies rainwater storage and detention pond merge design system, simulates the rainwater recycling system. The cumulative amount of rainwater in the rainwater storage pool is calculated by using the cumulative formula, formulates the building raft foundation simulation operation mode according to the rainwater collecting area and the optimal rainwater storage volume. With regional changes in rainfall, achieves the effective use of the purpose of the detention pond and rainwater reuse, as well as assessing the water saving benefits of the various models for different building types. This research concludes the results of the optimal operation model, the efficiency of rainwater replacement can be improved through the increase of rain collection area and storage volume. In addition, it can be effectively used of the rainwater recycling strategies for urban buildings by utilizing the raft foundation to store rainwater and flood detention, to reduce the urban water issues due to flood and drought.

Acknowledgements

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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.

Hsin-Yu Chen is the Master student at National Taiwan University of Science and Technology, Department of Architecture. His research focuses on water resources and Green Building.

Yau-Cheng Huang is the Master student at National Taiwan University of Science and Technology, Department of Architecture. His research focuses on water resources and Green Building..

Study of unit of design water supply amount and potential evaluation of rainwater utilization in middle-scale office building

A. Akasaka (1), T. Nishikawa (2)
1. dm18002@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

In recent years, in Japan, water consumption in office buildings has been decreasing owing to the popularization of water-saving devices. The unit of design water supply amount used to conclusively determine water supply capacity is different from water consumption in actual buildings. In a reference book[1)], the unit of design water supply amount of an office is 60–100L/(person・day) in this country. In addition, when water-saving devices are used, unit of design water supply amount is 40–60L/(person・day),which have been newly established.

In this report, we measured water consumption in middle-scale office building (hereinafter, referred to as study building) and evaluated the water consumption characteristics. Further, we studied the trend of the unit of water supply amount using actual measurements obtained from the study building against the literature data of reference book[1)]. In the study building, there are a few people per unit area and their staying time is short; thus, the unit of design water supply amount is generally less than the literature data. Moreover, we assumed that the study building utilized rainwater, calculated alternative ratio of potable water and rainwater utilization ratio, and predicted the optimal capacity of rainwater receiving tank by simulating rainwater utilization.

Keywords

Unit of design water supply amount; Rainwater utilization; Actual measurement; Middle-scale office building

1 Introduction

In recent years, in Japan, water consumption in office buildings has been decreasing owing to the popularization of water-saving devices. The unit of design water supply amount used to conclusively determine water supply capacity is different from water consumption in actual buildings. In a reference book[1)], the unit of design water supply amount of an office is 60–100L/(person・day) in this country. In addition, when water-saving devices are used, unit of design water supply amount is 40–60L/(person・day),which have been newly established. In this report, we measured water consumption in study building and evaluated the water consumption characteristics. Further, we studied the trend of the unit of water supply amount using actual measurements obtained from the study building against the literature data of reference book[1)]. Moreover, we assumed that the study building utilized rainwater, and predicted the optimal capacity of rainwater receiving tank.

2 Building, equipment and, measurement outlines of the study building

Table 1 lists details of the building and water equipment along with the measurement of the study building; figure 1 shows the schematic of the water supply system; and table 2 lists the number of plumbing fixtures. The study building has three floors aboveground. The study building is a middle-scale office building with a total floor area of approximately 3,700 m^2; it has an average of 60 working people. The water system provides water for toilet flushing in restrooms and sink in restrooms and hot water supply rooms. The water supply system is a direct supply system, and drainage is discharged to the public sewerage system. The received rainwater is discharged directly to the public sewerage system. We measured instantaneous water consumption using an ultrasonic flowmeter at the main pipe immediately after drawing water to the study building.

Table1-Building, water equipment, and measurement outlines

Number of stories	Three floors aboveground
Total floor area	Approximately 3,700m^2 (Excluding parking area)
Number of working people	Approximately 60 people
Water use	Toilet flushing and sink
Water supply system	Direct supply system
Drainage system	Sewerage of separate system Sanitary drain, wastewater and rainwater is discharged to the public sewage system
Measurement period	January 1 – July 17, 2018
Time interval	1 second

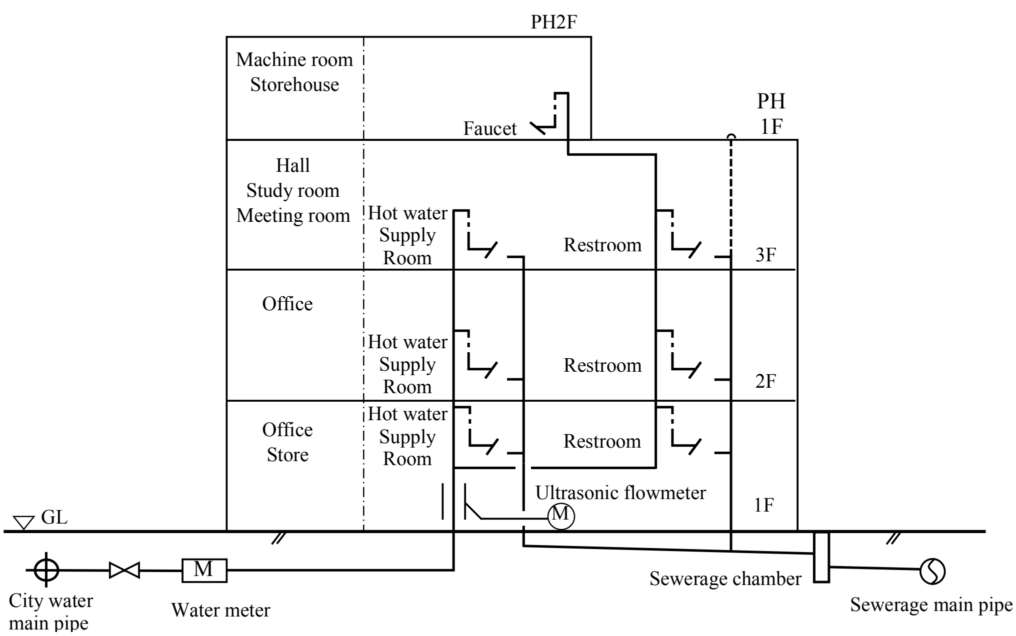


Figure1-Schematic of the water supply system

Table2-The number of plumbing fixtures

Fixture list	Restroom							Hot water supply room			Total
	1F		2F			3F		1F	2F	3F	
	gents	ladies	gents	ladies	accessible	gents	ladies				
WC(Western style)	1	2	1	2		2	2				10
WC(Japanese style)	1	1	1	1		1	2				7
WC(accessible)					1						1
Urinal	4		5			4					13
sink	3	3	2	3	1	2	3	2	4	2	25

Table header spanning all columns: Number of plumbing fixture

3 Water consumption characteristics and unit of design water supply amount

3.1 Water consumption characteristics of the study building

Figure 2 shows the daily water consumption measured using an ultrasonic flowmeter in the study building. In the evaluation period, the water consumption is consistent each month; it varies periodically every week. Hall and study room, and meeting room are used irregularly; therefore, we read hall and study room, and meeting room use situation by management records, and we distinguished the evaluation day between with and without those use (hereinafter referred as hall use and none). Moreover, the evaluation data is obtained on weekdays and holidays, separately and categorized accordingly.

Therefore, the medium value of daily water consumption data is calculated when arranging them in descending order. On weekdays, hall use is 2,149L/day; None is 992L/day. Further, on holidays, hall use is 2,125L/day; None is 393L/day.

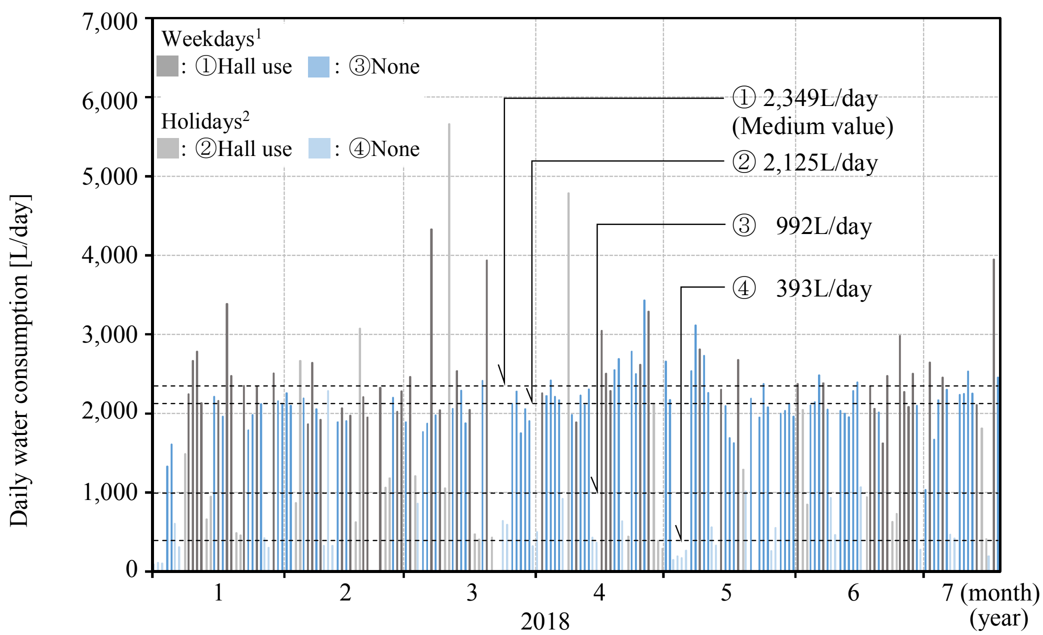


Figure2-The daily water consumption in the evaluation period

[1]Data on weekdays: From Monday to Friday except public holiday and January 1 to 3, February 21, 22, March 22,23 and May 22.
[2]Data on holidays: Days except weekdays

3.2 Unit of design water supply amount of the study building

To compare daily water consumption by the difference in building use situation, Figure 3 classified the measurement data hall use/none, weekdays/holidays, and summarized by maximum, medium, and minimum values.

On weekdays, None maximum, medium, and, minimum values are 3,434 L/day, 2,125 L/day, and 1,331 L/day; Hall use maximum, medium, and minimum values are 4,328 L/day, 2,349 L/day, and 1,627 L/day, respectively.

On holidays, None maximum, medium, and minimum values are 1,295 L/day, 393 L/day, and 95 L/day; Hall use maximum, medium, and minimum values are 5,667 L/day, 992 L/day, and 394 L/day, respectively.

On weekday, None was deemed to be appropriate to analyze water consumption characteristics of an office with few unspecified working people. We then considered the upper and lower limits of 10% to be singular values, excluded those, and calculated the unit of design water supply amount in the range of 1,840–2,536 L/day.

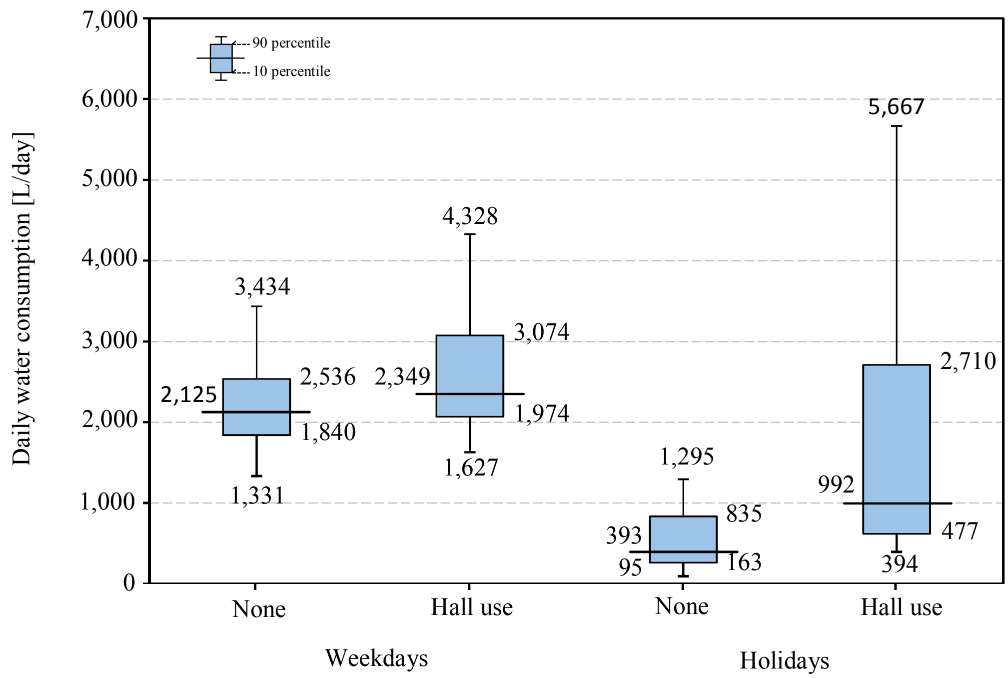


Figure3-Daily consumption by the difference in building use situation

The average of working people on weekdays (None) was set to 60 person/day, and the unit of design water supply amount was calculated.

The unit of design water supply amount by actual measurement was compared with the literature values[1)] shown in Figure 4.

Maximum, medium, and minimum values of the unit of design water supply amount by actual measurement are 42.3 L/(person・day)・35.4 L/(person・day)・30.7 L/(person・day), respectively.

In the study building, there are a few people per unit area and their staying time is short; thus, the unit of design water supply amount is generally less than 40–60 L(person・day) (unit water supply of government office/office(water-saving devices use)[1)]) and 60–100 L/(person・day) (unit water supply of government office/office[1)]).

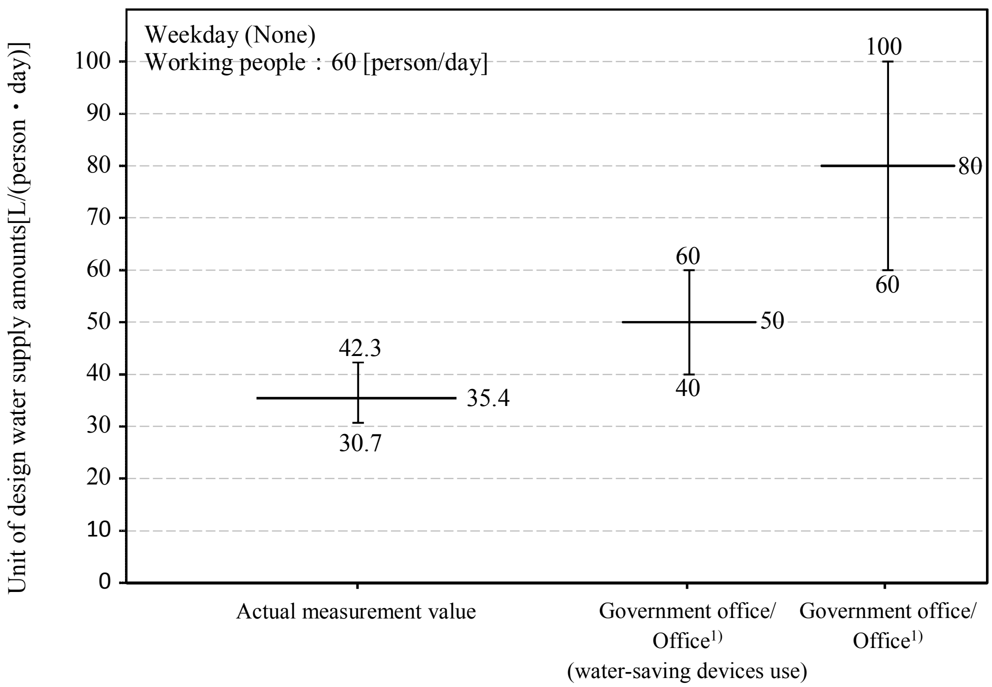


Figure4-Comparison of unit of design water supply amount

4 Potential evaluation of rainwater utilization

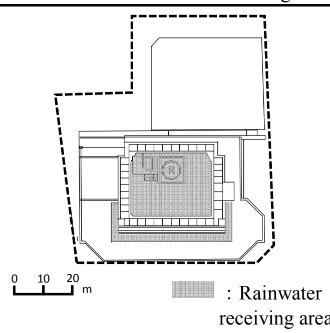
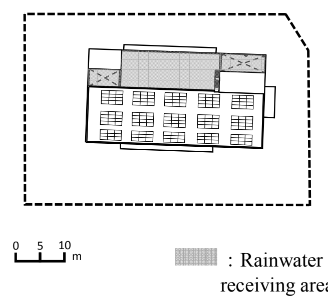
4.1 Simulation conditions

To evaluate the effectiveness of rainwater utilization in a study building, we conduct a simulation with reference to the previous research[2)], and we evaluated and compared building and office complex building (hereinafter referred to as rainwater utilization building) that was analyzed in the previous research[2)]. The rainwater utilization building has a receiving tank with a capacity of 300 m^3.

Table 3 summarizes the simulation results of the buildings compared. The building scale and number of people per unit area in both buildings to be compared were significantly different. Thus, when simulating the rainwater utilization of the study building, the capacity of the receiving tank was set to be relatively equal to the building by comparing the site area and total floor area of the rainwater utilization building.

When setting the capacity of the rainwater receiving tank, 10–150 m^3 was calculated every 5 m^3 based on the ratio of the site area and total floor area of the utilization building and study building. In addition, PH1F (358 m^2) of the study building is set as the rainwater receiving area.

Table3-Buildings compared in simulation

	Rainwater utilization building	Study building
Layout drawing		
Rainwater utilization	Yes (Use for toilet flushing and garden)	No
Location(Precipitation condition)	Niigata Prefecture, Niigata City	Iwate Prefecture, Miyako City
Site area	Approximately 6,100[m^2]	Approximately 3,000[m^2]
Building area (Rainwater receiving area)	Approximately 4,500 (Approximately 2,000)[m^2]	Approximately 1,200 (Approximately 360)[m^2]
Total floor area	Approximately 36,000[m^2]	Approximately 3,700[m^2]
Daily average precipitation density[3]	4.9[L/(m^2・day)]	3.4[L/(m^2・day)]
Daily average water consumption density (Non-potable water use)[4]	13.6[L/(m^2・day)]	3.4[L/(m^2・day)]
Capacity of rainwater receiving tank	300[m^3](Existing)	10─150[m^3](simulation conditions)

[3]Daily average precipitation density : a_d[L/(m^2・day)] is the value of daily average precipitation : a_{day}[mm/(m^2・day] divided by rainwater runoff coefficient (0.9). In addition, precipitation data for 1 year, which is equivalent to the climatic normal value, was used for both buildings. Climatic normal value is the average annual precipitation from 1981 to 2010 measured by Japan Meteorological Agency.

$$a_d = a_{day} \times 0.9$$

	Data	Measurement point	Evaluation period	The year and (climatic normal)
Precipitation	Rainwater utilization building	Meteorological Agency(Niigata)	2014/4/1-2015/3/31	1984(1821)[mm/年]
	Study building	Meteorological Agency(Miyako)	2018/1/1-2018/12/31	1361(1328)[mm/年]

[4]Daily water consumption density : Q_d[L/(m^2・日)] is the value of daily average non-potable water consumption : Q_{day} [L/日] divided by rainwater receiving area : S[m^2].

$$Q_d = Q_{day} / S$$

Figure 5 shows the rainwater utilization system of study building used for the simulation.
We assumed that the potable water system provides water to hot water supply rooms, the rainwater receiving tank, and faucets in restroom by direct supply system, and the drainage is discharged to the public sewerage system (without drainage reuse equipment). In addition, rainwater is received in roof drain on PH1F and its initial rainwater is eliminated by the initial rainwater exclusion system. Subsequently, it flows into the rainwater receiving tank in the underground pit and is used for flushing toilet. Potable water is supplied to the rainwater receiving tank when there is insufficient rainwater.
In such a system, a simulation is conducted using a rainwater receiving tank capacity of 10–150 m^3 as a parameter.

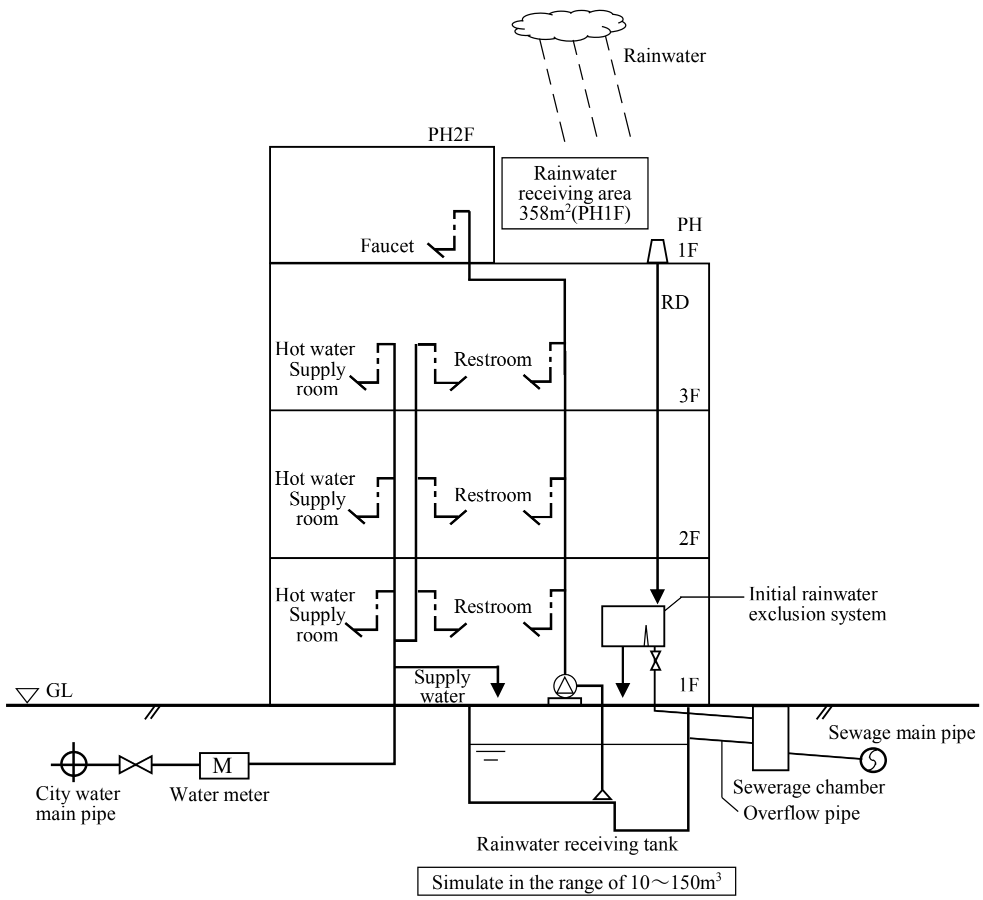


Figure5-The rainwater utilization system of study building used for simulation

Table 4 summarizes the simulation conditions. We set the rainwater receiving area to 358m^2, and the rainwater receiving tank was assumed to be full at the start of the simulation; the capacity of the rainwater receiving tank is calculated every 5 m^3 in the range of 10–150 m^3. Further, to prevent dry running of a rainwater receiving tank, we set the water supply start condition such that potable water is supplied to the rainwater receiving tank when the amount of water in it is less than 2 m^3; the supply is stopped when the amount of water exceeds 5 m^3. Thus, the potable water system provides water to the rainwater receiving tank when the water amount in the rainwater receiving tank is less than 2 m^3.

We calculated the alternative ratio of potable water and rainwater utilization ratio using the precipitation and non-potable water consumption as input data (actual values).

Table4- Simulation conditions

Input condition	Rainwater receiving	
	Rainwater receiving area	358[m^2]
	Water amount at the start of the simulation	Full of water (Same amounts as rainwater receiving tank capacity)
	Capacity of rainwater receiving tank	10~150[m^3](Calculated every 5m^3)
	Water amounts to start water supply	2[m^3]
	Water amounts to stop water supply	5[m^3]

Data		symbol	Measurement point	Time interval	Evaluation period
Input data (Actual values)	Precipitation	*a*	Japan Meteorological Agency (Miyako city)	1 hour	2018/1/1～2018/12/31
	Non-potable water consumption	*Q*	Main pipe in study building		
Output data (Predicted values)	Amount of received rainwater	*R*	—		
	Water amount in Rainwater receiving tank	*V*	—		
	Amount of rainwater utilization	*B*	—		
	Amount of potable water utilization	*CW*	—		
	Alternative ratio of potable water	U_1	—	1 data per tank capacity	
	Rainwater utilization ratio	U_2	—		

Alternative ratio of potable water: U_1 and rainwater utilization ratio: U_2 is calculated by some equations.

$$U_1 = B \div Q \times 100$$
$$U_2 = B \div R \times 100$$
$$R = a \times 358\ (A) \div 1000 \times 0.9\ (C)$$
$$B = Q\ \ (V > Q)$$
$$B = V\ \ (V < Q)$$
$$CW = Q - B$$

The amount of received rainwater: R [m^3/h] is a value obtained by integrated precipitation: a [mm/h], rainwater receiving area: A (358) [m^2] and rainwater runoff coefficient: C (0.9) [-]. If the daily precipitation is ≥4mm/day, the amount of received rainwater: R[m^3/h] is subtracted from 0.5mm as initial rainwater. If the daily precipitation is <4mm/day, the amount of received rainwater: R [m^3/h] is zero.

Further, non-potable water consumption: Q [m^3/h] is supplied by rainwater (rainwater utilization amount: B [m^3/h]) or potable water (potable water utilization amount: CW [m^3/h]) in the following order.

Therefore, the potable water is supplied when amount of rainwater utilization: B [m^3/h] is less than non-potable water consumption: Q [m^3/h].

Moreover, to understand the precipitation characteristics used for the simulation, Figure 6 shows the annual precipitation in 2018 in Miyako city where the study building is located. The annual precipitation in 2018 is 1,361mm/year, which is equivalent to the climatic normal value of 1,328.3 mm/year; thus, we used this value for the simulation.

In the simulation, all daily precipitation in days less than 4mm/year and initial rainwater 0.5mm of precipitation in days more than 4mm/year is excluded as initial rainwater. The daily precipitation measured by Japan Meteorological Agency and excluded daily initial rainwater on this figure. The received rainwater ratio, which is the ratio of received rainwater to precipitation, is 91.6%.

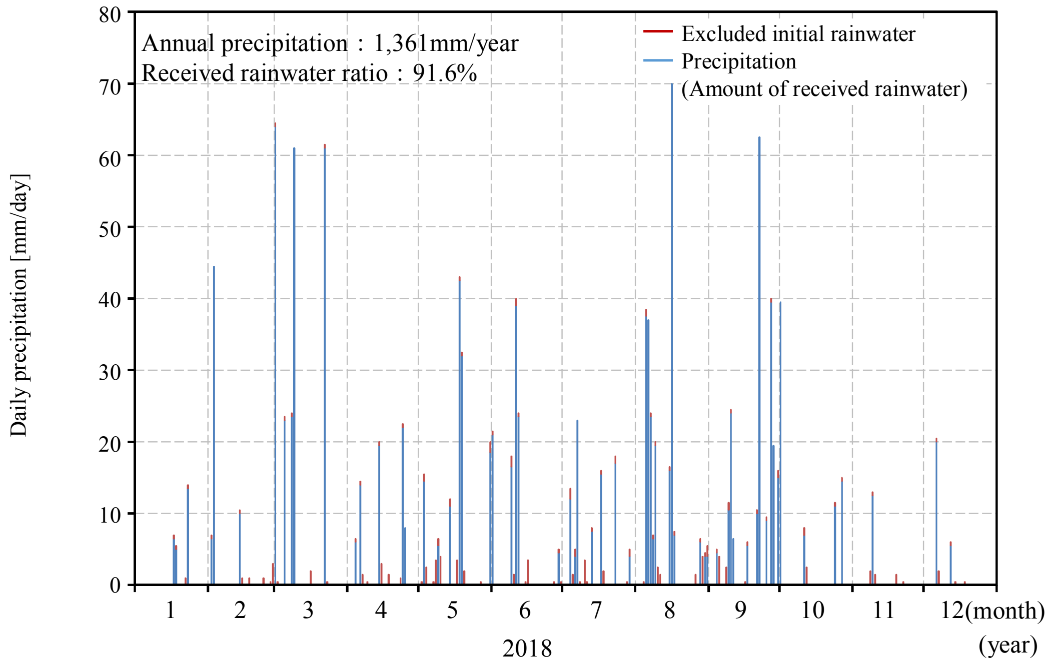


Figure6-Daily precipitation in 2018 in Miyako city

[5]Climatic normal value(1,328.3mm/year) is the average annual precipitation from 1981 to 2010 measured by Japan Meteorological Agency.

4.2 Transition of alternative ratio of potable water and rainwater utilization ratio to change of rainwater receiving tank capacity

To evaluate the effectiveness of utilization in the study building, Figure 7 shows the transition of alternative ratio of potable water and rainwater utilization ratio to change of rainwater receiving tank capacity.

In this figure, to relatively evaluate effectiveness of utilization in the study building, in addition to alternative ratio of potable water and rainwater utilization ratio, daily average precipitation density and daily average water consumption density are shown.

Because of the simulation in the study building, the capacity to use rainwater for all non-potable water consumption is 95 m^3, which is 100% alternative ratio of potable water and 86 % rainwater utilization ratio. Similar to that of a rainwater utilization building, the capacity of rainwater receiving tank that use rainwater for all non-potable water consumption is 300 m^3, which is 36% the alternative ratio of potable water and 100 % rainwater utilization ratio.

From these results, the daily average precipitation density on rainwater utilization building is1.4 times higher than that of the study building. It is confirmed that the rainwater utilization building is a high-rise building; thus, its daily average precipitation density is four times higher than that in the study building.

In addition, the value of daily average precipitation density / daily average precipitation density in the study building (1.0) is higher than that in rainwater utilization building (0.36), and its value is equivalent to alternative ratio of potable water.

It corresponds to 80 m^3 in the study building compared with the building area of both buildings. However, daily average precipitation density of the study building is low and rainwater receiving area / building area on the study building is smaller than that on rainwater utilization building; in other words, the rainwater receiving area of the study building is smaller than relative building area. From this perspective, at 80 m^3, rainwater cannot be used for all non-potable water consumption. Further, considering recent changes in precipitation characteristics, a capacity of 95 m^3 can be deemed to be appropriate for the study building.

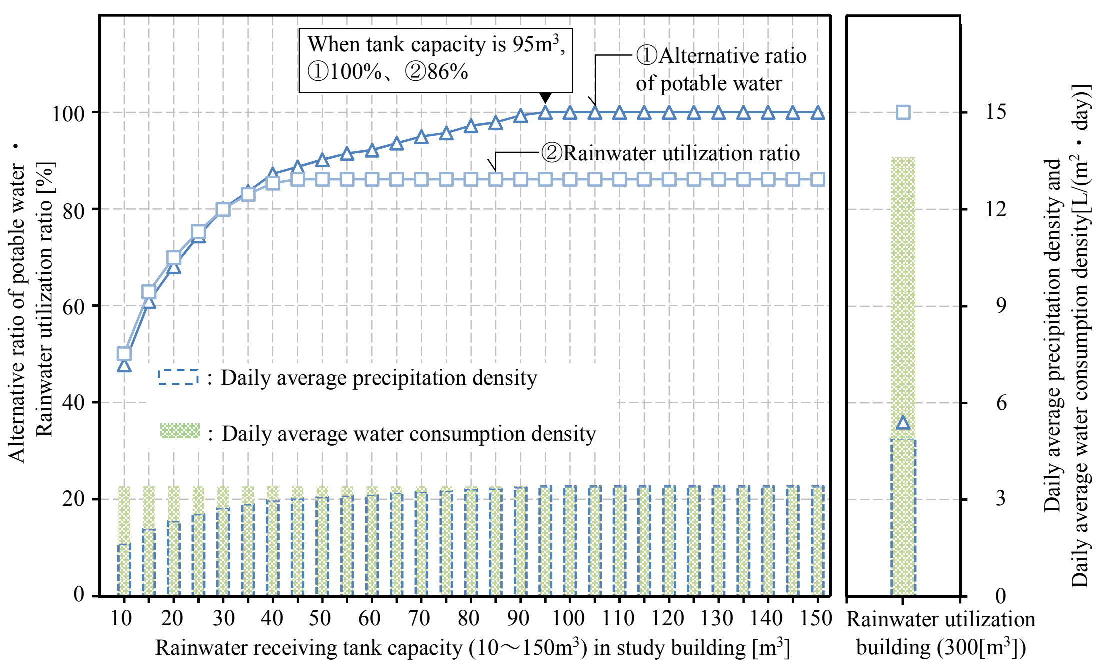


Figure7-The transition of alternative ratio of potable water and rainwater utilization ratio to change of rainwater receiving tank capacity

5 Conclusion

In recent years, in Japan, water consumption in office buildings has been decreasing owing to the popularization of water-saving devices. Thus, in this report, we measured water consumption in study building and evaluated the water consumption characteristics. Further, we studied the trend of the unit of water supply amount using actual measurements obtained from the study building against the literature data of reference book[1)].Moreover, we assumed that the study building utilized rainwater, calculated alternative ratio of potable water and rainwater utilization ratio, and predicted the optimal rainwater receiving tank capacity by simulating rainwater utilization.

In the study building, there are a few people per unit area and their staying time is short; thus, the unit of design water supply amount is generally less than 40–60 L(person・day) (unit water supply of government office/office(water-saving devices use)[1)]) and 60–100 L/(person・day) (unit water supply of government office/office[1)]).

It corresponds to 80 m^3 in the study building compared with the building area of both buildings. However, daily average precipitation density of the study building is low and rainwater receiving area / building area on the study building is smaller than that on rainwater utilization building; in other words, the rainwater receiving area of the study building is smaller than relative building area. From this perspective, at 80 m^3, rainwater cannot be used for all non-potable water consumption. Further, considering recent changes in precipitation characteristics, a capacity of 95 m^3 can be deemed to be appropriate for the study building.

6 Acknowledgment

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8 Presentation of Authors

Atsuya Akasaka is a graduate student of the Nishikawa laboratory, Kogakuin 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 current study on water environment in architecture.

Toyohiro NISHIKAWA is the Professor at School of Architecture, Kogakuin University, 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.

The application and efficiency of wall purification system in building

Yu-Fang Chen(1),Cheng-Li Cheng(2), Sadahico Kawamura(3)

1.m10713022@gapps.ntust.edu.tw

2. CCL@mail.ntust.edu.tw

3. sadahico@gmail.com

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

Abstract

This study evaluates the water-saving benefits of purifying green-wall in various types of buildings. In the limited installation space, explore how to increase the efficiency of water purification, and adjust planting groove unit to increase the green coverage proportion of green-wall and purification benefits in unit space area. The prototype of the purification green-wall system (PGWS) is divided and based on open building theory. It is divided into a support system and infill system. Systematically, standardized and modularized concept design the infilling system components, and proposed model would verify the purification efficiency of the different infilling sections. The green coverage ratio and purification efficiency of the purifying green-wall are improved in unit area, and the convenience of vegetation and medium replacement is increased.

Keywords

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

1.Introduction

On the issue of green buildings and sustainable environment, the benefits of green-wall applied to building exterior have been recognized to climate adaptation, mitigate urban heat island effects, increase greening, biodiversity and reduction of energy for air conditional cooling. As the combination of green-wall and constructed wetland, the application of natural purification mechanism to process domestic water has been proved. The PGWS is an 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 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 purification green-wall system (PGWS), the functional and operational optimization strategies and combine with the concept of individual grey water streams were explored in our previous studies.

On the aspect of green buildings and sustainable environmental issues, the benefits of green walls being applied to building facades to regulate climate, mitigate urban heat island effects, increase greening, biodiversity, and reduce air conditioning energy consumption have been recognized. But in the use of water resources, planting walls is a resource-consuming facility. Planting wall combined with artificial wetland, the application of natural purification mechanism to treat domestic sewage, so that it from the consumer to the role of producer, in addition to retaining the advantages of three-dimensional greening, but also improve its set-up efficiency to achieve the building's internal water resources short-distance cycle of resource regeneration concept. Based on the Purification Green Wall System (PGWS) prototype, this study would further discuss the water-saving benefits applied to various types of buildings, as well as various aspects such as operational optimization.

2 Theories and review

2.1 purified water theory

A wetland functions as a system that can purify water by removing, precipitating and decomposing, organic pollutants in water. Similarly to natural wetlands, constructed wetlands act as a bio-filter and can remove pollutants from water through a series of purification mechanisms. Constructed wetlands can be divided into surface flow and subsurface flow wetlands. The device can be further divided into two types: vertical and horizontal subsurface wetlands. The prototype of the purification green-wall system (PGWS) and the previously optimized operation belong to the horizontal subsurface constructed wetland. This study will continue to exam the efficiency of water purification of optimized horizontal subsurface flow constructed wetlands. It will also conduct the optimization of horizontal subsurface flow constructed wetlands.

A low lying land is filled with sand or gravel as a medium to support the growth of aquatic plants. The influent water flows between the sand, roots and rhizomes under the surface layer to achieve the purification effect. Based on the direction that water flows, constructed wetlands are divided into the two types. One is horizontal-flow system in which water flows from one end horizontally. (Figure1)The other is vertical-flow system that water seepages from surface to a collector in the bottom.（Figure2）

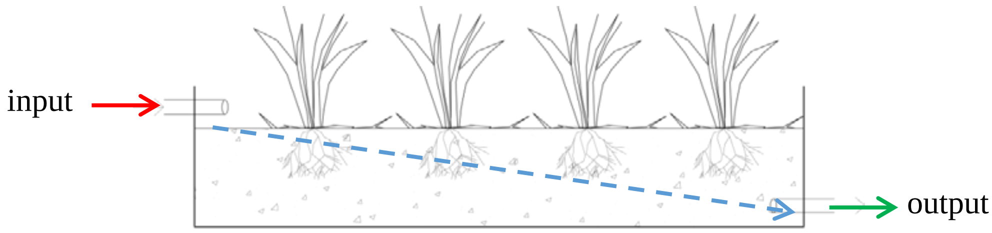

Figure1 -Horizontal flow constructed wetland HSF CWs

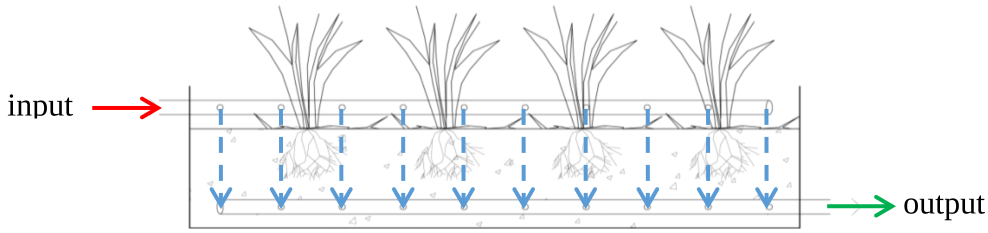

Figure 2 - Vertical flow constructed wetland VF CWs

By adopting the principle of constructed wetlands, a planting wall system is provided with the function of sewage treatment. A horizontal subsurface flow constructed wetland can be divided into several vertical units. A vertical subsurface flow constructed wetland can be divided into independent planting units. Both of two types maintain the mechanism of sewage treatment.

2.2 Plant coverage

The prototype of the purification green-wall system (PGWS) aimed at the experimental water purification benefit. The proportion of the trough area on the facade of the planting wall is large, and the coverage rate of the plant is insufficient. This study will adjust the tank unit and configuration to increase the coverage of planting. The calculation method compares the plant coverage ratio of planting plants in the planting trough, and compares the ratio of the number of squares to the number of plants that can be planted per unit area.

3. Experiment and results

3.1 Water purification effect

The experimental results of the purification green-wall system (PGWS) prototype confirmed [10] that good contaminant removal can be maintained in a short time HRT (one hour). However, E. coli will increase in a large amount after one hour, so it is necessary to sterilize chlorine in the storage tank during storage after purification to meet the specifications for flushing water. The prototype of the purification green-wall system (PGWS) is shown in Figure3. The experimental results are shown in Table 1.

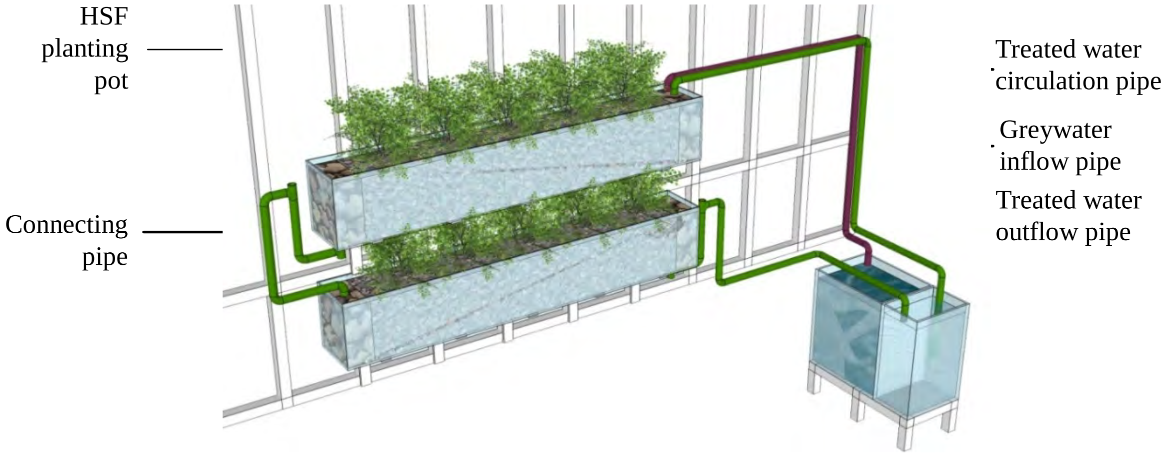

Figure3 - Purification green-wall system (PGWS)

Table 1 - Results of lab analysis

HRT	Total Coliform (TC)		BOD_5,20℃		Turbidity		pH
	CFU/100mL	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

This study follows the optimization of the water purification efficiency of the unit modules of the horizontal flow and vertical flow systems, and measure the E. coli population, BOD_5, 20 ° C, suspended solids concentration and pH value within purification.

3.2 Building water type

According to the water use projects and space, they can be divided into six categories, including residential and dormitory types of domestic water use, and public water use types. There are office, public space, and medical, catering, and leisure types of production water use. The water type for purifying plant wall recycling is bathing, hand washing water, replacing flushing water and other water after purification, detailed water use. The content and main water consumption items are shown in Table2. The water consumption of each type of construction water project is shown in Table 3.

Table 2 - Building water type classification

Water use type	Water project	Toilet Flushing※	Shower*	Washing Basin*	Laundry	Kitchen Sink	Clean	Others
water for live	Housing	○	○	○	○	○	○	○
	Dormitory	○	○	○	○	-	○	○
Public water	Office	○	-	○	-	-	○	○
	Public	◎	-	○	-	-	○	○
Production water	Medical	○	○	◎	◎	-	◎	○
	Repast	○	-	○	-	◎	○	○
	Leisure	○	◎	○	-	-	○	○

○Water project ◎Main water project *Recycle purification project ※Available recycled water project

Table 3 - Water consumption of tap water for each water type building

Water use situation	Tap-water consumption							Total	Recycle	Alternative	Alternative ratio
Housing	48	75	45	35	60	15	15	293	86	15	21.50%
Dormitory	48	75	45	35	0	15	15	233	86	15	27.04%
Office	48	0	15	0	0	15	15	93	12	12	16.13%
Public	12	0	15	0	0	15	15	57	12	3	26.32%
Medical	48	75	60	35	0	15	15	248	98	15	25.40%
Repast	12	0	15	0	60	15	15	117	12	3	12.82%
Leisure	24	75	15	0	0	15	15	144	62	6	27.08%

4.Discussion and application

4.1 Water saving benefits for various types of buildings

The survey shows the water consumption of tap water in each water-type building. In this study, according to the ratio of reclaimed water replacement and the feasibility and convenience of setting up a cleaned planting wall for this type of building, the residential, accommodation and office categories were discussed and analyzed. Daily water use and consumption. The amount of tap water used in residential buildings is 293 liters per person per day, including 48 liters of flushing, 75 liters of bathing, 45 liters of washing hands, 35 liters of washing, 60 liters of food, 15 liters of cleaning, and 15 liters of other water. It can replace 63 liters (21.5%) of tap water after using PGWS. The water supply and separation drainage system is shown in Figure4.

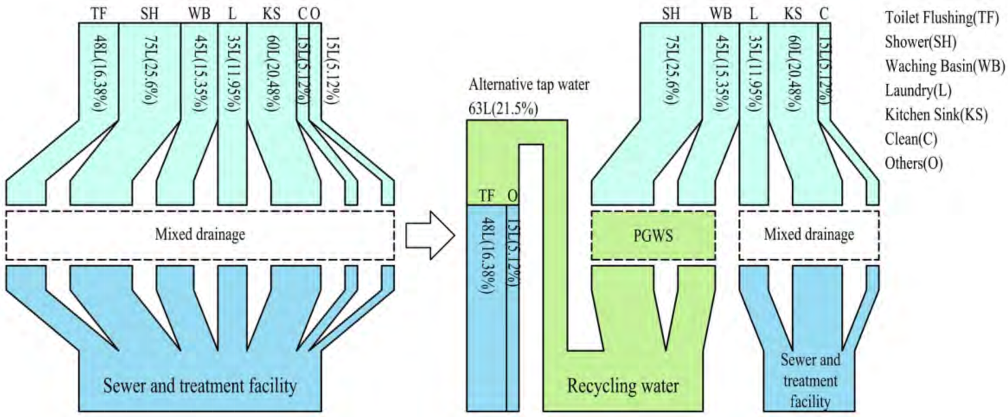

Figure 4 - Residential water supply and separation drainage system

The use of tap water in the dormitory category is 233 liters per person per day, of which 48 liters of flushing toilets, 75 liters of bathing, 45 liters of washing hands, 35 liters of washing, 15 liters of cleaning, and 15 liters of other water. It can replace 63 liters (27.04%) of tap water after using PGWS. The water supply and separation drainage system is shown in Figure5.

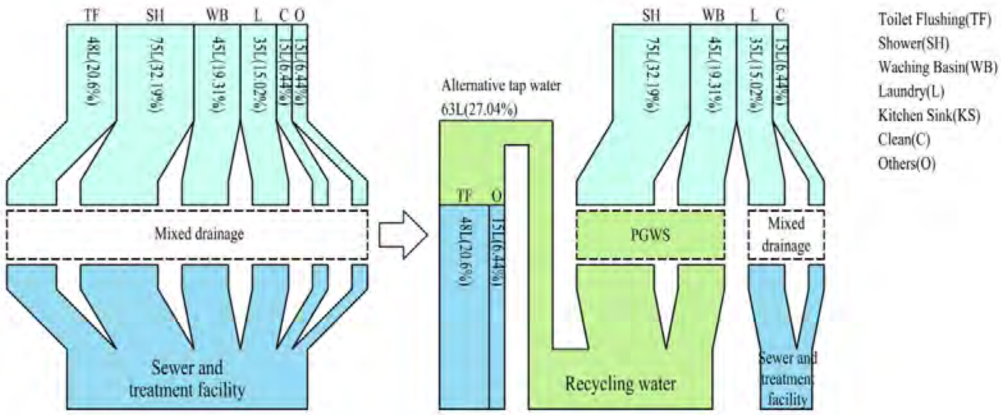

Figure5 - Dormitory water supply and separation drainage system

The amount of tap water used in office is 93 liters per person per day, of which 48 liters are flushed, 15 liters are washed, 15 liters are cleaned, and 15 liters are used. It can replace 15 liters (16.13%) of tap water after using PGWS. Since the amount of water that can be recycled is only 15 liters, flushing water plus other water needs 63 liters, so

48 liters of water still needs to be supplied by tap water. The water supply and separation drainage system is shown in Figure6.

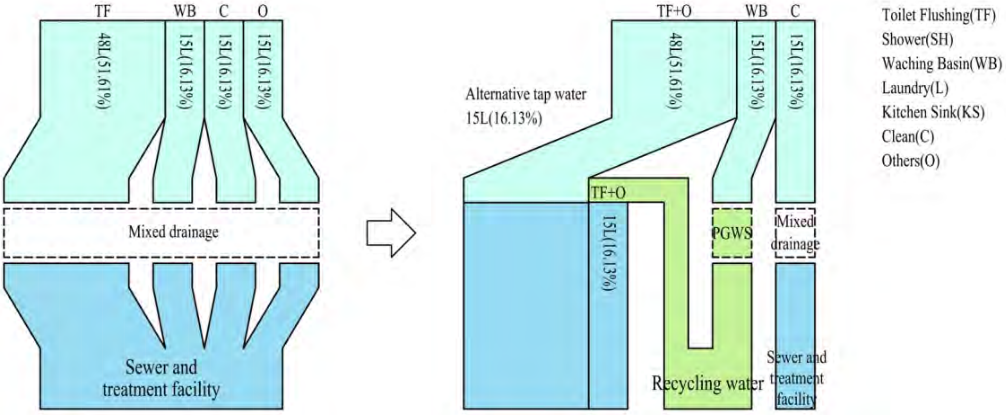

Figure6 - Office water supply and separation drainage system

The building water project is divided into seven parts: flushing, bathing, hand washing, washing, catering, cleaning and other water use. The items that can be recycled and reused are bathing and washing hands. The items that can be replaced by recycled water are flushing and other water. The amount of water that can be recovered and purified by various types of buildings and the amount of water that can be replaced are used to calculate the proportion of alternative buildings that can replace tap water. After calculation, the replacement ratio of drinking water for display leisure is up to 27.08%, followed by 27.04% for dormitory, 26.32% for public building, and 25.4% for medical. The water consumption of various types of construction water projects is shown in Figure7.

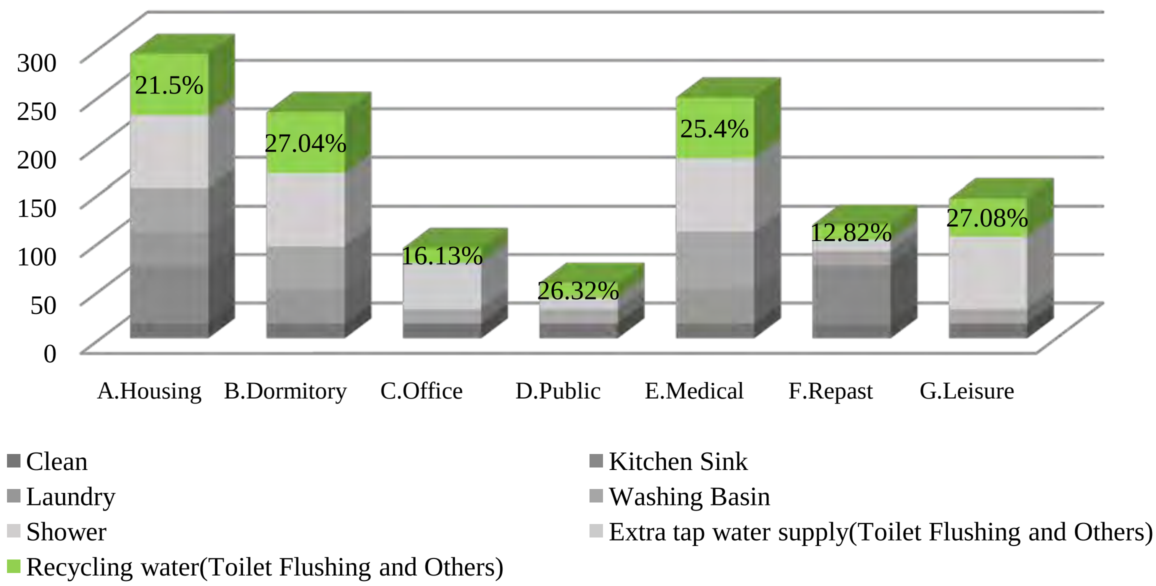

Figure7 - The recreational water recycling ratio of various types of building

4.2 Optimized purification of vegetation wall

The planting trough unit of the PGWS prototype is 150cm long, 20cm wide, 25cm high and 20cm deep. Considering the size and weight of the planting tank, one person cannot be finished, and it is inconvenient to replace the planting and planting boundaries. Therefore, this study attempts to optimize the PGWS prototype, increasing feasibility and convenience without affecting its water purification efficiency.

The horizontal flow optimization concept is to divide the planting trough into planting small units with a width of 10 cm, the inlet and outlet units are at both ends, and the central part is separated by a permeation partition. The planting unit is filled with a container made of non-woven fabric, each planting unit The matrix and plant can be transformed according to the needs, and the horizontal flow optimization concept is shown in Figure8.

The concept of vertical flow optimization is to divide the planting trough into planting small units with a width of 10 cm. The separation of each unit still does not affect its water purification efficiency, and then the horizontally arranged planting troughs are converted into vertical arrays. Transforming the substrate and planting, the vertical flow optimization concept is shown in Figure9.

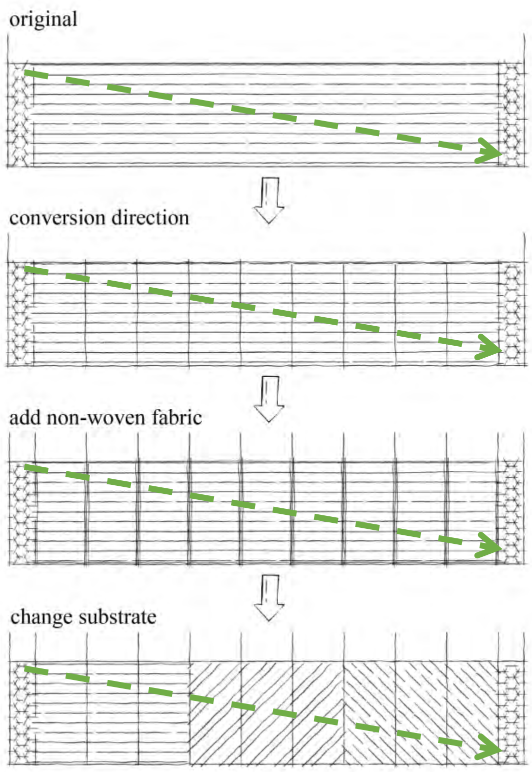

Figure 8 - Horizontal flow planting tank optimization concept

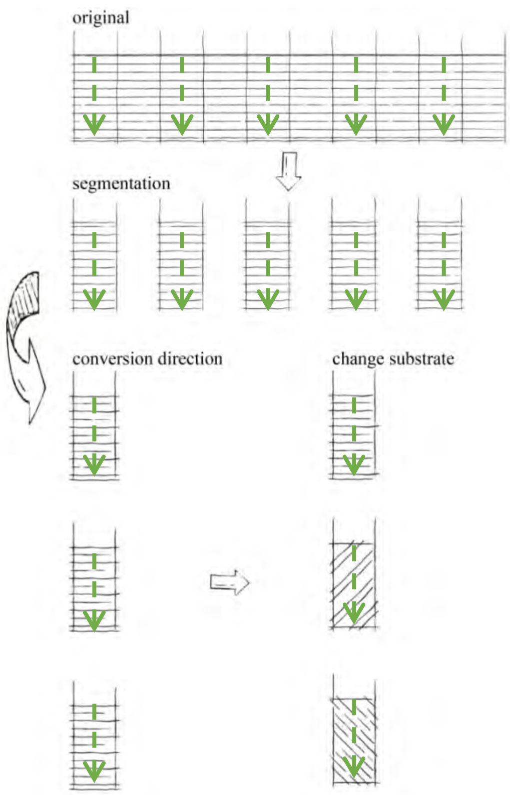

Figure 9 - Vertical flow planting tank optimization concept

The horizontal flow and vertical flow planting trough shape optimization concept is to shrink the bottom of the planting trough, so that the lower planting trough can bear the upper weight, reduce the bearing weight, and retain the plant growth height of 20cm. In the shape optimization process, the change factor of maintaining the water purification efficiency is not changed, and the sectional area of the fixed medium is increased to 32 cm in order to maintain the same sectional area. The optimized frontal area is 20*20=400 cm^2, and the optimized sectional area is 5*26+(10+26)*15/2=400 cm^2. The optimized front and back area are the same. The optimization concept is shown in Figure 10.

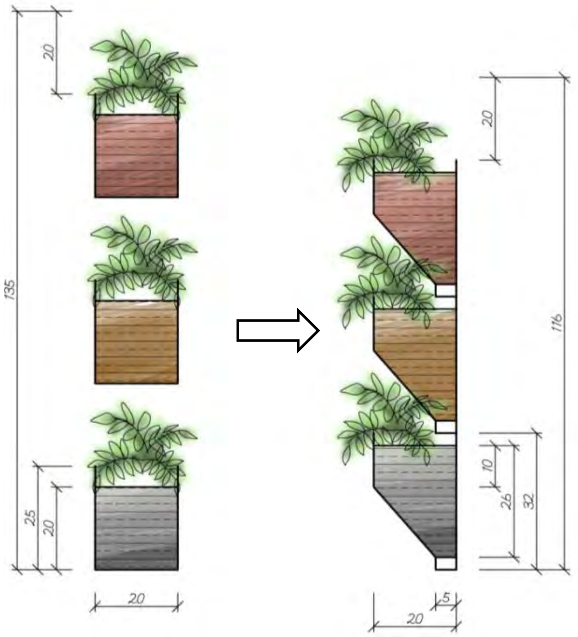

Figure 10 - Horizontal flow, vertical flow planting tank shape optimization concept

4.3 Planting coverage and calculation

The planting coverage rate is calculated by implanting the simulated PGWS prototype (Figure 11) with the optimized horizontal flow (Figure 12) and vertical flow (Figure 13), and inserting it into a 10*10 cm grid. Reserve 20cm above the planting tank as the boundary of the planting growth space, calculate the number of planted filling grids, account for 1/3 or more of the grid to calculate 0.5 grid, account for 1/2 or more of the grid to calculate by 1 grid, statistical planting The ratio of the number of grids occupied by the plant to the total number of grids is the plant coverage of the planting wall.

The calculation method of planting amount per unit area is to simulate the number of plants, and then calculate the width and height of the PGWS prototype and the optimized horizontal flow and vertical flow planting trough, and the product of width and height as the total area. A plant growth space of 20 cm is reserved above the planting tank. The ratio of planting quantity to total area is the number of plants that can be planted per unit area. The large value is the higher coverage rate of planting

Figure 11 - PGWS prototype simulation

Figure 12 - Optimized horizontal flow simulation

Figure 13 - Optimized vertical flow simulation

The planting coverage of the PGWS prototype is calculated as 135 grids of total grids, and the grid number of plants is 54 grids, 54/135=0.4, so the plant coverage rate of the PGWS prototype is 40%.The planting amount per unit area of the PGWS prototype was calculated to be 1*1.35M in width and height, and 27 plants were planted. 27/(1*1.35)=20 plants/m2, so there are 20 plants per unit area.

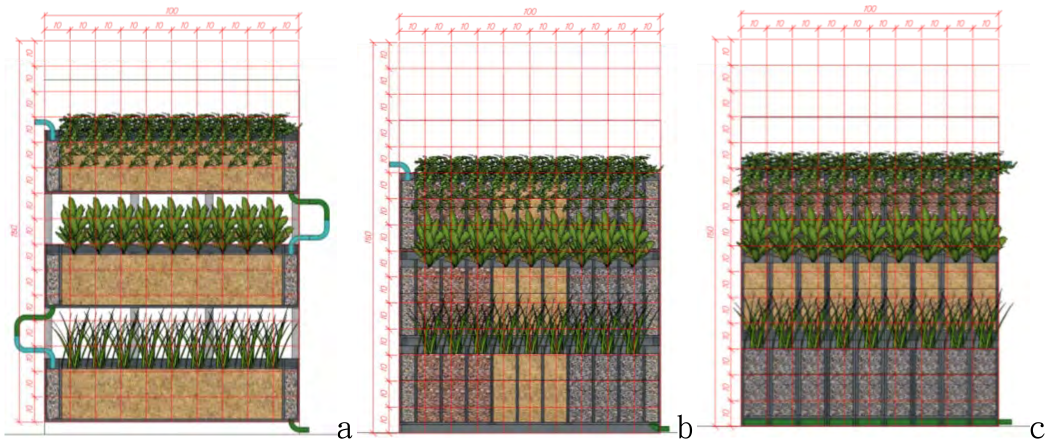

Figure 14 - PGWS prototype plant coverage calculation (a: prototype, b:horizontal flow, c: vertical flow)

The planting coverage of the horizontal flow is calculated as the total grid number of

120 grids, the number of grids planted by the plant is 56 grids, 54/120 = 0.45, so the plant coverage rate of the PGWS prototype is 45%. The planting amount per unit area of the horizontal flow is 1*1.2 m in width and height, and the number of planting plants is 27 plants. 27/(1*1.2)=22.5 plants/m^2, so there are 22.5 plants per unit area.

The planting coverage of the vertical flow is calculated as the total number of grids of 120 grids, and the number of grids planted by the plant is 60 grids. 60/120=0.5, so the plant coverage rate of the PGWS prototype is 50%.The planting amount per unit area of vertical flow is 1*1.2 m in width and height, and the number of planting plants is 27 plants. 27/(1*1.2)=22.5 plants/m^2, so there are 22.5 plants per unit area. The simulation diagram is as shown in Figure 14.

The results of planting coverage are vertical flow (50%)> horizontal flow (45%)> PGWS prototype (40%), and the calculation results per plant area were: vertical flow (22.5 plants) = horizontal flow (22.5 plants) > PGWS prototype (20 strains), after two optimizations, the plant coverage and unit area planting amount are larger than the PGWS prototype.

5.Conclusion

This study evaluates the water-saving benefits of purifying green-wall in various types of buildings. In the limited installation space, explore how to increase the efficiency of water purification, and adjust planting groove unit to increase the green coverage proportion of green-wall and purification benefits in unit space area. Systematically, standardized and modularized concept design the infilling system components, and proposed model verified the purification efficiency of the different infilling sections. The green coverage ratio and purification efficiency of the purifying green-wall are improved in unit area, and the convenience of vegetation and medium replacement is increased. The impact of setting location, method, and media, planting types on purification benefits would be conducted in the future.

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Presentation of Authors

Yu-Fang Chen is the Master student at National Taiwan University of Science and Technology, Department of Architecture. Her research is focus on water resources and green Building.

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.

Sadahico Kawamura is the Ph.D student at National Taiwan University of Science and Technology, Department of Architecture. His research is focus on energy conservation for green building

The hydrology and biodiversity characteristics of an experimental raingarden at RBGE in Scotland

D.A. Kelly (1), D. Knott (2), K. Wilson (3), and A. Kalaichelvan (4)
(1) d.a.kelly@hw.ac.uk
(2) dknott@rbge.org.uk
(3) kwilson@rbge.org.uk
(4) ka59@hw.ac.uk
(1) & (4) The Water Academy, Heriot-Watt University, Edinburgh, Scotland, UK.
(2) & (3) The Royal Botanic Garden Edinburgh, Edinburgh, Scotland, UK.

Abstract

In recent years, the Royal Botanic Garden Edinburgh (RBGE) has witnessed changing weather patterns that reflect how climate change is impacting Scotland. Longer periods of dry weather, followed by heavy downpours of rain, have proved particularly problematic in terms of maintaining plant health and avoiding localised flooding issues. To cope with these challenges, an experimental raingarden (a shallow planted basin) has been created at one of the areas of the garden most prone to waterlogging and flooding. Raingardens offer a sustainable solution to flood mitigation by mimicking natural rainwater retention and infiltration characteristics, whilst also providing multiple benefits related to biodiversity, ecology, amenity, recreation, and education value.

This paper reports on the preliminary hydrological modelling of the raingarden and surrounding area, including details of the amended soils used to enhance rainwater infiltration rates within the raingarden to reduce runoff. Details are also provided on the biodiversity of the raingarden and, in particular, the selection of native and non-native plants being trialled that are able to tolerate both drought and wet conditions. The creation and ongoing assessment of the raingarden will be helpful for understanding and planning future site management strategies for coping with an unpredictable and changing climate.

Keywords

Climate change, flooding, raingarden, biodiversity, hydrological modelling.

1 Introduction

The Royal Botanic Garden Edinburgh (RBGE) dates back to 1670 when it began as Scotland's first physic garden (RBGE, 2019a). It became one of Britain's first botanic gardens and today is a world-renowned centre for plant science, horticulture, education, and public engagement, see Figure 1a. RBGE now extends over four gardens (Edinburgh, Benmore, Dawyck, and Logan) curating a rich collection of native and non-native plants (of some 13,500 species) and welcoming over one million visitors each year.

In recent years, however, RBGE has experienced changing weather patterns that reflect how the climate is changing in Scotland. Longer periods of dry weather, followed by heavy downpours of rain, have proved particularly problematic in terms of maintaining plant health and avoiding localised flooding issues. With extreme weather events expected to become more frequent and intense over the coming decades, RBGE are working to increase the resilience of its gardens to reduce its vulnerability to future climate change (Martin, 2014).

A particular challenge has been dealing with more frequent heavy rainfall which has brought problems of water logging and localised flooding in some parts of the garden, causing damage to plant-beds, lawns, and footpaths and impacting visitor access due to the closure of affected areas. An area of the garden that has been particularly affected is the Birch Lawn, see Figure 1b, which has suffered waterlogging and flooding during heavy rainfall events due, mainly, to its low-laying position within the garden.

To help reduce the susceptibility of the Birch Lawn to flooding, an experimental raingarden has been created with enhanced rainwater retention and infiltration characteristics. A raingarden is a shallow basin with absorbent, yet free draining, soil and planted with vegetation that can withstand occasional drought and flooding (Bray *et al.,* 2012). They offer a sustainable solution to flood mitigation whilst also providing multiple benefits related to biodiversity, ecology, amenity, recreation, and education value.

Figure 1: Location of (a) RBGE within the city of Edinburgh, and (b) the Birch Lawn within RBGE (source: Google Maps, © 2019 Google)

This paper reports on the preliminary hydrological modelling of the raingarden, including details of the digital terrain model used, and the amended soils developed to enhance rainwater infiltration rates. Details of the biodiversity of the raingarden are also provided, in particular, the selection of native and non-native plants being trialled for their ability to withstand both very dry and extremely wet conditions.

2 Changing rainfall patterns in Scotland

The climate in Scotland is changing, and the latest climate projections indicate that further change is expected over the coming century (SCCAP-CC, 2019). Extreme weather events are expected to become more frequent and intense over the coming decades.

2.1 Past trends and recent rainfall anomalies

In the past few decades there has been an increase in annual average rainfall over Scotland. Since 1970, the annual rainfall has increased by around 13% over Scotland compared with the average for the early decades of the 20th century (ASC, 2016). Heavy seasonal and annual rainfall events have also increased. Seven of the 10 wettest years for the UK have occurred since 1998 (Kendon, 2018).

Heavy rainfall events have increased significantly in winter, particularly in northern and western regions, with an average increase of almost 60% in winter months in northern and western Scotland (2006). Data for the UK shows that summers have been on average 20% wetter than 1961–1990, with only summer 2013 drier than average (Kendon, 2018). Most recently, parts of north-east Scotland experienced more than twice the normal rainfall during May 2019 (Met Office, 2019a). Total rainfall from extremely wet days (days exceeding the 99th percentile of the 1961-1990 baseline) has increased by around 17% for the UK, however, changes are largest for Scotland.

2.2 Future rainfall projections

The UK Climate Projections 2018 (UKCP18) is a state-of-the-art climate analysis tool based on the latest developments in climate science (Met Office, 2019b). Climate projection for Scotland and the UK suggest a move towards warmer, wetter winters and hotter, drier summers. However, natural variations will mean that seasonal and regional differences will continue to vary in the future. For example, winter precipitation is expected to increase more over southern and central England whilst summer rainfall reductions tend to be largest in the south of England. Likewise, the west of Scotland is likely to see a greater increase in mean winter precipitation than the north and east of Scotland (Murphy et al., 2018). By 2070, in the high emissions scenario, average winter precipitation is projected to increase by up to 35% for the UK and, although summers are expected to become drier, the likelihood of individual wet summers reduces only slightly.

3 Extreme rainfall impacts at RBGE

Whilst individual weather anomalies and extreme rainfall events cannot be directly attributed to climate change as they occur, due to the natural variability of the climate, projections show that climate change will result in an increased frequency and severity of some extreme events such as storms, floods, and heatwaves (Martin, 2014). Observations of recent rainfall events at RBGE reflect an increased frequency and severity of intense events. Figure 2 presents the total annual rainfall recorded by the RBGE weather station (an official Met Office weather station) from 1976 until 2017.

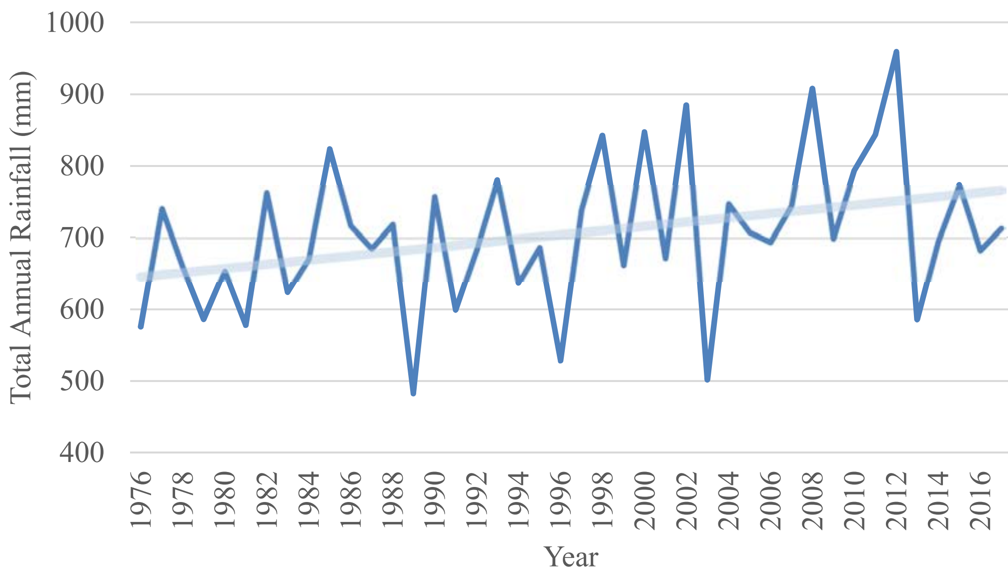

Figure 2: Total annual rainfall recorded at RBGE (1976 – 2017) illustrating both the annual variability and the increasing trend of total rainfall

Overall, 2012 was the wettest year on record at RBGE with a total of 960mm of rain; 136% of the long term annual average rainfall since 1976 [706mm]. During the same year, the UK annual rainfall was the second highest on record with a total of 1335mm of rain, narrowly beaten by 2000 with 1337mm of rain (Met Office, 2019a).

The wettest month at RBGE was August 2008 with 202mm of rain (323% of the average for August [63mm]), followed by July 2012 with 182mm of rain (272% of the average for July [67mm]), and June 2017 with 181mm of rain (289% of the average for June [63mm]). In fact, the summer season (from June to August) of those years have been the wettest on record at RBGE with summer 2012 the wettest (410mm of rain), followed by summer 2008 (367mm of rain) and summer 2017 (344mm of rain). The wettest winter season (from December to February) was 2015/2016 with 360mm of rain falling during those three months. Winter 2015/2016 was also the wettest recorded for Scotland and the second-wettest for the UK, beaten by winter 2013/2014 (Met Office, 2019a). The wettest day recorded at RBGE was 26th July 1985 with 82mm of rain over a 24-hour period.

Heavy downpours of rain have brought problems of localised flooding and caused damage to plant-beds, lawns, and footpaths at RBGE (Martin, 2014). This has affected visitor access within the Garden due to the closure of waterlogged and slippery paths (see Figure 3). In some locations, tree and shrub roots have been submerged in rainwater with possible consequences for their health. Waterlogging of lawns have also affected garden maintenance, making grass cutting difficult, and causing soil compaction. After such events, remedial work has been necessary to repair the footpaths and plant-beds where soil and surface materials had been washed away.

Figure 3: Examples of problems at RBGE caused by heavy downpours of rain, including flooded footpaths, waterlogged lawns, and submerged roots.

Consequently, an ongoing review of rainwater drainage is now underway at the Garden. New drainage and soakaways were installed at critical areas where capacity was insufficient and now, when new areas of the Garden are upgraded, drainage and maintenance plans are reviewed and updated where necessary.

In addition to periods of wetter than average weather, RBGE has also experienced periods drier than average. The driest year from 1976 onwards was 1989 when only 483mm of rain fell (just 68% of the annual average), however, the driest year on record at RBGE was 1959 with only 436mm of rain (62% of the annual average). The driest month was February 1993 when just 3.7mm of rain fell (RBGE, 2019b). As a result, mulches are now being used to help conserve soil moisture during dry periods.

The impact of extreme wet and dry weather presents many challenges to the Garden, particularly in terms of plant health, garden maintenance, and visitor experience. The UK Climate Projects 2018 (UKCP18) suggest greater weather variability throughout the year and greater occurrence of extreme events. Climate change resilience planning is therefore crucial to minimise future risk.

4 Raingarden design

The experimental raingarden was designed to intercept, capture, and infiltrate rainwater during heavy rain events. The site of the raingarden is the Birch Lawn (see Figure 1b) which had previously suffered from flooded footpaths, waterlogged lawn, and submerged tree and shrub roots. Initial site conditions were assessed by measuring the infiltration rates of the existing soil. A digital terrain model was then used to assess the surface water flow characteristics at the site and the corresponding rainwater volumes generated under different design storms. An amended soil was then developed and incorporated into the raingarden site in order to enhance the rate of infiltration. Plant selection, undertaken by horticulturists at RBGE, included a number of native and non-native species chosen for their ability to help create habitat for wildlife, and their hardiness to thrive within both wet and dry conditions.

4.1 Soil infiltration tests

To understand the existing site conditions, the infiltration rate of the soil at the Birch Lawn was measured using a Mini Disc Infiltrometer by Decagon Devices (see Figure 4). The Infiltrometer is designed to accurately measure the unsaturated hydraulic conductivity of any soil (i.e. the rate at which water can move through the soil).

The upper and lower chambers are both filled with water. The upper chamber controls suction to account for the effects of macropores within the soil which generally fill with air. The water within the lower chamber infiltrates into the soil at a rate determined by the suction selected in the upper chamber. A suction rate of 2 cm was selected as this is recommended by the manufacturer to be used for most soil types.

The bottom of the Infiltrometer has a porous sintered stainless steel disc that does not allow water to leak in open air. When the Infiltrometer is placed on soil, water begins to leave the lower chamber and infiltrate into the soil at a rate determined by the hydraulic properties of the soil. As the water level drops, the volume remaining can be read from the graduated cylinder of the lower chamber.

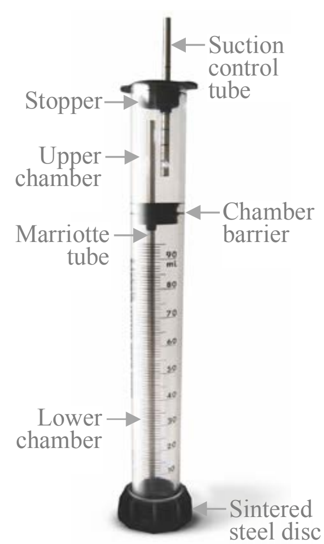

Figure 4: Mini Disk infiltrometer

Figure 5 illustrates the cumulative infiltration against the square root of time for four test locations on the Birch Lawn, once the water volume recorded from the infiltrometer (in ml) has been converted to water depth (in cm). Test 1 and Test 2 measured the soil infiltration of the lawn itself, whilst Test 3 and Test 4 measured at bare soil around the base of existing trees. A clear difference can be seen between the infiltration of lawn soil (Figure 5a and 5b) and the bare soil (Figure 5c and 5d). The roots of the lawn appeared to help improve inflation, whilst the bare soil was found to be heavily compacted, thus reducing surface infiltration capability.

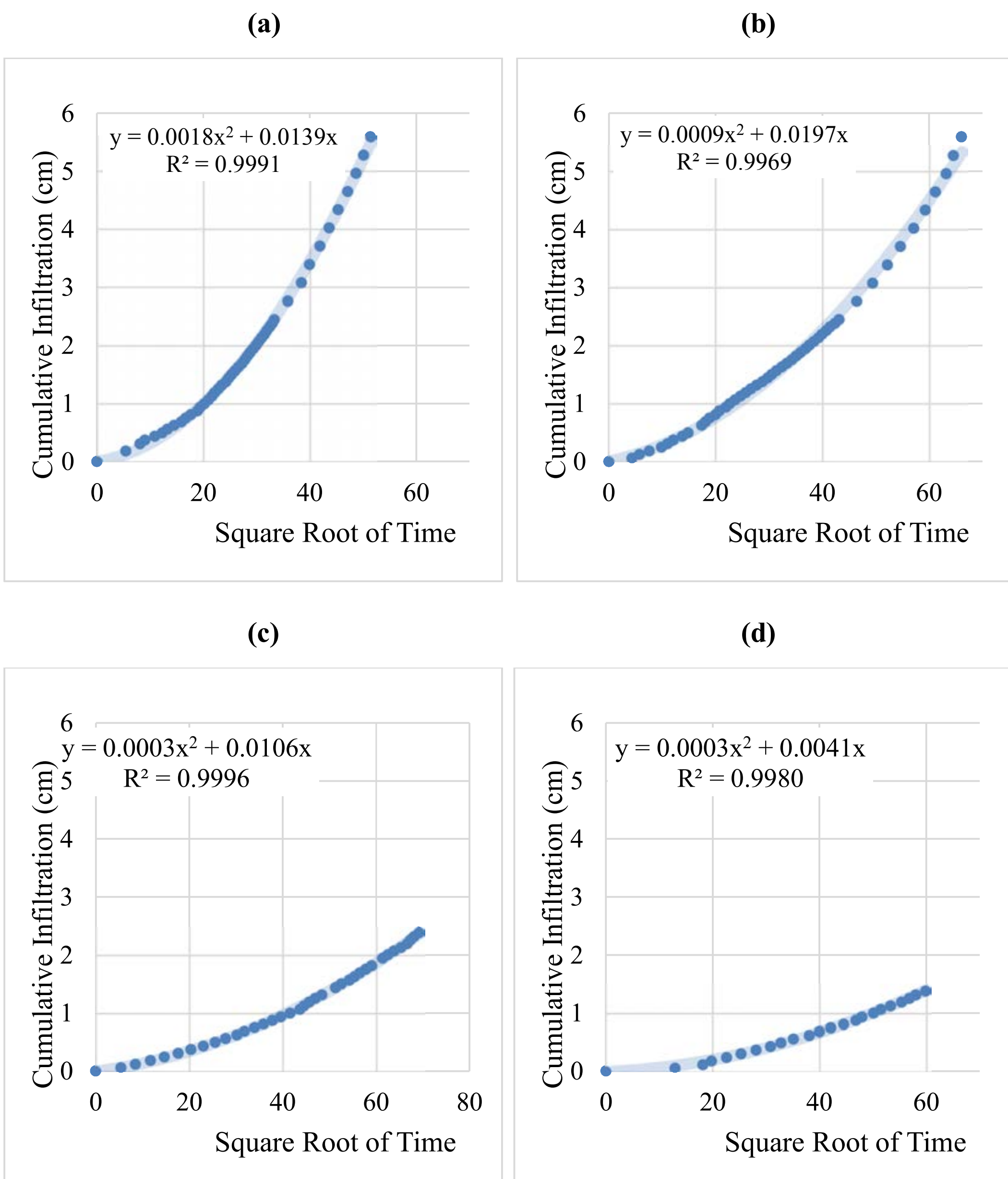

Figure 5: Cumulative infiltration of existing soil measured at four test locations on the Birch Lawn at RBGE: (a) Test 1, (b) Test 2, (c) Test 3, and (d) Test 4

Soil infiltration rate, k, can then be calculated from:

$$k = \frac{C_1}{A} \tag{1}$$

where C_1 is the slope of the curve of the cumulative infiltration versus the square root of time, and A is a value relating to the van Genuchten parameters for a given soil type to the suction rate and radius of the infiltrometer disk (Meter Group, 2018). Figure 6 illustrates the infiltration rates for each test across twelve soil texture types.

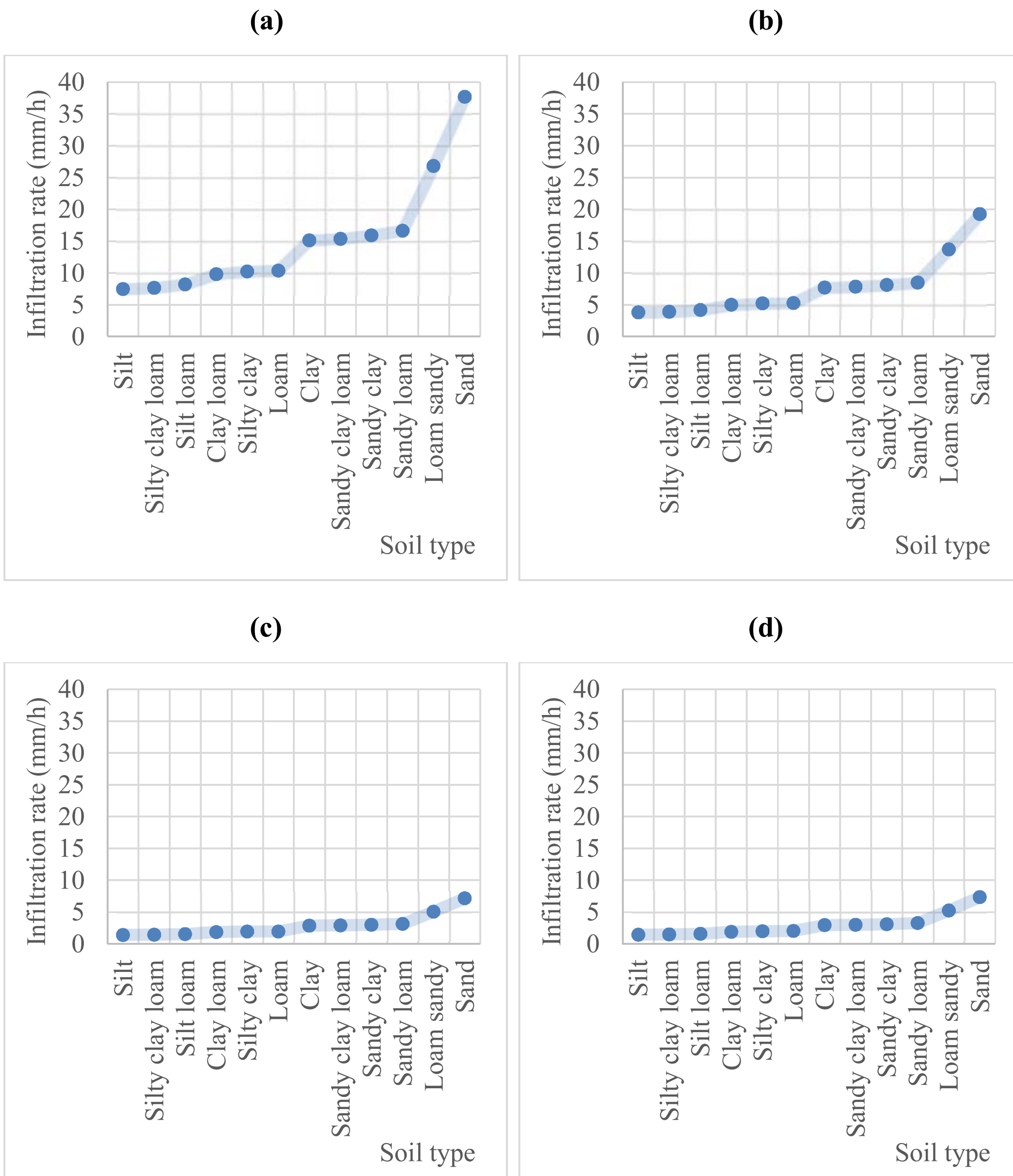

Figure 6: Infiltration rate of existing soil measured at four test locations on the Birch Lawn at RBGE: (a) Test 1, (b) Test 2, (c) Test 3, and (d) Test 4

Soil type can have a significant effect on infiltration rate. Course well-drained soils (such as loamy sand) have a high rate of water transmission and tend to display high infiltration rates, with the majority of rainfall being able to infiltrate into the soil. Finer clay soils tend to have very low rates of water transmission and so display low infiltration rates (Natural Resources Conservation Service, 1986). Saturated soils and compacted soils will also display lower infiltration rates.

Whilst the soil type for the Birch Lawn is still to be determined, looking across the range of soil types, the infiltration rates at each test location can be estimated: Test 1 (Figure 6a) shows an average infiltration rate of 15.1 mm/h (with a range of 7.5 – 37.7 mm/h); Test 2 (Figure 6b) shows an average of 7.7 mm/h (with a range of 3.8 – 19.2 mmm/h); Test 3 (Figure 6c) shows an average of 2.9 mm/h (with a range of 1.4 – 7.2 mm/h); and Test 4 (Figure 6d) shows an average of 3.0 mm/h (with a range of 1.5 – 7.4 mm/h).

Soil samples taken from the Birch Lawn are currently being prepared for particle size distribution (PSD) analysis and infiltration rate testing in order to determine the soil type classification.

4.2 Digital Terrain Model

To better inform the design of the raingarden, the topography of RBGE was assessed using the Digital Terrain Model (DTM), QGIS, which is an open source Geographic Information System (GIS). The DTM data used has a grid cell resolution of 2m and was sourced from the Environment Agency UK.

Figure 7a shows the extent of the RBGE site boundary within the DTM and Figure 7b shows the site elevations with the red areas being the highest points within the garden, and the blue areas the lowest points. The Birch Lawn watershed boundary, which is delineated by the blue polygon, can be seen to sit at a natural low point to its surroundings.

Figure 7c shows the watershed routing at, and adjacent to, the Birch Lawn. Assessment showed that the rainwater drainage routes within the watershed, slope at a steep fall of 1 in 10 and culminate at the footpath (indicated by the white line in Figure 7c) adjacent to the Birch Lawn.

Figure 7d shows the details of the Birch Lawn watershed boundary, including contour lines, indicating a change in elevation from the highest point (23.9 m) to the lowest point (19 m) of almost 5 m. The optimum position of the raingarden was is also indicated in Figure 7d; located at the lowest elevation point of the Birch Lawn in order to best capture the overland surface flow of rainfall runoff.

The analysis completed in GIS allowed the drainage area and primary overland surface water flow routing at the Birch Lawn to be estimated. This key information was then used as input to the raingarden design.

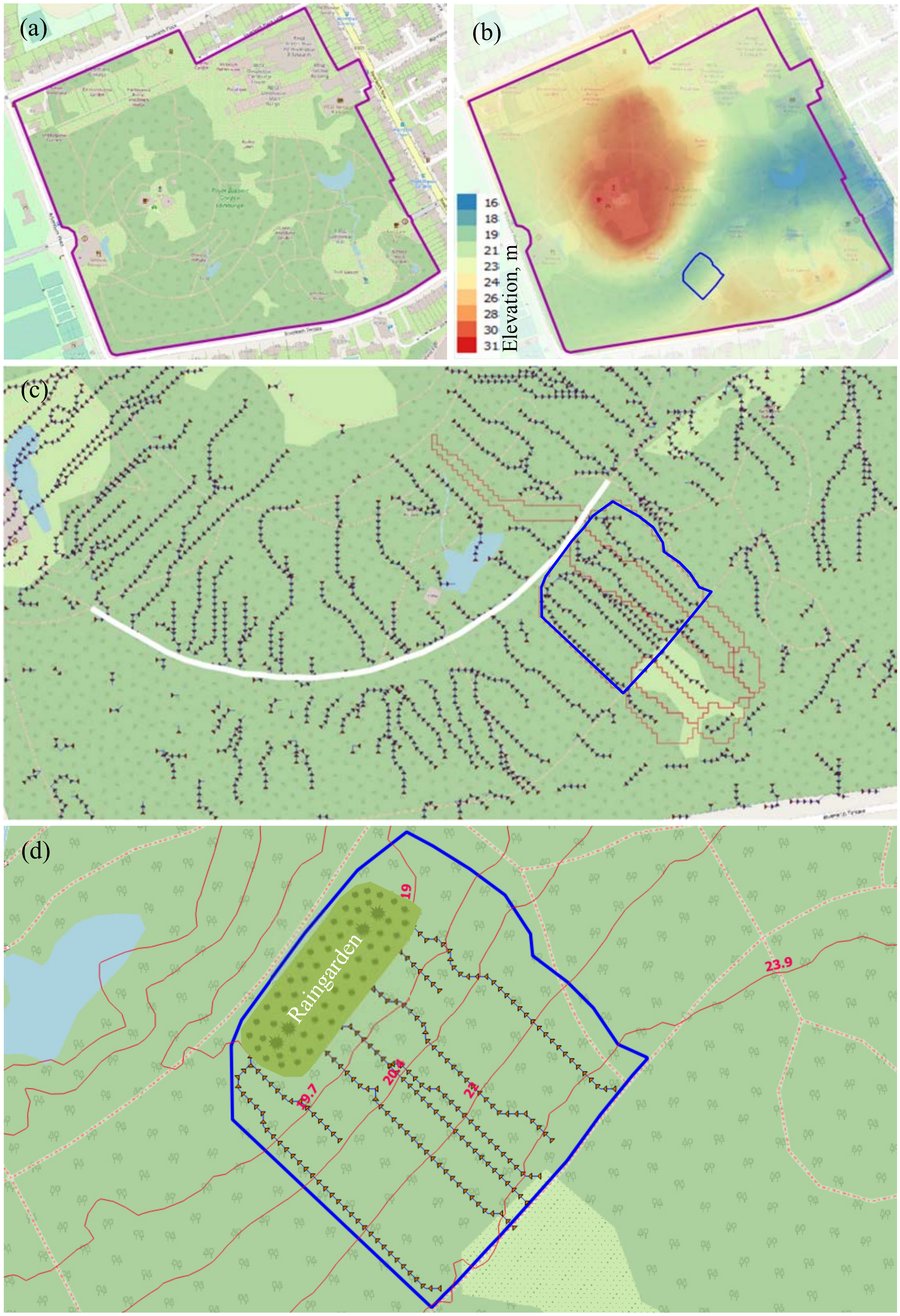

Figure 7: Simulation of the watershed routing using the DTM, QGIS: (a) the RBGE site boundary, (b) the RBGE site elevations, (c) watershed routing adjacent to the Birch Lawn, and (d) watershed routing at the Birch Lawn and raingarden

4.3 Planning and design (location, size, and shape)

As mentioned above, the raingarden was planned to be located at the lowest elevation point within the Birch Lawn watershed boundary in order to capture the overland surface water runoff. The design objective of the raingarden was to intercept the runoff, retain the collected rainwater, and then allow it to infiltrate into the soil naturally for storm events up to a 30-year return period.

Rainfall data for the RBGE site was obtained from the Flood Estimation Handbook (FEH) 2013 rainfall model (Centre for Ecology and Hydrology, 2013). This model is widely used for storm drainage design in the UK and is based on the statistical assessment of historic observed rainfall records, providing an estimate of total rainfall depth corresponding to a particular event duration and return period. To account for future climate change, a 20% uplift was applied, giving a target design rainfall intensity for a 30-year return period event of 32.8 mm/h. Inflow to the raingarden, Q, was calculated using the rational formula:

$$Q = ciA \tag{2}$$

where, c is the runoff coefficient, i is the rainfall intensity, and A is the drainage area. Based on an assumed raingarden infiltration rate of 30 mm/h (based on a review of the literature) and an existing soil infiltration rate of 5 mm/h (equivalent to clay soil) below the depth of the raingarden, the raingarden was designed to have an overall area of 130 m^2, a central depth of 450 mm, and an overall volume of 59 m^3.

4.4 Amended soil

The SuDS Manual (Woods-Ballard *et al.,* 2015) sets out design recommendations for the filter medium of bioretention systems such as raingardens. For optimal design, the filter media should be adequately permeable to enable rainwater to infiltrate through it, so that the surface of the raingarden does not become water logged. It should also contain sufficient organic material and nutrients to support planted vegetation.

A soil infiltration rate of between 100 mm/h and 300 mm/h is recommended to accommodate rainfall flowing from contributing areas. To allow for clogging, the design infiltration rate should be based on 50% of the target soil infiltration rate. In order to improve soil infiltration (see Section 4.1) whilst ensuring sufficient organic materials and nutrients, an amended soil composition of 30% existing soil, 55% sand, and 15% compost is suggested (Woods-Ballard *et al.,* 2015). With advice from the RBGE horticulturalists, in addition to the suggested composition, an amended soil retaining 45% existing soil was also developed to assess the long-term impact of soil composition on plant health. Table 1 summarises the composition of the two amended soils. In each case, the existing soil was mixed with compost made on site at RBGE, and sand and fine gravel (to the specified particle range size) obtained from a local supplier.

Table 1: Composition of the two amended soils developed for use in the raingarden

	Existing soil	Sand	Fine gravel	Compost
Soil type 1	30%	45%	10%	15%
Soil type 2	45%	35%	8%	12%

4.5 Planting and biodiversity

A selection of both native and non-native plants were selected for the raingarden. Each will be monitored and compared to assess how well they cope with occasional temporary drought and flood conditions within the raingarden. Plants native to Scotland provide the benefit of creating a naturally occurring ecological community, however, they may prove less hardy than the non-native equivalents. The plants within the raingarden will help to enhance biodiversity value and, ideally, be characterised by relatively high rates of evapotranspiration. The selected native plants include: *Saxifraga granulate, Succisa pratensis, Anthyllis vulneraria, Filipendula ulmaria, Knautia arvensis,* and *Festuca altissima.* The selected non-native plants include: *Aruncus gombalanus* (China), *Ligularia fischeri* (E Asia), *Aquilegia Formosa* (Western N America), *Primula poissonii* (China), *and Hosta sieboldiana* (Japan).

A number of established native and non-native trees were already growing at the Birch Lawn, including: *A. glutinosa* (native), *B. pendula* (native), *C. avelana* (native)*, Quercus robur 'filicifolia'* (cultivar of a native species), *A. japonica* (Japan), *Alnus rubra* (N. America), *Betula alleghaniensis* (NE North America), *Betula papyrifera* (N North America), *B. nigra* (USA), *Corylus sieboldiana* (Japan, Korea)*,* and *Populus alba* (S and central Europe). In addition, a non-native herbaceous plant, *Gunnera manicata* (Brazil), is also growing at the Birch Lawn.

5 Discussion and conclusion

In recent years, the Birch Lawn at RBGE has suffered from waterlogging and localised flooding following heavy rainfall events. The results from the DTM show that the Birch Lawn sits at one of the lowest elevation points within the garden and so watershed from surrounding slopes culminate at this point. In addition, infiltration tests of the soil within the Birch Lawn indicate very low rates of soil infiltration overall. The creation of an experimental raingarden at the Birch Lawn, with enhanced infiltration capacity, aims to capture and retain the rainfall, allowing it to infiltrate naturally into the ground.

Going forward, the raingarden will function as a "living laboratory" to learn more about raingarden hydrology and associated plant health, particularly native Scottish plants and their ability to cope with occasional drought and flood conditions. It will also act as a valuable demonstration tool for public engagement on sustainable flood management techniques. The raingarden will also be helpful in understanding and planning future site management strategies for coping with an unpredictable and changing climate, and ensuring uninterrupted provision of the important public amenity at RBGE.

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7 Presentation of authors

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.

David Knott is Curator of Living Collections at the Royal Botanic Garden Edinburgh. He contributed to the Global Strategy for Plant Conservation Target 8 project in Scotland and has undertaken fieldwork in China, Japan, Korea, and Nepal. He is a member of the National Tree Collections of Scotland, UK Plant Collections Group, Westonbirt & Bedgebury Advisory Committee, Drummond & Grimesthorpe Council, Director of Trellis & Gardening Scotland, and President of the Royal Caledonian Horticultural Society.

Kirsty Wilson is Herbaceous Supervisor at the Royal Botanic Garden Edinburgh. She has also worked at other prestigious gardens including Highgrove Royal Gardens, Longwood Gardens in America, and St Andrews Botanic Garden in Fife. She is also a presenter on the BBC TV Beechgrove Garden show. Her passion is to inspire people to grow plants, to connect with nature, and have a positive impact on the world.

Aravindan Kalaichelvam is Senior Engineer in the Infrastructure division at Atkins. He has over 12 years of experience working in hydraulic modelling of sewer and storm network drainage flows. He is also working on his PhD (part time) in the field of Sustainable Drainage Systems (SuDS) at Heriot-Watt University.

Drainage capacity of cork boards applied as base layers on living walls.

C. Pimentel-Rodrigues (1, 2), N. Simões (3,4), A. Tadeu (3,4) and A. Silva-Afonso (1,2)

(1) Portuguese Association for Quality in Building Installations (ANQIP), Portugal; anqip@anqip.pt
(2) RISCO (University of Aveiro, Portugal)
(3) ITeCons - Institute for Research and Technological Development in Construction, Energy, Environment and Sustainability, Portugal
(4) ADAI – LAETA, Department of Civil Engineering (University of Coimbra, Portugal)

Abstract

Introduction and aims: Urban growth is the cause of numerous environmental problems, and today we recognize the importance of adding green areas to the urban environment as an essential contribution to ensure sustainability in cities. Green roofs and vertical greening systems (VGSs) are considered as very suitable strategies to mitigate these negative effects. As regards VGSs, green facades and living walls are recent solutions that are beginning to become popular, but which normally require watering and drainage. The objective of this paper is to present the results of an experimental study to evaluate the drainage capacity of insulation cork boards, with a view to their use as a base layer in plant supports for living walls. **Method:** In the paper we characterize various types of cork boards on the market for insulation and are presented the tests carried out to evaluate the drainage capacity of these boards, applied as base layers of plant supports in living walls. **Results and conclusion:** The experimental studies have allowed for determination of the amount of water flowing through the material, the time required for a certain amount of water to flow out, the peak of the water flow and the amount of water retained in the material. It has been found that the cork boards are suitable for application in living walls if grooves are cut in the boards **Contributions:** The paper demonstrates the feasibility of applying insulation cork boards as base layers for plant support in living walls, as well as the conditions to enable such use.

Keywords water drainage, vertical greenery systems, living walls, living facades, cork boards

1 Introduction

Urban growth is the cause of numerous environmental problems, and today we recognize the importance of adding green areas to the urban environment as an essential contribution to ensure sustainable cities. Green roofs and vertical greening systems (VGSs) are considered as very suitable strategies to mitigate these negative effects.

VGSs are recent solutions that are starting to become popular. They consist of vertical structures that fix the vegetation (also called bio walls or vertical gardens) and are generally a solution for exterior facades, but may also be considered in interior walls.

The species should be selected in relation to geographical location, aesthetic criteria, sun exposition, local climate, etc. The benefits of VGSs are well documented in the literature and are felt in terms of temperature, hydrology, acoustics, air quality, aesthetics, biodiversity, etc. [1,2].

Vertical greening systems can be classified into two large groups [3-6]: green facades and living walls (Figure 1). In green facade systems, the vegetation is usually rooted near the base of a wall or facade, next to a special vertical structure through which the plants climb. Green facade systems can also be designed with plants grown on rooftops, forming a green cascade. In the living walls there are several levels of planting, demanding more complex systems of fixation and support [1,2].

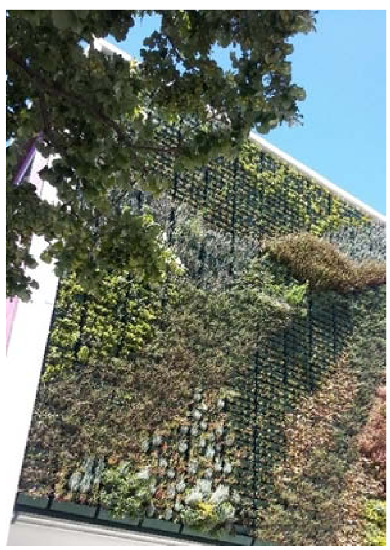

Figure 1 – Living wall (Coimbra, Portugal)

Recently, there have appeared on the market solutions for the integration of living walls with building systems of ventilation and air conditioning in which air is forced through the bio wall and collected afterwards. In these solutions, designated as "active living wall", the "recycled" fresh air is supplied to the building's interior, more cooled, filtered and humidified by the plants and growing media.

Common types of living facades usually require irrigation and drainage at different levels and also require a vertical impermeable membrane between the living wall and the building in order to avoid dampness problems. Panels with pre-vegetated supports are a common solution for planting these living facades.

Although there are other technical solutions, living walls constituted by trays are a common configuration and can be constructed similarly to a green roof, with the same type of layers. In a top-down sequence, these layers are: vegetation, substrate as root support and growing medium, filter sheet, the drainage and water storage element and a mechanical protection mat or root barrier laid over waterproofing membranes or insulation boards, depending on the solution.

The living walls have particular requirements for water drainage and water storage. Because they usually work with a small substrate depth, the water storage and drainage layers are significant for plant health and development. The objective of this paper is to present the results of an experimental study to evaluate the drainage capacity of insulation cork boards , with a view to their use as a base layer in plant supports for living walls.

Insulation cork board (ICB) is a 100% natural material [7], made solely from the waste generated by both the extraction and the subsequent processing of cork. It is processed by compressing granules of cork in an autoclave with superheated steam. Cork granule agglomeration is produced by induced superheating and pressure and by the release of suberin triggered by this process. In the building sector, where the production of most raw and finished materials involves high energy consumption, ICB is an environmentally friendly material with a negative carbon footprint [8].

The result is a block which is then cut to form boards of the desired thickness [9]. It can be produced with various mass densities and is mostly used in buildings for insulation purposes, given the natural properties of cork. Because of ICB's insulation characteristics [10,11], the use of ICB in green roofs allows us to simplify the system and eliminate the conventional insulation layer by changing the drainage and water storage layer materials.

This paper examines ICB water drainage and retention characteristics and compares the results with a reference product on the market, the cup style Floradrain FD25-E drainage and water storage element. The drainage and water retention performance of different ICB densities and thicknesses was assessed to determine the most suitable ICB density and thickness for use in trays of a living wall.

The literature has several studies that address water drainage and water retention in green roof systems. Generally, they follow well described methods set out in FLL (*Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau*) guidelines for determining maximum water capacity and water permeability or make use of lysimeter gear [12,13] when evapotranspiration is a factor.

However, in relation to the evaluation of water drainage in living walls, the available studies are very scarce [14]. In addition, the referred methods for green roofs are more suitable for assessing the behaviour of the system as a whole rather than an individual component, as this research set out to do.

2 Experimental methodology

2.1 General

The design of a living wall with ICB is represented in Figure 2, in a schematic form. The width of the trays is approximately 25 cm, this value having been adopted for the test samples. All the tests were carried out using calibrated equipment and were performed under controlled laboratory conditions (T=23±2 ºC and RH=50±5 %).

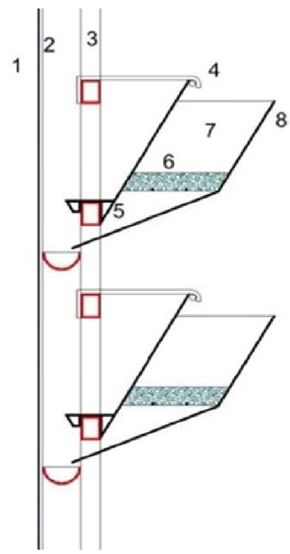

Figure 2 – Living wall simplified scheme: 1 – Wall; 2 – Waterproof membrane; 3 – Metal support module; 4 – Watering pipe; 5 – Drain; 6 – ICB; 7 – Substrate; 8 – Plastic tray for plants

Insulation cork board samples of two different nominal mass densities (manufactured by "*Amorim Isolamentos*", in Portugal) were tested: Standard ICB (STD), mass density between 90 and130 kg/m^3, and Medium ICB (MD), with mass density between 140 and 160 kg/m^3. The variation in mass density is due to the uneven characteristics of ICB made only with natural cork granules. There is still a high density (HD) ICB, but it has not been tested because it is not considered of interest for this application, due to its compactness.

A commercially available thermally strengthened polypropylene filter sheet, SF from ZinCo, was used to separate the ICB (or FD25-E) and the substrate. The tests used a technical substrate common in green roofs, developed to meet FLL guidelines, consisting of fermented pine bark humus, blonde peat, expanded clay, volcanic rock, 74.42 % organic matter ratio, and with pH corrected to 5.5-6.5.

2.2 Experimental tests

The purpose of the experimental programme was to assess the vertical drainage and storage capacity of the ICB when subjected to the effect of gravity. Three main sets of vertical water flow tests were performed, one with bare ICB, another using ICB, filter and substrate and the last with FD25-E instead of ICB.

The test specimen was loaded with a certain quantity of water and the discharge was measured continuously over a period of 24 hours. The tests were repeated consecutively 3 times (T1, T2 and T3) for each specimen. The apparatus built for the tests includes a box container for the ICB, substrate and loaded water, a metal workbench for holding the box test specimen, a receptacle for collecting the water, and a precision calibrated weighing scale connected to a computer (Figure 3).

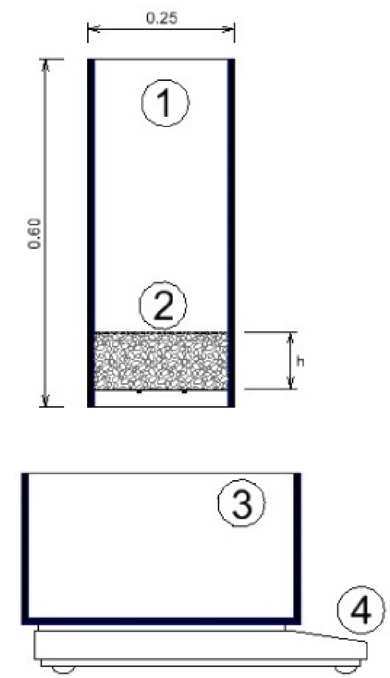

Figure 3 –Test apparatus: 1 - Container for ICB specimens, substrate and water; 2 – ICB specimen (h = 50 mm or 100 mm); 3 – Water collector box; 4 – Weighing scale connected to a computer

The first series of tests (with bare ICB) used specimens with 50 mm and 100 mm thick in two densities, STD and MD. For each specimen three test samples were cut from the same original board (total of 12 tests). During the tests the ICB with the thickness of 100 mm was revealed to be unsuitable for living walls (although the results may be of interest to green roofs) and for this reason, the values obtained with the ICB 100 mm will not be analysed in this paper.

All test specimens were weighed before and after the test to determine water retention. In all tests, the box container was loaded with 11.25 litres of water, equivalent to a 180 mm water blade on the tested area. The discharged water was continuously weighed for 24 hours (5 measurements per second), until there were no more water drops.

3 Results and discussion

3.1 General aspects

In the plotted figures, the designations "STD*n* T*m* *S*" and "MD*n* T*m* *S*" were used for the three types of ICB, and "FD25-E T*m* *S*" for the reference material, where *n* identifies the specimen, *m* the number of the test performed using the same test specimen (samples 1, 2 and 3) and *S* when the substrate was also included. At the start of test T1, the sample was dry; but for T2 and T3 the samples were wet, as a result of the previous tests. Tests T2 and T3 were run 24 hours after the start of the previous test.

3.2 Bare ICB

Figure 4 presents the accumulated drained water and the associated flow rate results obtained with the bare standard (STD) ICB test specimens. As expected, it can be seen that the thickness of the material affected the time taken to drain the same amount of water. STD ICB 100 mm thick required approximately twice as long to drain the same amount of water as the 50 mm specimen.

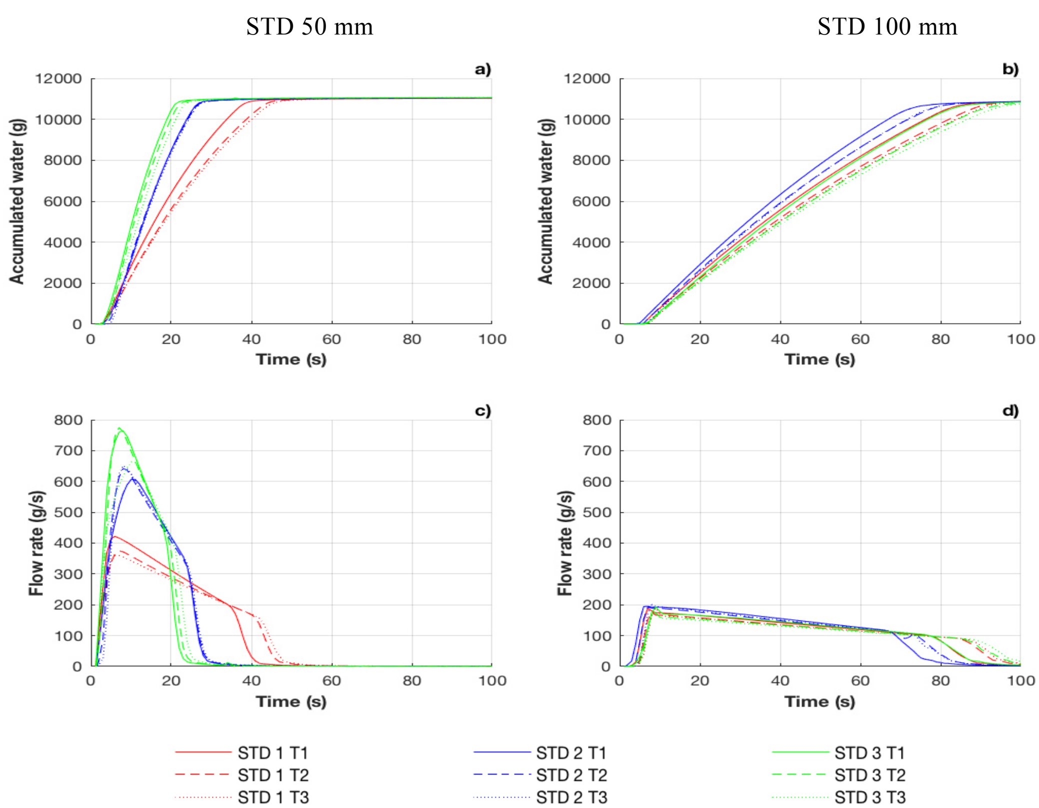

Figure 4 – STD ICB (bare state): a) Accumulated water for ICB 50 mm thick; b) Accumulated water for ICB 100 mm thick; c) Flow rate for ICB 50 mm thick; d) Flow rate for ICB 100 mm thick.

In the following tests, T2 (dashed lines) and T3 (dotted line) with the sample already wet, a slight decrease was found in the ICB material's capacity to drain the water. On the other hand, for each performed test the water retention increases from 1309 g/m^2 in STD50 T1 to a maximum of 3077g/m^2 in STD50 T3. It can also be seen that the results obtained with the three test specimens cut from the same ICB board (Figure 4, red, blue and green lines) exhibit some dispersion. The flow rates for the three test specimens (Figure 4c) and d) illustrate this behaviour. This dispersion is most relevant for the 50 mm test specimens.

The experimental results for the medium (MD) ICB test specimens are not presented in this paper, due to extension limits.

The results for the FD25-E (polyolefin 'cup' style boards) (Figure 5) are presented in Figure 6. This material needed about 60 seconds to drain most of the loaded water. The peak water flow barely changed between tests, recording 352.3 g/s in T1 and 358.5 g/s in T3.

Figure 5 – Floradrain FD25-E (ZinCo, 'Floradrain® FD 25-E Product Data Sheet)

Water retention behaviour is different from that of the ICB material. FD25-E achieved almost the maximum water retention capacity in the first test run as the cups filled up. The maximum water retention registered is 2848 g / m^2 in T3, just 5.6% more than in T1.

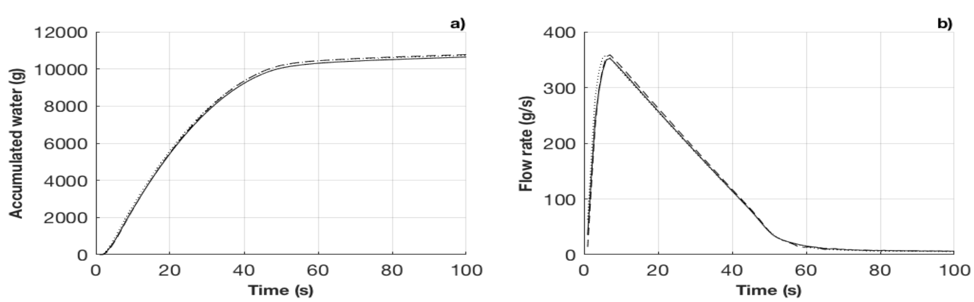

Figure 6 - FD25-E: a) Accumulated water for FD25-E; b) Flow rate for FD25-E.

All the tests make it very clear that ICB, an uneven natural material made from compressed cork granules, gives results with some dispersion, even though samples of each density were carefully taken from the same board. Peak flow can be as much as double for the same material, meaning that significantly different amounts of time are taken to drain the same amount of loaded water.

The reference material (FD25-E), however, shows nearly equal flow results for all the tests and reaches near maximum water retention in T1. In T2 and T3, the additional water retention is marginal, confirming that under bare state conditions the reference product exhausts its capacity for water storage in the first test. All the other ICB samples show an increasing water storage capacity as the tests are performed, thus surpassing the reference product retention values at the end of the test cycle.

3.3 ICB test specimens with a layer of substrate

The addition of substrate to test specimens reduced the capacity to drain water for all samples, as expected. Figure 7 illustrates this behaviour by comparing the performance of STD ICB in the bare state and with added filter and substrate. Looking at c) and d), there is much more impact on the peak flow of the 50 mm specimen than on that of the 100 mm specimen.

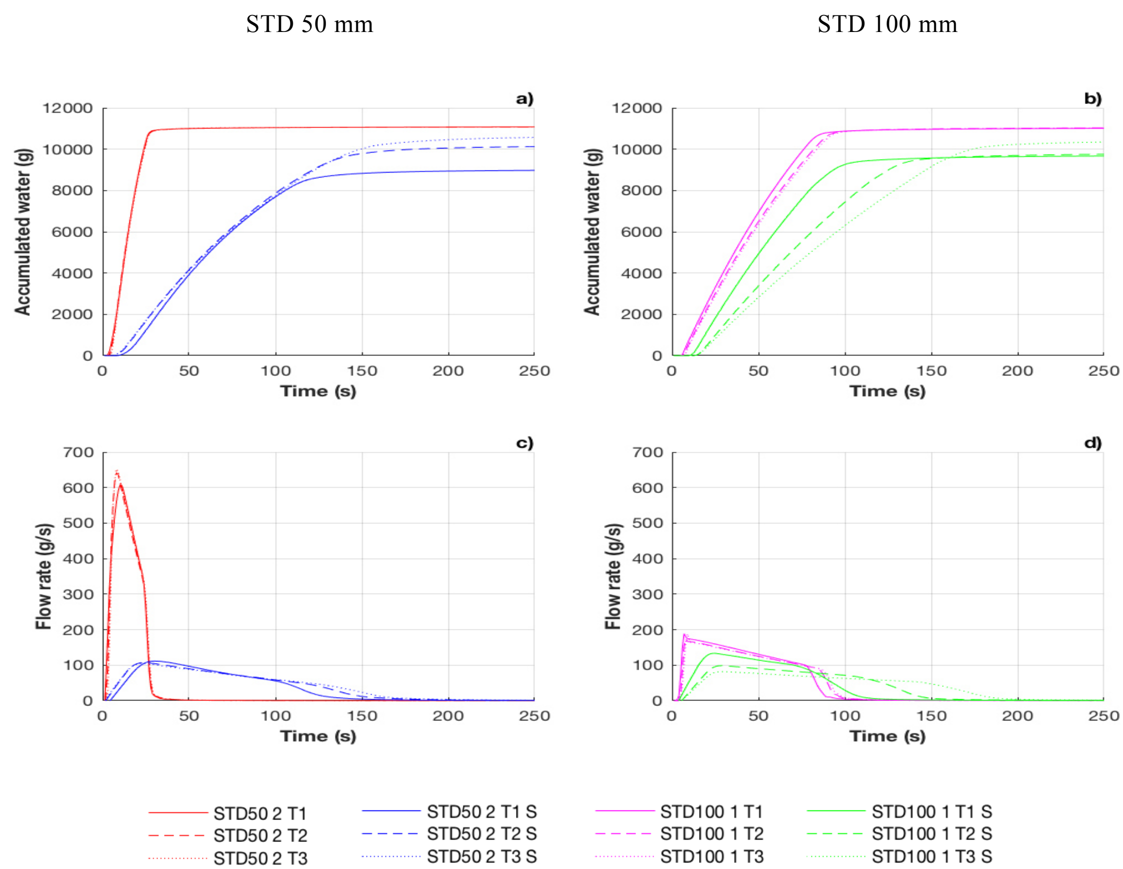

Figure 7 - STD ICB bare versus STD ICB with substrate vertical water flow: a) Accumulated water for ICB 50 mm thick; b) Accumulated water for ICB 100 mm thick; c) Flow rate for ICB 50 mm thick; d) Flow rate for ICB 100 mm thick.

For the MD ICB, a lower capacity to drain water when the substrate has been added is again observed. However, as the peak water flow on the bare MD was found to be already reduced, the differences in the drainage performance after the substrate was added were found to be less striking than for the STD. On the other hand, the addition of substrate to the test samples leads to much higher values of water retention in all the studied materials.

Figure 8 displays the values obtained for the accumulated water drainage and flow rate for 50 mm and 100 mm STD and MD ICB against the reference solution (FD25-E), now with substrate. Both the 50 mm and 100 mm STD ICB (Figures 8 a) and c) drain water more quickly than the FD25-E.

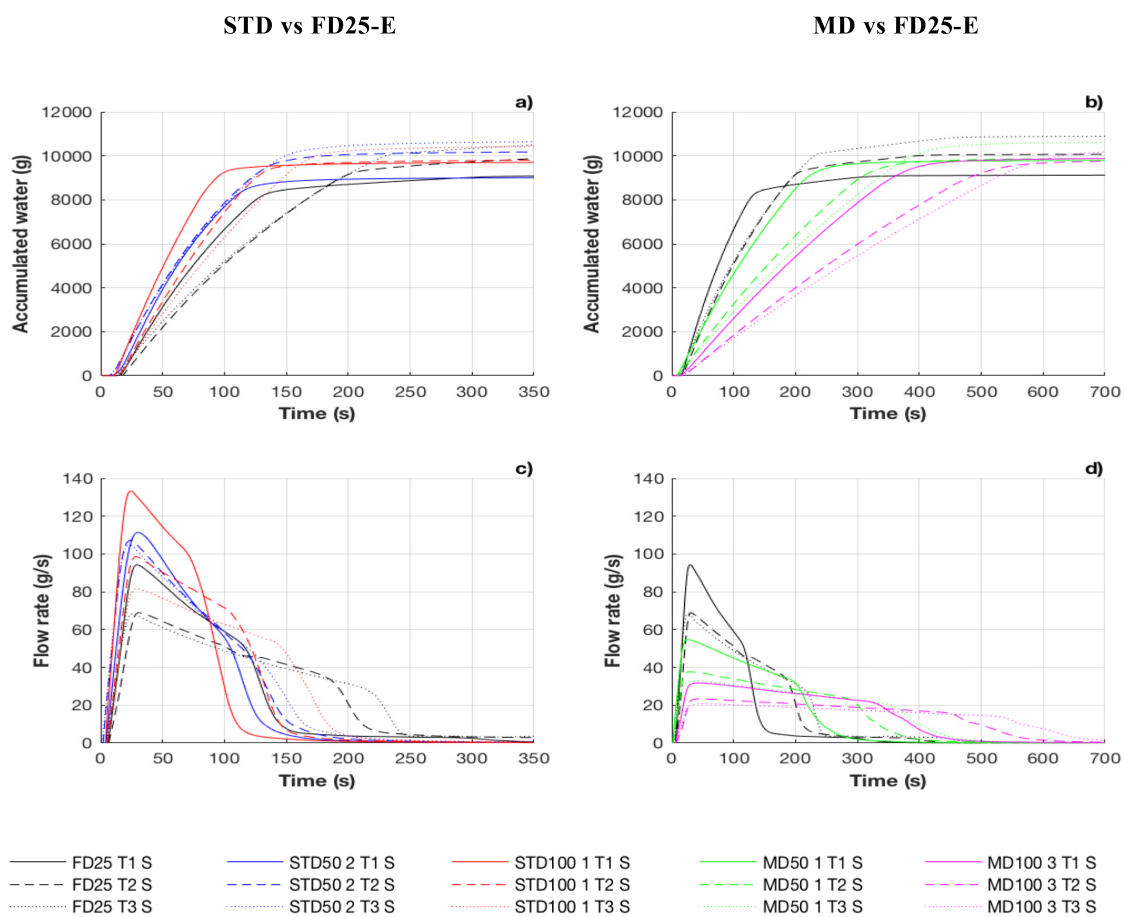

Figure 8 - ICB versus FD25-E (with substrate): a) Accumulated water for STD ICB 50 mm, 100 mm thick and FD25-E; b) The same for MD ICB; c) Flow rate for STD ICB 50 mm, 100 mm thick and FD25-E; d) The sane for MD ICB

In the first discharge, STD ICB registers a flow rate above 130 g/s, while FD25-E reaches a value of 94 g/s. After wetting, in the second and third test (T2 and T3), although all samples lose some drainage capacity, the ICB performance compares even more favourably with the reference product than before. Figure 10c) shows a greater gap for T2 peak flow rate between STD ICB and FD25-E (107 g/s for STD50 and 69 g/s for FD25-E). On the other hand, the results in Figure 8 b) and d) show that the MD ICB is less able to drain water than the reference product. The peak flow with substrate is only 55 g/s and 32 g/s for the MD50 T1.

4 Conclusions

Figure 9 summarizes the results of the tests carried out and shows the time taken to drain 25 %, 50 % and 75 % of the total loaded water on samples in the bare state (solid colours) and with substrate (faded colours). There was a clear increase in time for the bare ICB tests when both density and material thickness increase. For the natural ICB material the time taken for water drainage was also clearly longer in tests T2 and T3, when samples were already wet from the previous test.

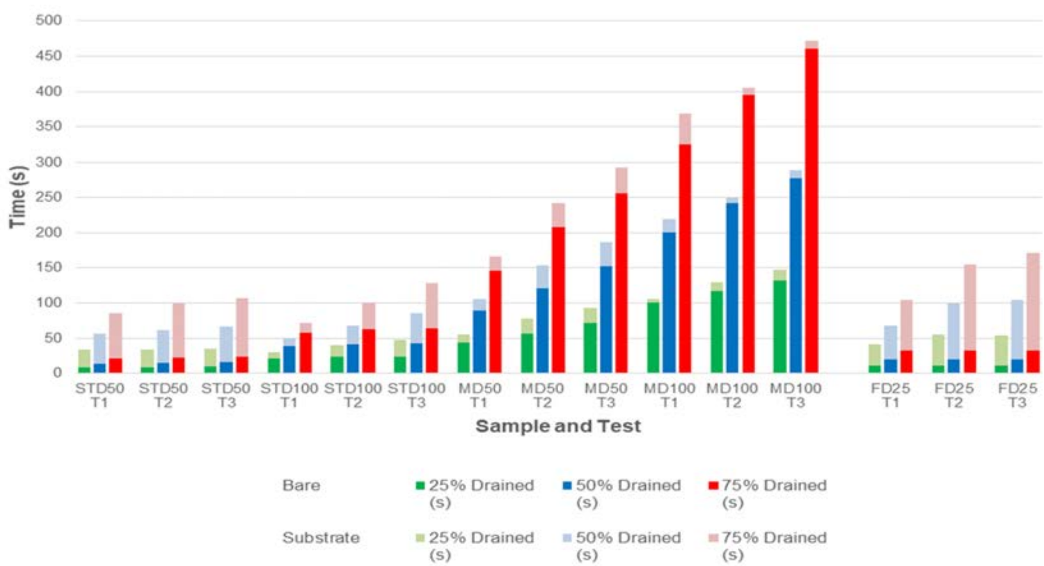

Figure 10 - Time taken to drain 25%, 50% and 75% of the total amount of loaded water.

For the reference material, FD25-E, the time is similar for all water discharges. In this state, only the 50 mm STD ICB is able to drain the water more quickly than the reference product, despite the performance being poorer in tests T2 and T3. However, some of this behaviour changed after the substrate was added to the test specimens. Despite all specimens taking longer to drain the same amount of water, the first noticeable change was that the reference product also took more time to drain water in consecutive tests, as had previously occurred with the bare ICB.

After performing the tests and comparing the results with those of the reference product, it was concluded that STD ICB is suitable for application in living wall trays, helping to make more natural vertical greening systems.

5 Acknowledgements

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7 Presentation of Authors

Carla Pimentel Rodrigues holds a PhD from the University of Aveiro (Portugal) in Civil Engineering (water efficiency). She is Technical Director at ANQIP – National Association for Quality in Building Installations and is also member of the Research Centre RISCO at the University of Aveiro. She he has published 2 books in the field of water efficinecy in buildings and one chapter in an international book.

Nuno Simões (in Civil Engineering) is Assistant Professor in the Department of Civil Engineering, University of Coimbra and Senior Scientific and Technical Researcher at IteCons; he has published 34 papers in indexed scientific international journals and presented more than 60 communications in conferences. He has participated in 11 funded research projects and has supervised 2 PhD theses, with 6 others in progress.

António Tadeu (PhD in Civil Engineering) is full Professor in the Department of Civil Engineering, University of Coimbra and current President of the board of IteCons; he has published 4 books and 132 papers in international scientific periodicals with referees (ISI), in the research areas of numerical modeling, experimental and analytical studies on applied mechanics, and building physics; he has participated in more than 25 different research projects and supervised 16 completed PhD theses.

Armando Silva-Afonso is a retired Full Professor at the University of Aveiro (Portugal), Department of Civil Engineering, where he collaborates as Visiting Professor. His specializations are urban and building hydraulics and water efficiency in buildings, and he is President of the Board of ANQIP - National Association for Quality in Building Installations, in Portugal. He is also an invited expert of the European Commission for water efficiency in buildings.

The performance assessment of heat pump integrated with chilled water wall in different controlled parameters

M.C. Jeffrey Lee (1), Y. M. Fang (1), Christoph Mitterer (2), Hartwig. M. Künzel (2)

(1) MCJL@nutc.edu.tw, Department of Interior Design, National Taichung University of Science And Technology, No.129, Sec.3, Sanmin Rd., Taichung City, 404, Taiwan(R.O.C)

(2)Christoph.Mitterer@zv.fraunhofer.de,Fraunhofer-Gesellschaft, Internatinoal Business Develepment, Head of Team Innovation Markets, Hansastraße 27c, 80686 München, Germany

Abstract

The heat pump integrated with chilled wall has developed for air cooling, dehumidifying, air cleaning, and water heating, as we presented in 2018 CIB062 symposium. It was followed the fix flow rate to change the indoor hygrothermal environment. This study tries to change the falling speed by different flow rate in 300 L/h, 400 L/h, and 500 L/h to assess the performance of indoor hygrothermal environment and indoor air quality. It also considers the water heating performance while the heat pump operating. The results present the flow rate reaches to 400 L/h is the optima conditions for heat pump integrated with chilled water wall to influence the cooling, dehumidifying, air cleaning and water heating.

Keywords

energy efficiency; heat pump; chilled water wall; dehumidifying; cooling; heating.

1 Introduction

Surface-cooling systems that cool indoor air have been developed for a few years and include chilled-ceiling systems. The systems cool an indoor air environment evenly, but water can easily condense and drip from the ceiling when the cooled air temperature is lower than the dew point in the hot and humid climate zone. To prevent conditions from being favorable for mold growth, the surface humidity must always be kept below 80% relative humidity. [1] The surface temperature of a chilled ceiling must be higher than the dew point of the indoor air temperature. This causes the cooling efficiency to be low, and the air-conditioning performance of chilled ceilings is thus limited in the hot and humid climate zone.

A new type of air-conditioning system called the chilled water wall (CWW) has been developed for air cooling, dehumidifying, and air cleaning. The system operates at temperatures below the indoor air dew point, and moisture in the air is condensed into a water film that is discharged into a water basin. The water temperature is controlled by a cooling unit placed outside the air-conditioned zone. The CWW cools the convective air flow while simultaneously forming a heat sink for absorbing the long-wave radiation emitted by people and objects in the room. Mitterer provided climate-specific design principles for optimizing the energy efficiency and occupant comfort of buildings. [2] Surface-cooling elements such as cooling walls noticeably reduced the amount of noise and uncomfortable draughts and had an additional benefit by providing radiative heat exchange. Unlike with a chilled ceiling, the advantage of a CWW is that the air flowing over the water film is not only cooled but also simultaneously dehumidified because the water has a temperature below the dew point of the indoor air.

CWWs are designed to chill water, dehumidify, and clean the air. Moreover, they are connected to a heat pump that chills and heats water on both sides simultaneously, which reduces the energy consumption for these dual functions, as illustrated in Figure 1. The heat pump integrated with a CWW supplies not only chilled water for air conditioning but also domestic hot water, improving energy efficiency through its multifunctionality. The chilled water temperature, dew point for dehumidifying indoor air, water falling speed, and water quality are the factors that should be considered and optimized for different climate zones.

Research on the indoor environment quality (IEQ) of CWWs has focused on temperate climates, with less results and discussion related to the hot and humid climate zone.

Numerous thermal comfort standards have been published in the past years, especially International Organization for Standardization 7730 [3] and American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)55-2017[4], but the ASHRAE standard is only applicable to the North American climate. Q. J. Kwong et al. [5] showed that most of them didn't meet the thermal comfort interval defined by ASHRAE.

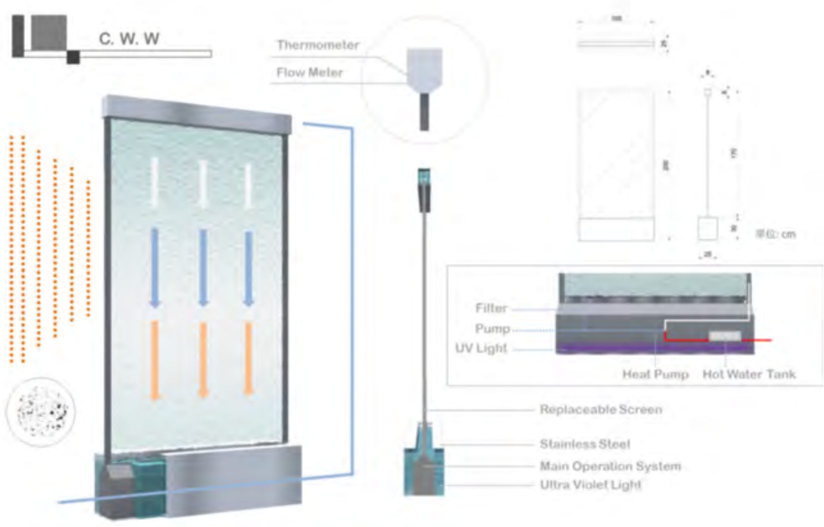


Fig. 1 Scheme of CWW as an A/C, air cleaning, and water heater with heat pump

R.L. Hwang et al. [6] investigated the difference between the thermal comfort range of Taiwanese (hot and humid zone) and ASHRAE. The survey included 10 natural ventilation and 26 university classrooms with air conditioning. A total of 1294 samples were sampled, of which only 12% were in the ASHRAE thermal comfort zone. This shows that Taiwanese comfortable range is large different from ASHRAE definition. Under the conditions acceptable to 80% of personnel, Taiwanese feel comfortable in the range of 24.2ET*-29.5ET*, which is much higher than the upper limit of 23.2ET*-26.5ET* defined by ASHRAE. This is because the occupants who living in hot and humid climate zone have become accustomed to the subtropical climate of high temperature and high humidity, and the tolerance for temperature is higher than that of European and American countries, as shown in Figure 2.

Lee et al. [7] discovered that the thermal comfort area in a hot and humid zone is different from that specified in the ASHRAE standard. Givoni [8] suggested that the thermal comfort temperate range had to be modified to 29°C and the humidity to 80% for hot and humid tropical regions.

CWW research has been conducted at the Fraunhofer Institute for Building Physics. However, the research results have indicated that no empirical values are available regarding how the existing model performs for a relative humidity higher than 80% or an air temperature above 26℃, conditions common in Taiwan, which in most areas has a yearly average relative humidity of higher than 75% and has monthly average relative humidity above 70%.[9] Therefore, because the existing model was developed using empirical data, a more detailed theoretical model must be constructed for conducting research with all conceivable boundary conditions. Measurements made in subtropical and tropical climate zones must be verified to evaluate the performance of CWWs.

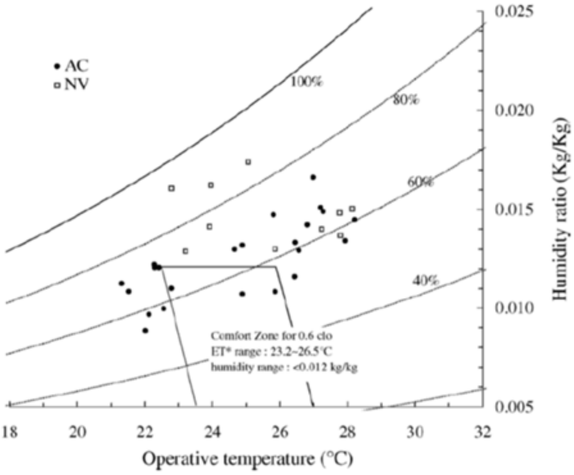


Fig. 2 Comparison of Taiwan and ASHRAE Thermal Comfort range [6]

2 Methodology

The temperature of chilled water affects the radiative cooling efficiency at a given distance. According to WUFI® simulation of a 5 m × 5 m space at 26℃, the effective radiant cooling distance is approximately 2.5 m from a CWW when its chilled water temperature is 2℃, as shown in Figure 3 [10].

A validation experiment was conducted in a full-size climate room to verify the parameters and boundary conditions for WUFI simulation. This study referred to the simulation results to design an experiment for determining the efficiency of a CWW in a hot and humid climate.

Two rooms of the same size were set up to compare climate conditions. The temperature of the CWW and air were measured, as well as the relative humidity of the air at various distances from the CWW, as shown in Figure 4. A prototype CWW was placed in room A, as were the sensors used to measure the temperature, flow rate, and pressure of the chilled water in the prototype.

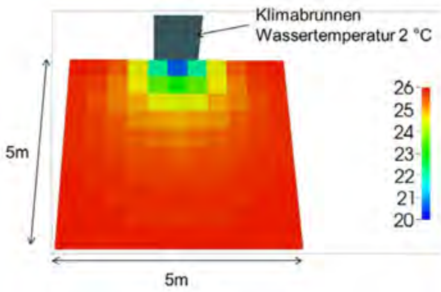


Fig. 3 The effective cooling distance simulation by WUFI [8]

Fig. 4 The validation experiment and the sensors setup in two test room

K. Cakyova, F. Vranay & M. Kusnir [11] indicated that the change of flow rate will change thickness of water film. During the running of the water wall, the optimal rate of water flow is from 300 l/h to 500 l/h, at lower speed, water film was not formed in whole width, while water bounced off the water film at a higher speed. To verify the performance of indoor hygrothermal environment and indoor air quality, these three kinds of fixed flow rates will be used for the experiment of CWW.

To evaluate the performance of the CWW, the chilled water temperatures in the water supply pipe (T_{CW}) and basin (T_W) of the water film were measured. The chilled and heated water temperatures (T_{CW} and T_{HW}), water velocities (V_{CW} and V_{HW}), and water pressures (P_{CW} and P_{HW}) were measured by sensors connected to a data logger (CR1000: Micro logger®).

To validate the simulation and real-site results, sensors measuring the air temperature (Ta_i) and relative humidity (RHa_i) were set up at points 0 to 3 (i = 0~3) corresponding to distances from the CWW of 0~3 m (selected on the basis of the WUFI simulation result). A thermometer was also placed in the middle of room B and acted as point of a comparison. In addition to monitoring data of water temperature and flow during the water cycle, water quality was maintained using ultraviolet light and a filter for ensuring the CWW with heat pump was operating favorably, as shown in Figure 5. A water insulation storage bucket was employed to maintain the temperature of the chilled water and hot water from the heat pump that was used in the next CWW water cycle.

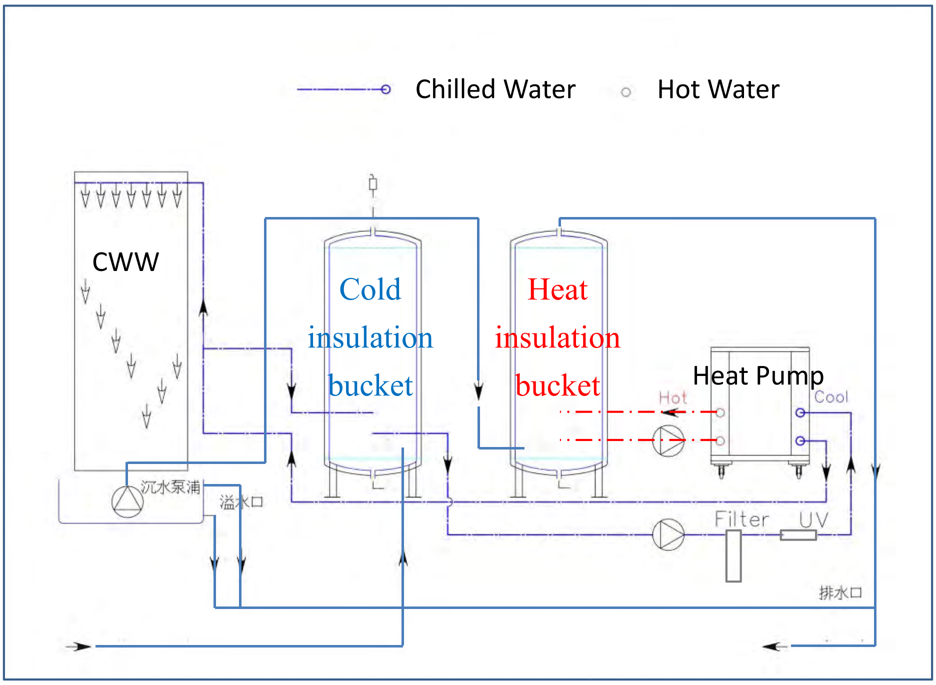


Fig. 5 The connection of CWW integrated with the heat pump

3 Results & Discussion

The test was conducted in the summer, when the indoor ambient temperature was approximately 32°C and the relative humidity was approximately 58.5%. The area of each room was approximately 20 m^2. Data were obtained every 5 min for 8 hours by using the automatic sampling method.

According to Figure 6, the temperatures at the sensors located from the CWW (distance of 0 m) to 3 m away were 27°C, 30°C, and 32°C, respectively, when the chilled water temperature was 8°C to 9°C and the indoor ambient temperature was approximately 32°C. Comparing the charts of indoor air temperature, relative humidity, and absolute humidity, which are displayed in Figures 6 and 7, the absolute humidity can be observed to be affected by the distance from the CWW. This verified that the CWW exerts a dehumidifying effect under these climate conditions. (The absolute humidity in room B was the highest absolute humidity measured in this test.) The relative humidity at point 0 (RH0) and point 1 (RH1) were always higher than that in room B because of the lower temperature in room A. The temperatures at point 2 (T2) and point 3 (T3) were similar to the indoor ambient temperature (approximately 32°C), and the difference in relative humidity between point 2 (RH2) and point 3 (RH3) indicates that the dehumidifying effect was stronger at point 2 than point 3, which was further from the CWW.

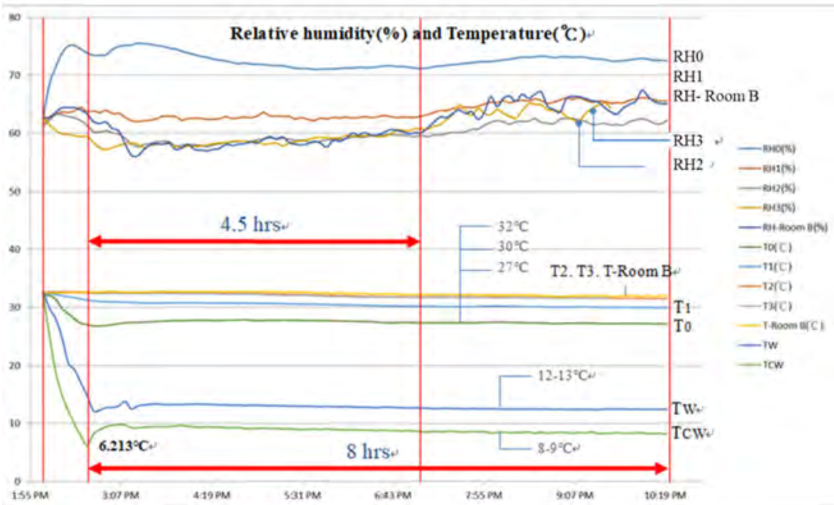


Fig. 6 The chart of temperature (°C) and relative humidity (%)

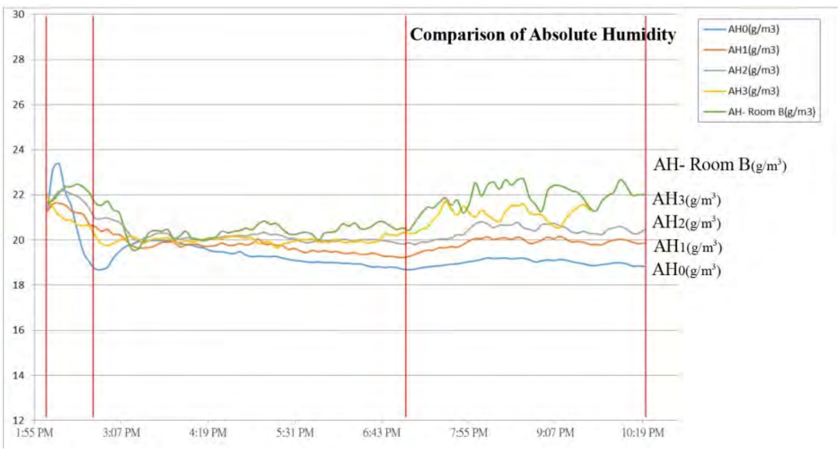


Fig. 7 The comparison of absolute humidity from each point

This result verifies the performance of the CWW at air cooling and dehumidifying, but some additional points are worth discussing regarding the dehumidifying and air-cooling effect of distance from the CWW. When the average water temperature is lower than the dew point temperature of indoor air, moisture in the air condenses more easily onto the water film, which must be reflected by a drop in the relative humidity. This study speculated that if the chilled water temperature was lower than or equal to 6°C for a long time, the cooling effect at each temperature point in room A would be stronger.

In this experiment, the average chilled and heated temperatures of water in the heat pump were approximately 9°C and 37°C, respectively, and the average chilled water flow was 2.8 L/min. The variation in the chilled and heated water temperature in this experiment is displayed in Figure 8. The coefficient of performance of the heat pump was calculated to verify the energy efficiency, which is integrated with CWW.

To research all conceivable boundary conditions in subtropical and tropical climate zones, future studies must verify the performance of the CWW at air cooling and dehumidifying for various parameters of the CWW to reflect different climate zones (constant water temperature with constant water flow, constant water temperature with variable water flow, variable water temperature with constant water flow, and variable water temperature with variable water flow).

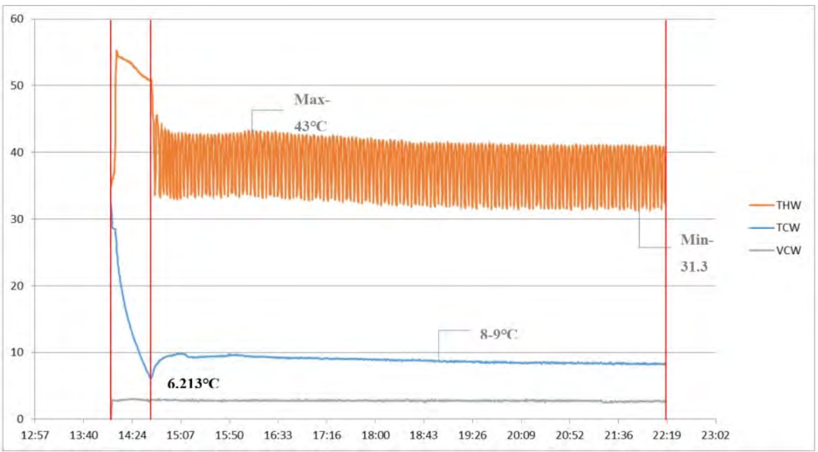
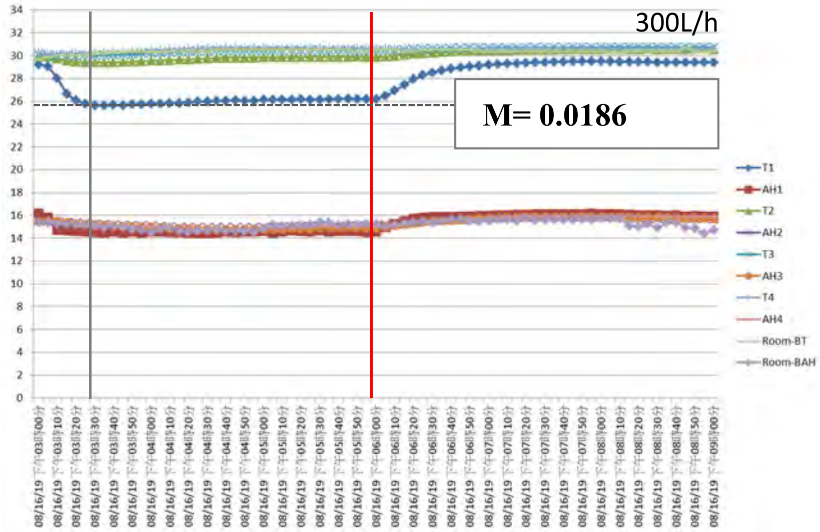


Fig. 8 Temperature of chilled and heated water in the heat pump

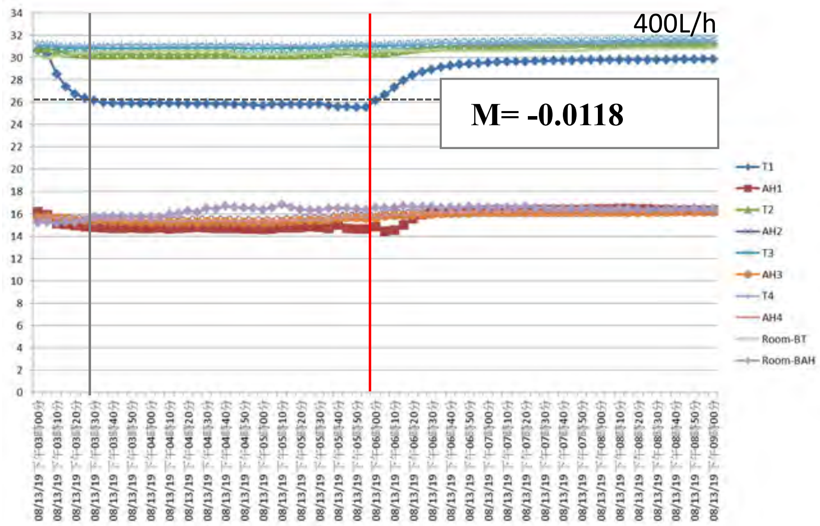
This study tries to change the falling speed by different flow rate in 300 L/h, 400 L/h, and 500 L/h to assess the performance of indoor hygrothermal environment and indoor air quality. Three different flow rate tests were conducted in the summer afternoon (15:00 to 21:00, stop running CWW 3 hours later). The indoor ambient temperatures were approximately 30°C. Three charts verify the temperature of chilled water affects the radiative cooling efficiency at a given distance, besides, compare the cooling performance of different flow rate, to calculate the slope between two points from 3:30 pm to 6:00 pm. The slope of the indoor air temperature in 300 L/h, 400 L/h, and 500 L/h is 0.0186, -0.0118 and -0.02027. The results of three different fixed flow rate show that the flow rate reaches at least to 400 L/h could cool the indoor air temperature effectively, as shown in Figure 9.

Compare to the absolute humidity of room B, the performance of dehumidifying in 300 L/h is not obvious, and it is even higher than room B. The results of three different fixed flow rates show that 400 L/h is not only the optima conditions for heat pump integrated with chilled water wall to influence the cooling, dehumidifying, air cleaning and water heating, but also more energy efficient than 500 L/h.

Ambient temperature 29.7°C
RH- 67.5%
AH- 15.4 g/m^3



Ambient temperature 30.1°C
RH 66%
AH- 15.2 g/m^3



Ambient temperature 30.8°C
RH- 68.7%
AH- 16.1 g/m^3

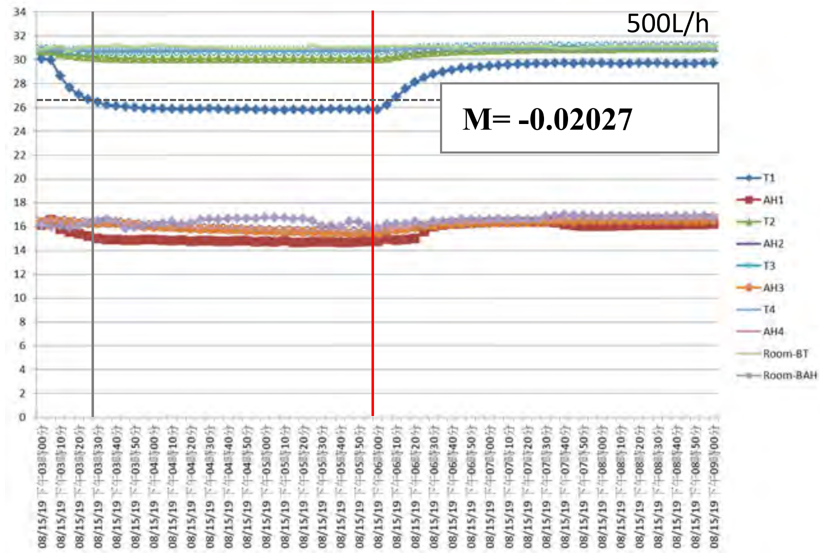


Fig. 9 The chart of temperature (°C) and absolute humidity(g/m^3)

Besides to verify the performance of CWW, this study will collect the IEQ questionnaires and the predicted mean vote and predicted percentage dissatisfied calculated to determine satisfaction with the environment in greater detail. The IEQ results will be integrated, and the modified CWW parameters will be compared with the original CWW parameters for a different climate zone to verify the favorable performance of the CWW. In the next experiment, some impact factors may be need to be controlled, such as the effective radiant cooling effect and dehumidifying distance from the CWW in different climate zones, chilled water temperature, pumping speed, and water quality for flushing air pollutants into water (using ultraviolet light and a filter).

4 Conclusion

The effective radiant cooling distance is approximately 2 m from a CWW when its chilled water temperature is 8°C to 9°C and the indoor ambient temperature was approximately 32°C. In addition, the results of three different fixed flow rates show that 400 L/h is not only the optima conditions for heat pump integrated with chilled water wall to influence the cooling, dehumidifying, air cleaning and water heating, but also more energy efficient than 500 L/h.

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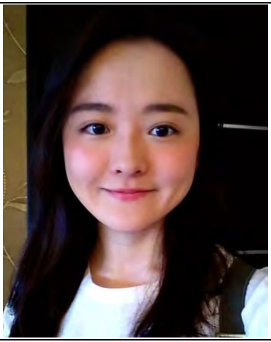
Presentation of Authors

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.

Yi-Ming Fang is the graduate student at National Taichung University of Science and Technology, Department of Interior Design	

The Development of ISO Standard PC 31600 - Water Efficient Products

Coauthors: Dr. Steve Cummings (1); Peter DeMarco (2)

1. scummings@gwagroup.com.au
2. pete.demarco@iapmo.org

(1) Director of Innovation, GWA Group, Australia
(2) Executive Vice President of Advocacy and Research, The IAPMO Group, USA

Abstract

Consumer water efficiency labeling programs such as the Australian WELS program and the U.S. EPA's WaterSense program, have been proven to save trillions of liters of potable water and billions of dollars for consumers in reduced water utility bills. While these programs have been developed to work effectively in more economically advanced countries with strong supporting standards and government agencies, the water saving benefits from these programs have not been available to developing countries and countries that do not yet have a water efficiency labeling program.

In 2017, Standards Australia issued a proposal to the International Organization for Standardization (ISO) to develop an international standard that would work to "encourage the development and marketing of water efficient products, enable consumers to clearly identify and purchase the best products within the industry, and positively influence manufacturing to improve the performance of their products through consumer power and information." Importantly, the standard, which will be developed as ISO PC-31600, will provide countries that do not have existing standards and consumer water efficiency labelling programs to apply an international standard that will save many more trillion liters of water globally.

The scope of ISO PC-316 will include the establishment of water efficiency flow rates and consumption values along with key performance test requirements for plumbing products and appliances, specifically: showerheads and mixing valves, faucets/taps, flow control devices, toilets (all types), urinals, flushometer valves, dishwashers for domestic use, clothes washers for domestic use, and the dryer function of combination washer/dryers, where water is used to dry washing loads. It is expected that an important outcome from the ISO 316 technical committee's work will be the establishment of suggested universal rating/and or labelling requirements based on a set of water consumption tests.

Meeting the requirements of the standard will allow manufacturers to apply an internationally recognized label to their products, identifying them as being both high performing and water

efficient. The standard will also be designed to work seamlessly with existing national-based consumer labeling programs already in place, such as the Australian WELS program and the U.S. EPA's WaterSense program.

Keywords

ISO, ISO PC 31600, water efficiency, flexibility

1 Introduction

On January 17, 2018, Standards Australia issued a proposal to the International Organization for Standardization (ISO) To develop an international standard for water efficient products that would include test requirements and contain water efficiency "banding" criteria to indicate water efficiency of plumbing fixtures and fittings and water consuming appliances for consumer labelling and other purposes.

This paper is intended to detail the rationale, development approach and model together with the need for this international standard. Also detailed is the intended scope, the development status of the standard to date (as of Summer of 2019), detail the ongoing development process and timelines, and to importantly, advise potential new stakeholders that this international standard is under development.

2 Background

2.1 Water efficiency labelling schemes/programs

Water efficiency labelling schemes/programs for plumbing fixtures, fittings and water consuming appliances have been established as either mandatory or voluntary schemes/programs are operating successfully in many countries globally. These programs are designed provide consumers with independent information via a label showing the product's water consumption rating that is used to compare against others so that the consumers can make an informed decision on the purchase of the product. To ensure that the information provided to consumers is independent the programs are normally administered by government agencies where licenses are provided to manufactures for compliance. Compliance is based on the water consumption test results when tested to the countries product standards. Examples of water efficiency labelling schemes/programs showing different labelling approaches are detailed in Figure 1 below.

Figure 1 – Different country approaches to water efficiency labelling programs

Singapore **Malaysia** **New Zealand** **China**

Experience with the Australian WELS program and the U.S. EPA's program has proven to save the nations trillions of litres of potable water and saved consumers billions of dollars in reduced utility bills. In Australia the WELS program could cumulatively, save "potentially total 2,853 Gigalitres (GL) of water saved by 2030. with its water savings potentially having a cumulative economic value by 2030 as high as $4.8 billion".

2.2 Requirement for an International Standard water efficiency labelling program

Domestic water use accounts for 12% of total global water extractions (Wada et al, 2016). This is projected to increase significantly, with some models and scenarios showing a 250% increase on 2010 levels by 2050 (ibid). Increases in urban water use are being driven by rapid population growth, economic development and climate change (Flörke, et al 2018). The growth in urban water demand is likely to result in significant shortfalls between demand and supply as well as conflicts for available water with other sectors, particularly agriculture (ibid). Improved urban water efficiency has been identified as a key mechanism to manage rising urban water scarcity (UN Water, 2018). This includes efficient water-using appliances and fixtures, with water efficiency labelling and standards to improve consumer awareness specifically cited by Global leaders (High Level Panel on Water, 2017).

A study by McDonald et al, 2011 showed the spatial distribution of large cities (>1 million population in 2000) and their water shortage status, in 2000 and 2050 are detailed in Figure 2 below.

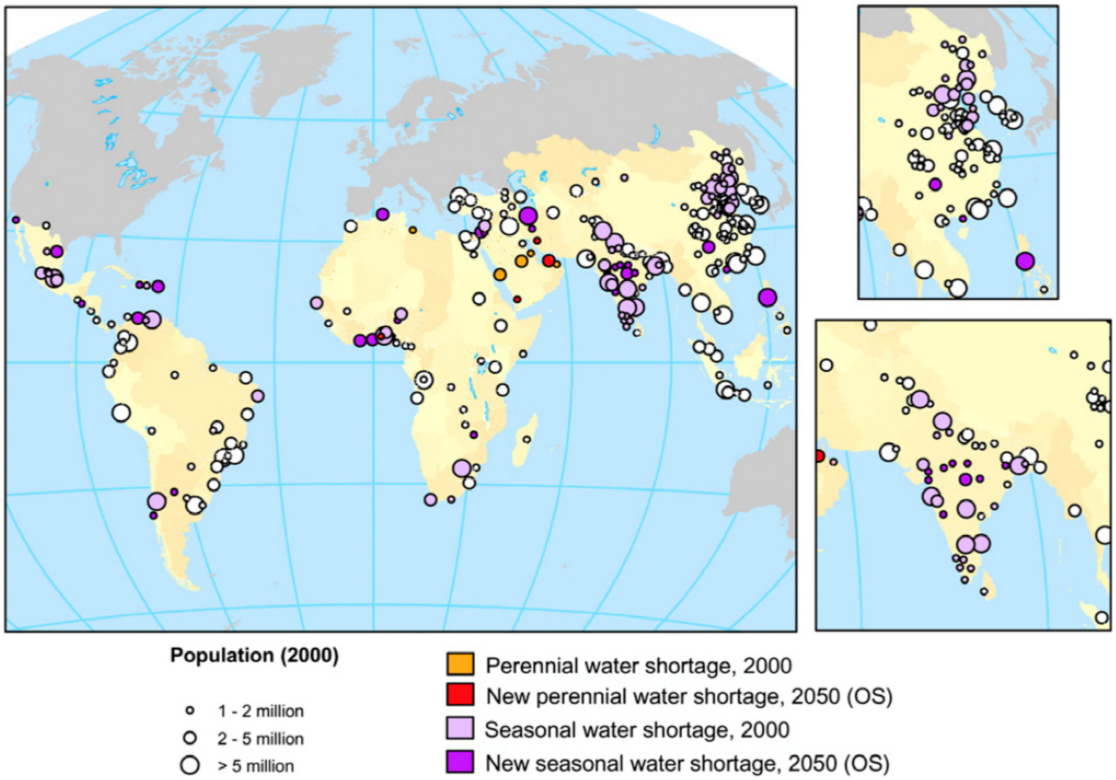


Figure 2 Change in projected water scarcity status 200 to 2050 (McDonald et al, 2011)
Note the circle size is proportional to city population in 2000. Countries within our study area are shown in beige, whereas countries not studied are shown in gray. Insets: Maps of India and China

In Australia it became clear that an international standard will make it easier for more countries to significantly benefit from effectively water efficiency labelling programs while also providing consistency with greater trade opportunities together with reduced manufacturing and compliance costs. Importantly, an international standard will provide developing countries and countries that do not have existing standards and consumer water efficiency labelling programs to apply an international standard that will additionally save many more trillions of liters of water globally. Based on this, Australia became committed to developing an ISO standard on water efficiency as part of its membership in the United Nations and World Bank High Level Panel on Water. The International Organization for Standardization (ISO) is an independent, non-governmental organization with a membership of 164 national standards bodies. ISO standards facilitate trade and can be used to ensure that products and services are safe, reliable and of good quality.

2.3 Proposal for an ISO water efficiency and labelling scheme/program
WELS formed a partnership with Standards Australia who are Australia's national standards and ISO member body to prepare a New Work Item Proposal to ISO for the development of an international standard for a water efficiency and labelling/scheme program. This also had in principal support from Australian industry. As ISO will only support a new work item if a 2/3 majority of members who vote support the New Work Item Proposal, therefore further support was required. This support was provided by other countries in the Asia Pacific Region has similar WELS programs the proposal was developed Singapore, China, Malaysia and New

Zealand. The final proposal was work shopped through webinars with regional standards bodies and their stakeholders.

In 2017, Standards Australia issued a proposal to the International Organization for Standardization (ISO) to develop an international standard that would work to "encourage the development and marketing of water efficient products, enable consumers to clearly identify and purchase the best products within the industry, and positively influence manufacturing to improve the performance of their products through consumer power and information".
In January 2018 voting closed with over 70% of those who voted in favour for ISO to establish a new Project Committee: PC316 Water efficient products – Rating. The ISO 316 committee comprised of 13 participating countries, with another 19 countries observing.

2.4 ISO 316 development approach

Discussions were held early with stakeholders where became clear that the development and drafting of the ISO 316 standard would require a new flexible approach for the development and drafting of the standard. This was critical to allow for the requirements of participating countries, all with varying national standards and water efficiency labelling schemes/programs while meeting the three-year development timeframe for the completion of the draft for publication of the standard in 2021.

A potential desirable outcome for ISO 316 was to establish universal test criteria that would provide the same water consumption result between participating countries when tested in accordance to the universal tests.

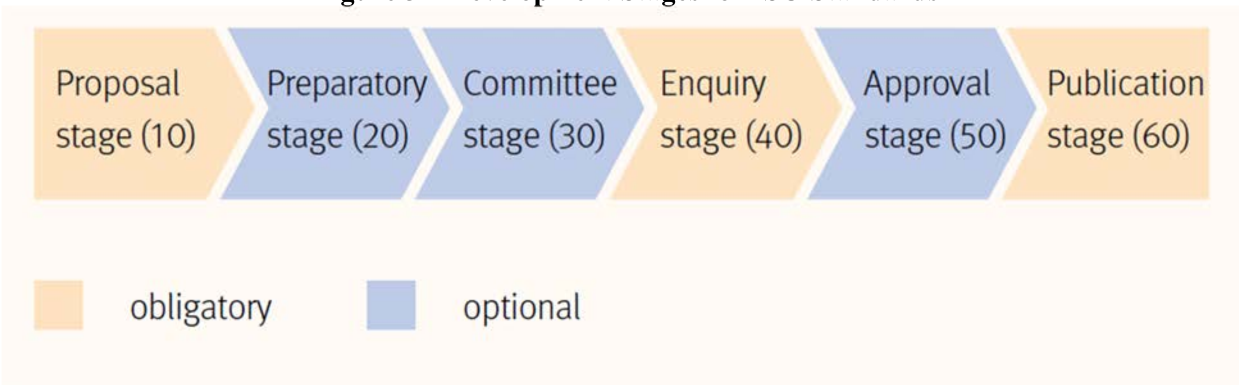
In preparation for the first committee meeting of ISO 316 it was decided to propose an outline of the important factors that would make up the 'flexible approach' for the consideration and guidance of the committee. These factors were –

- Maintain the countries product standard as a prerequisite for compliance to ISO 316.
- Repository of countries testing methods to be produced for all participating countries.
- Development of universal tests to determine the requirements of appliances and plumbing products.
- Development of universal banding requirements.

2.5 ISO 316 development stages

The ISO standards development process that will be used to develop ISO 316 is robust and typically consists of six (6) stages as shown in Figure 1. A strict code of conduct for participation on the development committees requires that participants; work for the benefits of the international community, uphold consensus and governance, agree to a clear scope and purpose, participate actively and manage effective representation, escalate and resolve disputes, behave ethically and respect others.

Figure 3 – Development Stages for ISO Standards



3. Development of ISO 316 and project status

3.1 First meeting of ISO 316 – Sydney, Australia July 2018

Due to the scale of the project work required to complete the drafting of ISO 316 the committee agreed to establish one working group with two Ad Hoc Groups created under the working group to develop specific requirements needed for plumbing products and appliances.

Significant progress was made at the Sydney committee meeting of ISO 316 where the committee agreed with the following main points:

- Update of the name for ISO 316 to Water Efficient Products – Rating.
- The project scope.
- That national product Standards would not be included in the scope.
- The model for the Standard proposed by the ISO/PC 316 Chair was adopted with some modifications made by the committee.
- That the test requirements currently used in existing schemes should be accommodated in the repository of Standards, to avoid mandating changes to schemes currently in use.
- The concept of identifying a single recommended test for water consumption was identified as a key area of work to be discussed, due to the large variety of methods and conditions, particularly for appliances.
- The proposed project timeframe and with the approximate dates and deadlines.

Resolutions taken at the meeting were unanimously approved by the delegates.

During the Sydney meeting, the intent of the standard was discussed in detail. Several participating members confirmed that existing water efficiency programs were already in place in their nations and that those programs have enjoyed great popularity and success. Examples of existing programs include the Water Efficiency Labelling Scheme (WELS) program in Australia, the U.S. Environmental Protection Agency's (U.S. EPA) WaterSense program in the United States and the Mandatory Water Efficiency Labelling Scheme (MWELS) program in Singapore. It was universally agreed that the ISO 31600 would not seek to replace or compete with those programs, but would be developed to provide a new water efficiency standard in nations that do not currently have such a standard in place and to provide an internationally recognized water efficiency labelling option to manufacturers of water efficient products.

It was further noted that the standards and water efficiency labelling programs already in existence have vastly differing test procedures, water efficiency requirements and conformity assessment requirements.

Some program were voluntary, meaning that manufacturers were not required to participate and label their products, while others were mandatory for market acceptance. Some programs had pass fail criteria only, where meeting or exceeding a water efficiency threshold flow rate or consumption value qualified the product to be labelled. Other programs established tiered water efficiency targets (banding), awarding labels with consumer-friendly graphics such as stars or water droplets to indicate the water efficiency performance of the labelled product.

As a result of these discussions, the PC 31600 Committee reaffirmed the desire to ensure that the standard would not result in market confusion or necessitate new testing or regulatory requirements in nations where manufacturers were already complying with the requirements associated with those existing programs. In addition, it was agreed to that the standard will be voluntary, not require that products bear a label, and, while the standard will indicate various compliance paths to help ensure that the appropriate products are specified for the nation of intended installation, it will not include certification requirements.

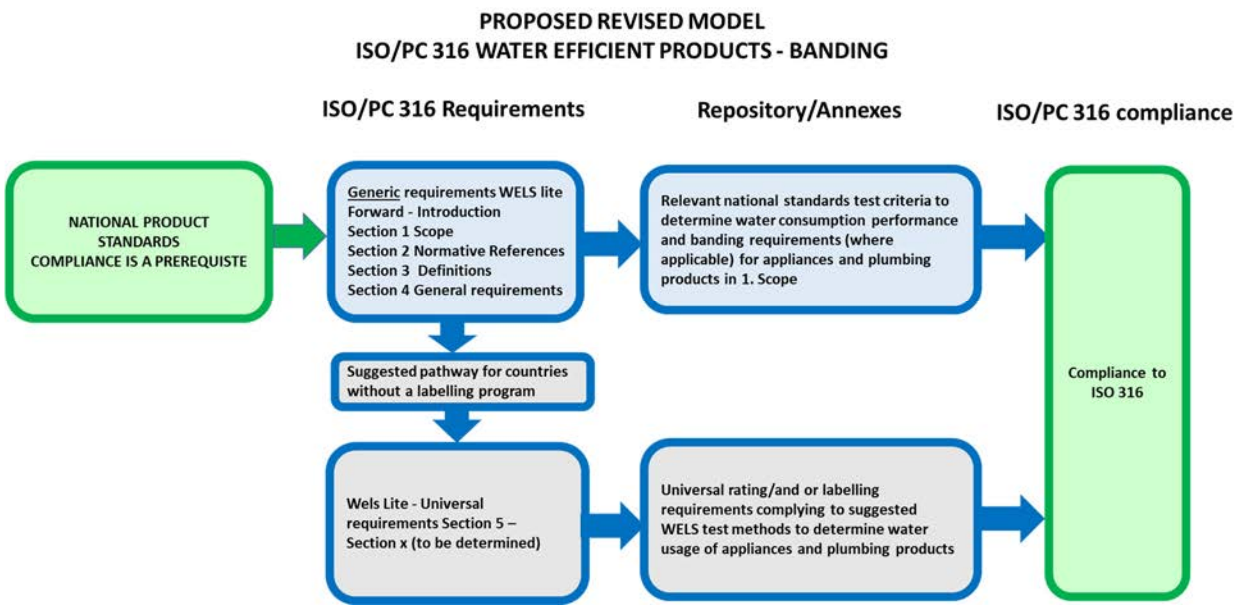
Another issue that the committee considered is that plumbing products and appliances are designed differently throughout the world. These differences are due to, among other reasons, differing construction norms and cultural or consumer preferences. As a result, trying to establish a single testing regimen for all products contained in the scope of PC 31600 would be extremely difficult, time consuming and unnecessarily costly. Further, it was important for nations that do not currently have national product standards or water efficiency labelling standards to be able to reference and / or adopt the standards that provide products best suited for their markets. Due to the reasons discussed above, it was agreed that ISO PC 31600 would include a normative appendix containing a list of national standards and water efficiency labelling standards.

3.2 Second meeting of ISO 316 – Jona, Switzerland April 2019

A second face to face meeting of the ISO PC 31600 Committee was convened in Rapperswil - Jona, Switzerland in April of 2019. A gap analysis was conducted to capture all outstanding submittals from participating members. The important Purpose Statement section of the standard was reviewed and edited. Among other issues, the General Requirements section of standard was reviewed along with a graphic model detailing potential compliance paths for in-scope water efficient products. Development goals for the standard prior to the next face to face meeting were established. A Working Draft of ISO PC 31600 was issued in late May, 2019.

On two AHG-1 teleconferences that followed the meeting in Switzerland, AHG-1 members discussed how the standard will be structured considering that ISO PC 316 will only provide tests and requirements for the water efficiency aspects of the products in its scope. It will not address health and safety requirements, reliability or product performance requirements typically contained in product standards. To ensure that products are safe, reliable and perform well, labelled products must also meet an appropriate national product standard. In order to demonstrate compliance to ISO PC 316, a product would need to be tested to and meet all of the requirements contained in ISO PC 31600 plus the requirements contained in a national product standard that has provisions for health and safety, reliability and general performance requirements. Alternatively, where a product is intended for installation where existing national product standard and / or water efficiency labelling standards are in place, the product will need to show compliance to the Purpose, Scope, Definitions and General Requirements section of ISO PC 31600, plus all the requirements of the national product standard and water efficiency labelling standard as required by the nation of intended installation in order to bear the ISO PC 316 label. Figure 3, which will be further considered by the ISO PC 31600 Committee for incorporation into the standard, details the various compliance paths available and how they are to be applied.

Figure 4 – Draft Compliance Paths for ISO 31600

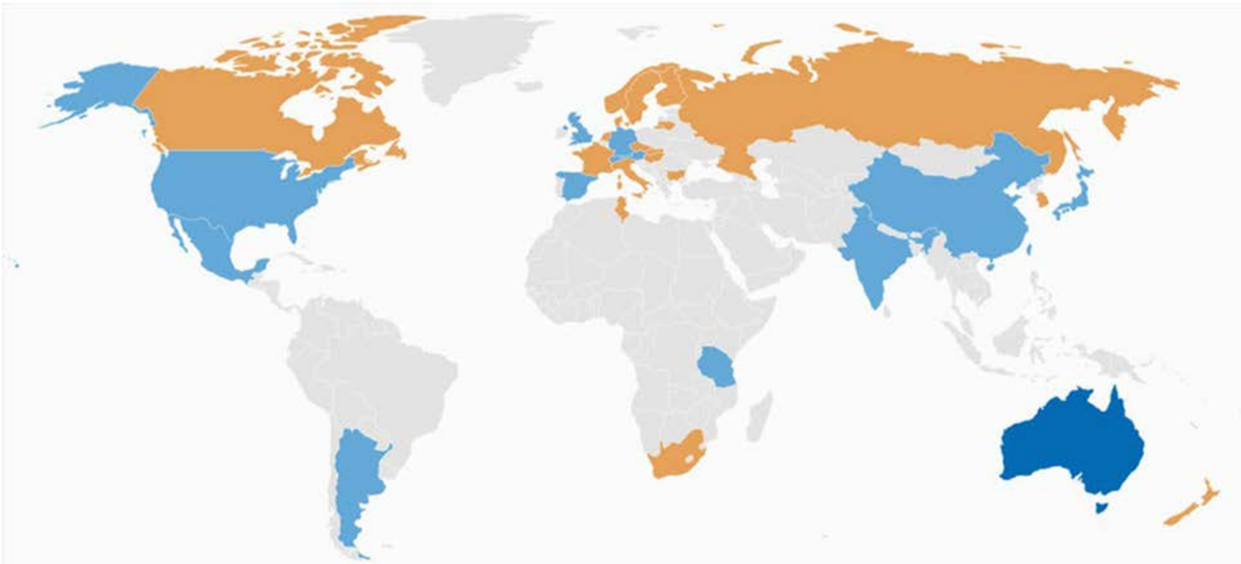


The next meeting of the ISO PC 31600 Committee will take place on October 16 – 18, 2019 in Singapore. The Ad Hoc Groups and the Technical Committee will meet to resolve comments issued by participating and observer members on the May 2019 Working Draft, finalize the General Requirements section and associated graphic, discuss the product scope for some plumbing products that are still in question, and review normative appendix to ensure that all the appropriate national product standard and water efficiency labelling standard are represented. The United States will host a ISO PC 31600 meeting in the San Diego area in April of 2020. Publication of ISO PC 316000 is anticipated for 3rd or 4th Quarter of 2021.

3.3 ISO PC 31600 Participating and Observer Nations

Since the ISO 316 meeting in Sydney it is pleasing that the number of participating countries and observing countries has increased steadily. The nations currently participating in or observing the development of ISO PC 31600 are shown below with the applicable standards developing organization acronym as shown in Figure 5.

Figure 5 - ISO PC 31600 Participating and Observer Nations



Participating (P) Members: Argentina (IRAM), Australia (SA), Austria (ASI), Canada (SCC) China (SAC), Germany (DIN), India (BIS), Japan (JISC), Mexico (DGN), Singapore (ESG), South Africa (SABS), Spain (UNE), Switzerland (SNV), Tanzania (TBS), United Kingdom (BSI), U.S.A. (ANSI)

Observing (O) Members: Bulgaria (BDS), Czech Republic (UNMZ), Denmark (DS), Finland (SFS), France (AFNOR), Hungary MSZT), Italy (UNI), Republic of Korea (KATS), Lithuania (LST), Netherlands (NEN), New Zealand (NZSO), Norway (SN), Russian Federation (GOSTR), Slovakia (UNMS SR), Sweden (SIS)

4. Conclusion

The development ISO 316 is a unique opportunity to produce an international standard that has significant implications for developing countries and countries that do not have existing standards and consumer water efficiency labelling programs. Once published, ISO PC 31600 will provide a mechanism for these countries to save many trillions of liters of water globally.

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6 Presentation of Authors

Dr Steve Cummings is the Director Innovation at GWA Bathrooms and Kitchens where he is responsible the research and development of innovative sustainable bathroom and kitchen solutions. He has had a long-standing commitment to water conservation and related advanced drainage research internationally. He is associate of the Institute for Sustainable Futures, University of Technology - Sydney.

Steve is currently the chair of ISO 316 Water Efficient Products – Banding. He is a member of the Australian Plumbing Code Committee and chair of number of AS/NZS standard committees including the Water efficiency labelling and standards advisory group – WELSAG.

Peter DeMarco is the Executive Vice President of Advocacy and Research for the IAPMO Group. His responsibilities include oversight of IAPMO’s government relations department, water efficiency and green building initiatives, standards development activities, domestic and international plumbing programs, industry outreach programs and development of research projects relating to water efficiency. Pete is the founder of the Plumbing Efficiency Research Coalition (PERC), an organization dedicated to conducting research pertaining to plumbing systems in consideration of the emerging trends towards lower water consuming plumbing fixtures and appliances. He currently serves as Chair of the Board of Directors for the Alliance for Water Efficiency (AWE) and previously served on the Board of Directors and on the Executive Committee for the Plumbing Manufacturers International (PMI). Regarding ISO 316, Pete is currently serving as the Convenor of Ad Hoc Group 1 for plumbing products.

Understanding of Discharge Characteristics and Carrying Performance of a Water-saving Toilet with a Movable Discharge Mechanism When Used during an Emergency

Shogo Sato (1), Masayuki Otsuka (2), Takafumi Matsuo (3)
(1) m18J3004@kanto-gakuin.ac.jp
(2) dmotsuka@kanto-gakuin.ac.jp
(3) matsuo.takafumi314@jp.panasonic.com
(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

Japan was struck by the Great East Japan Earthquake in March 2011 and the Kumamoto Earthquakes in April 2016. The affected areas suffered devastating damage not only to the buildings and structures but also to the infrastructures including the water and sewerage systems which were disrupted from functioning as lifelines for a long period of time. The local residents had the inconvenience of being unable to use their toilets in the usual manner; every time they used a toilet, they had to manually flush away waste and toilet paper with a bucket of water, and this crippled everyday life. Meanwhile, trouble with drainage pipes and sewage pipes caused by blockage and stagnant wastewater was identified.

With this background in mind, this study focuses on a toilet equipped with a movable discharge mechanism which uses an emergency power source, such as a battery, to ensure steady discharge even during an emergency, and aims to identify the discharge characteristics and carrying performance of the toilet. The study also aims to clarify, from the findings, the effectiveness of the toilet with a movable discharge mechanism which can be used during an emergency.

Keywords

movable discharge mechanism, water-saving toilet, emergency, discharge characteristics, carrying performance

1. Background and objective

Japan is said to be a country that suffers many earthquakes compared to other countries in the world. The Great East Japan Earthquake in March 2011 and the Kumamoto Earthquakes in April 2016 are still fresh in our memory. In the immediate aftermath of these earthquake disasters, more than 400,000 dwellings had their water and electricity cut off, and their lifelines were disrupted for a long period of time. With this background in mind, this study aims to identify the carrying performance and fixture discharge characteristics of a water-saving toilet having a movable discharge mechanism that operates by electrical energy supplied from commonly-available batteries, thereby discussing the effectiveness of said toilet during an emergency/power outage.

2. Experiment overview

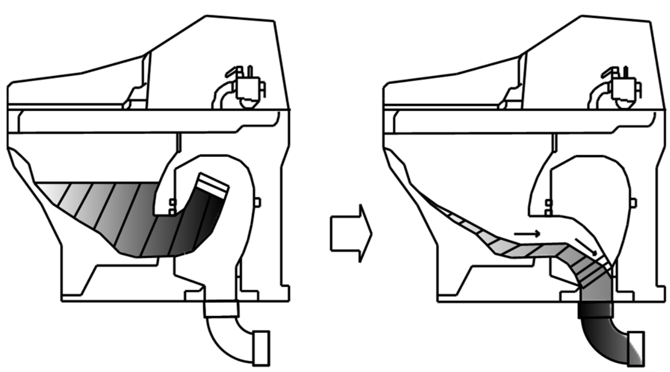
2.1.1 Fixture discharge characteristics experiment

(1) Experimental toilet

Photo 1 shows the experimental toilet. A nominal maximum amount of 4.8L of water was used for flushing the toilet. Moreover, the experimental toilet was equipped with a movable discharge mechanism, which is illustrated in Fig. 1, and the flushing system employed a turn trap. Incidentally, power can be supplied from a power receptacle or from a commonly-available battery (9V) which can be used in the event of a power outage, and the latter method was used in the experiment to operate the experimental toilet. Photo 2 shows the battery (9V) in installation position.

Photo 1 Experimental toilet

Photo 2 Battery in installation

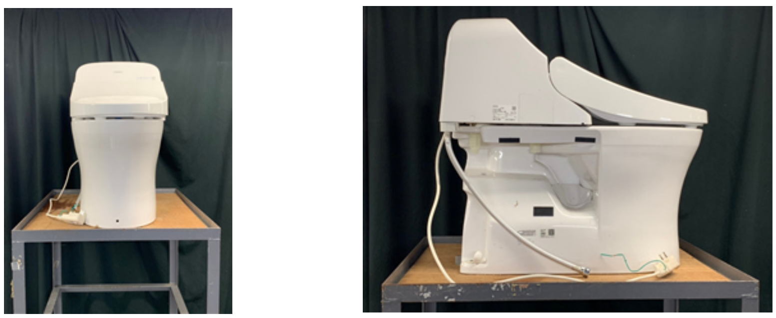


(1) Not flushed (2) Flushed

Fig. 1 Movable discharge mechanism

(2) Wash-out type toilet

Photo 3 shows the wash-out type toilet having a low cistern (hereinafter referred to as “conventional toilet), which was used for making a comparison with the experimental toilet in the experiment. The conventional toilet is classified as water-saving type II, so is the experimental toilet, in accordance with JIS A 5207-2014 Sanitary Wares. A nominal maximum amount of 4.8L of water was also used for flushing the conventional toilet.



(1) Front (2) Side

Photo 3 Convention toilet

2.1.2 Experimental horizontal fixture drain branch system

Fig. 2 illustrates the horizontal fixture drain branch system that was used for the experiment. Each pipe is transparent and rigid and made of vinyl chloride. The fixture drainpipe and the horizontal fixture drain branch both have a pipe diameter of 75A (actual inner diameter 78[mm]). The length of the fixture drainpipe is 150[mm], and the gradient of the horizontal fixture drain branch is 1/100 which is the minimum gradient needed. The straight pipework shown in the same drawing was extended by 1m at a time, using JIS-DV socket fittings, until the entire length of the experimental horizontal fixture drain branch reached 10m. It should be noted that a drainage basin was arranged, with a liquid-contact type transducer installed thereto, at the end of the experimental horizontal fixture drain branch at all times. Outputs from the transducer were converted into variations in drainage volume and variations in drainage flow rate.

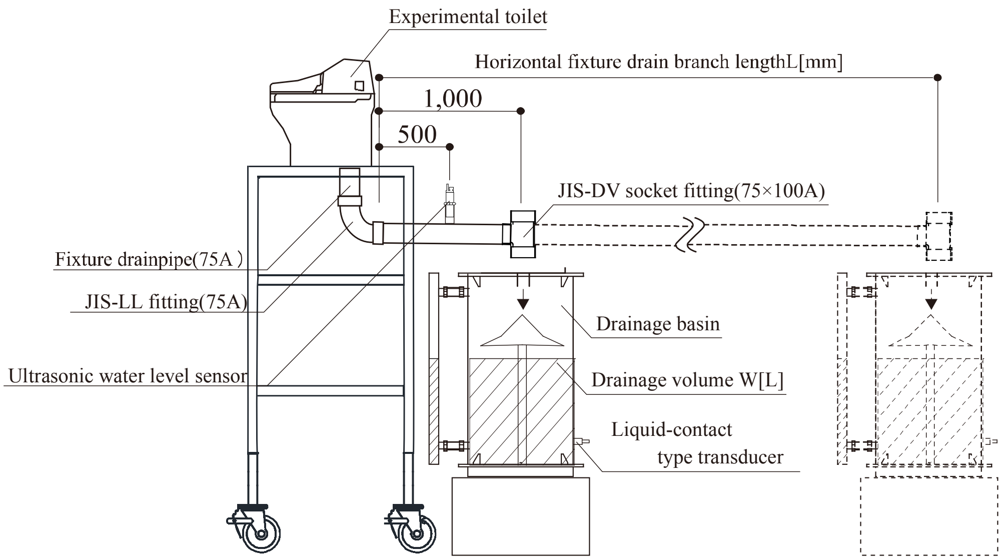


Fig. 2 Experimental horizontal fixture drain branch system

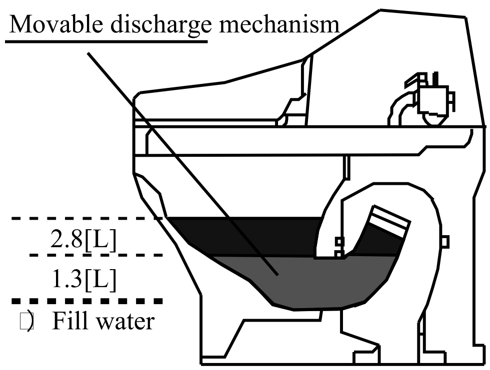
2.1.3 Test patterns

(1) Experimental toilet

Table 1 shows the discharge patterns which were applied to the experimental toilet during the experiment. 4.8[L] refers to the amount of flush water used under normal circumstances. The other amounts refer to amounts of flush water used during an emergency; 2.8[L] or 1.3[L] of fill water in the toilet bowl (Fig. 3 I), and total discharge volumes of 1.3-6.8[L] (Table 1 III) with additional amounts of 0-4.0[L] (Fig. 4 II). Additional water was applied into the toilet bowl 1 second after the toilet was flushed and the fill water was drained. Incidentally, the discharge patterns were applied five times, respectively, and the average value was calculated for each pattern.

Table 1 Fixture discharge characteristics experiment-discharge

No.	Condition of use	I Fill water ［L］	II Bucket of water ［L］	III Total discharge volume ［L］
1	Normal	2.8		4.8
2	Emergency	2.8	+0	2.8
3			+0.5	3.3
4			+1.0	3.8
5			+1.5	4.3
6			+2.0	4.8
7			+3.0	5.8
8			+4.0	6.8
9		1.3	+0	1.3
10			+0.5	1.8
11			+1.0	2.3
12			+1.5	2.8
13			+2.0	3.3
14			+3.0	3.3
15			+4.0	3.8



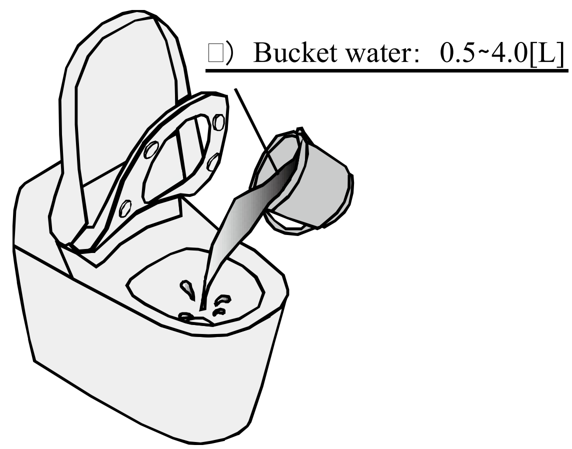


Fig. 3 Experimental toilet　　　　Fig. 4 How to apply additional water

(2) Wash-out type toilet

Table 2 shows the discharge patterns which were applied to the wash-out toilet during the experiment. 4.8[L] refers to the amount of flush water used under normal circumstances. The other amounts refer to amounts of flush water used during an emergency; 1.2[L] of fill water in the toilet bowl (Fig. 5 I) and 1.3[L]-6.8[L] bucket of water added into the bowl (Fig. 6 II), and by this method, the total discharge volume is 1.3[L]-6.8[L] (Table 2 III).

Table 2 Fixture discharge characteristics experiment - discharge patterns

No.	Condition of use	I Fill water ［L］	II Bucket of water ［L］	III Total discharge volume ［L］
1	Normal	1.2		4.8
2			+1.3	1.3
3			+1.8	1.8
4			+2.3	2.3
5			+2.8	2.8
6			+3.3	3.3
7	Emergency	1.2	+3.8	3.8
8			+4.3	4.3
9			+4.8	4.8
10			+5.3	5.3
11			+5.8	5.8
12			+6.8	6.8

※The fill water (1.2[L]) is not included in the total discharge volume.

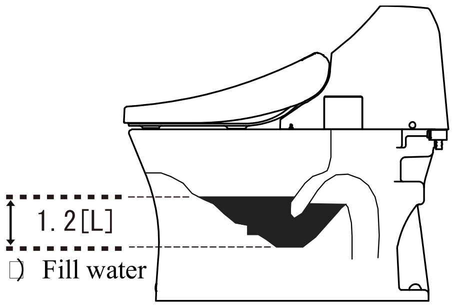


Fig. 5 Experimental toilet

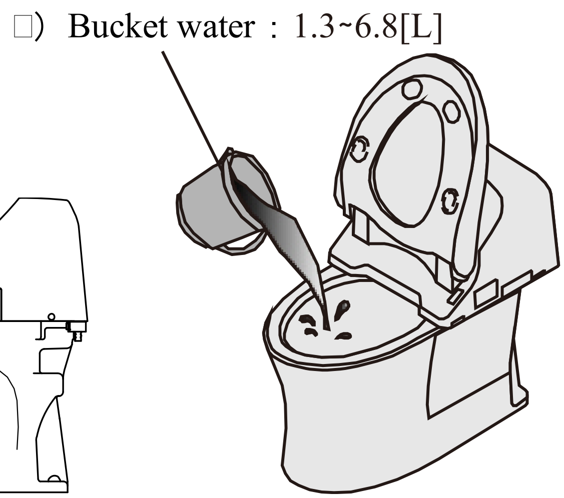


Fig. 6 How to apply additional water

2.2.1 Carrying performance experiment

Experimental waste substitutes were used for this experiment. Each type of waste substitute was applied in the experimental toilet and the conventional toilet, and as soon as the waste substitute soaked enough water, the toilets were flushed completely. Thereafter, the position at which the waste substitute became stationary in the experimental horizontal fixture drain branch was measured, and the carrying distance of the waste substitute was identified. Two types of experimental waste substitutes were used; BL and D, as shown in Table 3.

Table 3 Experimental waste substitutes

Type Description	Outline	
BL standard	1-ply toilet paper 0.9m×4pieces 8folds Flat	BLE WC:2013standard Common load condition according to Better Living Standard
D	1-ply toilet paper 0.9m×6pieces 8folds Flat	Load 1.7(approx) according to Better Living Standard

2.2.2 Test pattern

Three factors; the amount of fill water, the amount of water in the bucket and the experimental waste substitutes, were used to create different conditions for carrying out the experiment. The amount of fill water and the amount of water in the bucket, and the timing of flushing the toilets refer to the method described in 2.1.3.

3. Experiment results

3.1 Total discharge volume and carrying performance

Fig. 7 and 8 show carrying distances which are relative to total discharge volumes. Fig. 7 shows the experiment results which were obtained when the experimental waste substitute BL was used. When a total discharge volume of 2.8L was applied, the carrying distance reached around 5m[3)], which corresponds to the pipe length actually used from the drainage stack to the drainage basin of a drainage system for a house or an apartment house. When comparing the average values between the toilets, the experimental toilet is slightly less efficient than the conventional toilet. Nevertheless, the difference between the two is considered small as indicated by the maximum total discharge volumes and the minimum total discharge volumes overlap each other. Fig. 8 shows the experiment results which were obtained when the experimental waste substitute D was used. The carrying distance also reached around 5m when a total discharge volume of 2.8L was applied. However, a total discharge volume of 3.3L was required for the carrying distance to completely exceed said 5m.

	Total discharge volume [L]					
Toilet	1.3	1.8	2.3	2.8	3.3	4.3
Experimental	0.00	0.36	2.86	5.16	7.09	9.86
Conventional	0.00	0.00	4.61	7.41	8.77	9.63

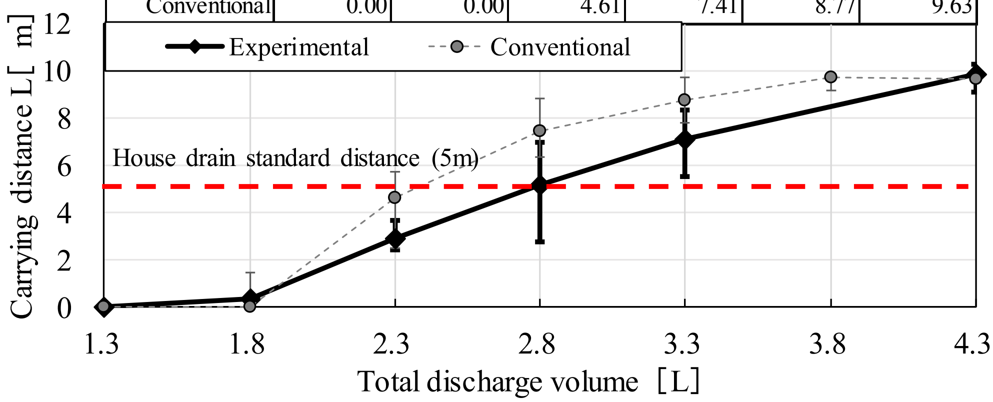


Fig. 7 Correlation between total discharge volume and carrying distance (waste substitute BL)

	Total discharge volume ［L］					
Toilet	1. 3L	1. 8L	2. 3L	2. 8L	3. 3L	4. 3L
Experimental	0	0	1. 93	4. 41	5. 23	8. 17
Conventional	0	0	4. 34	5. 50	7. 13	9. 69

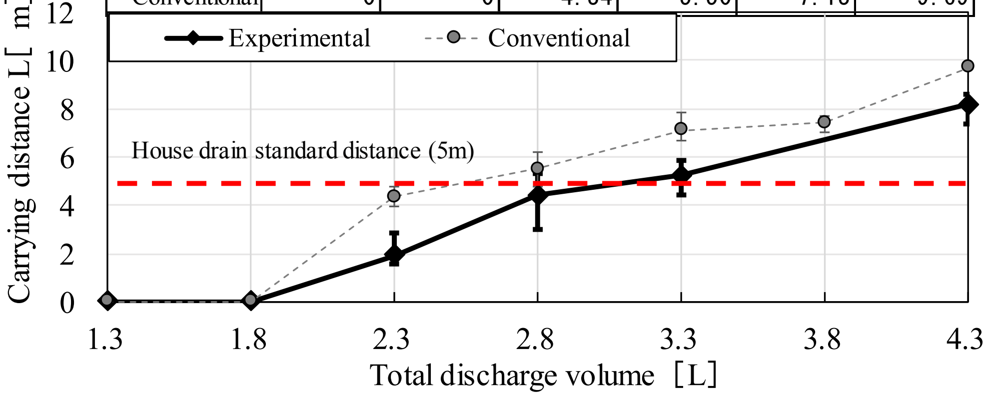


Fig. 8 Correlation between total discharge volume and carrying distance (waste substitute D)

3.2 Repeated flushing experiment

Fig. 9 shows the results of the experiment in which the experimental waste substitute BL was flushed down the experimental toilet (the first flush), and the toilet was flushed once more (the second flush) three minutes after the waste substitute became stationary in the pipe. Fig. 9 indicates that by applying a total discharge volume of 1.8-3.3L, the waste, which once became stationary in the pipe, can be carried further by approximately 3.5m from the second flush onwards. The experiment results also confirm that even when waste has not completely been drained down the pipe after the first flush, the waste, which once became stationary in the pipe, can be gradually carried further by repeated flushing, and is not likely to accumulate in the pipework.

Ⅰ Fill water ［L］	Ⅱ Bucket of water ［L］	Ⅲ Total discharge volume ［L］	No,of flushes
1.3	0	1.3	1st flush
			2nd flush
	0.5	1.8	1st flush
			2nd flush
	1.0	2.3	1st flush
			2nd flush
	1.5	2.8	1st flush
			2nd flush
	2.0	3.3	1st flush
			2nd flush

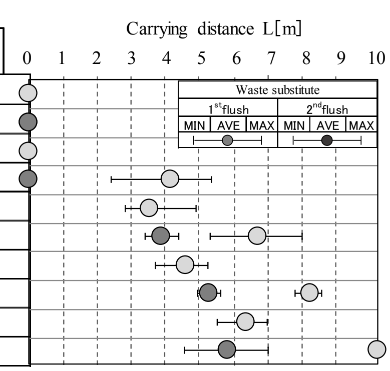


Fig. 9 Carrying distances by repeated flushing

3.3 Comparison of carrying limits qd'cp

Fig. 10 compares the experimental toilet and the conventional toilet in the respect of the correlation between the average fixture discharge volume qd' and the carrying distance L when a total discharge volume of 3.3L is applied. When the experimental waste substitute BL is used, there is only a slight difference, approximately 0.1L/s, between the carrying limits qd'cp[4)] of the toilets. Similarly, when the experimental waste substitute D is used, qd'cp values of the toilets are both approximately 0.2L/s. The past study [4)] discloses that the standard qd'cp value is approximately 0.3L/s, and there is a slight difference between said standard value and the results obtained in this study. It is considered that the difference occurred due to the difference between applying the normal amount of water and applying a bucket of water to flush the toilets.

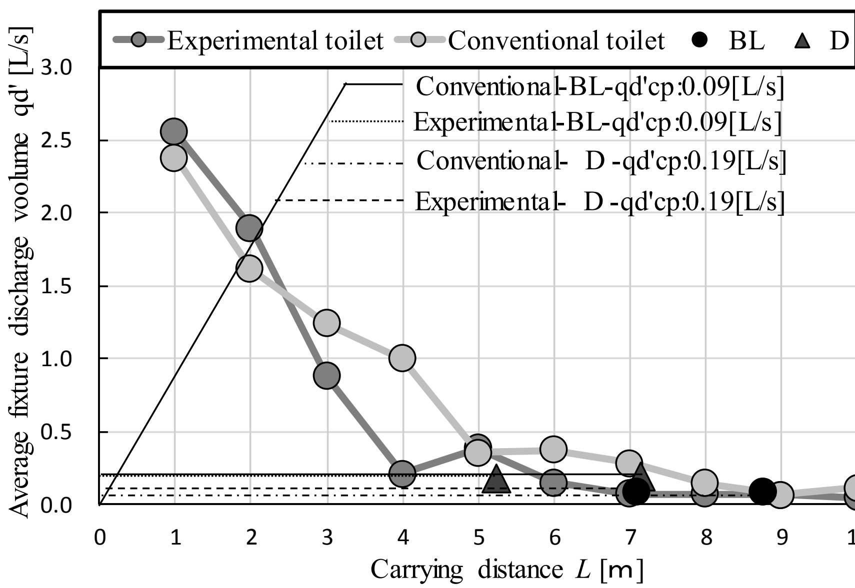


Fig. 10 Correlation between carrying distance and qd'

4. Summary

The results of the carrying performance experiment confirm that it is possible to carry a waste substitute a distance of approximately 5m[3)], which is a standard length for house drains for dwellings, by flushing the experimental toilet using the flushing method applicable during an emergency. Moreover, the results of the repeated flushing experiment confirm that a waste substitute, which once became stationary in the pipe, can be pushed further by approximately 3.5m from the second flush onwards when a total discharge amount of 1.8-3.3L is applied. This clarifies that even if waste became stationary in the pipe after the first flush, draining can continue smoothly from the second flush onwards. Therefore, it is considered that the experimental toilet and the flushing method cause no problems to the carrying performance and are applicable in real emergency situations, and the effectiveness thereof is ensured.

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6. Presentations of Authors

Shogo Sato is a graduate student of the Otsuka laboratory at 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 study relates to drainage experiments on high-rise buildings.

Masayuki Otsuka is a professor at the 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 hybrid drainage systems that use both force feed type and gravity type drainage methods compatible with commercial building conversion.

Takafumi Matsuo is a member of the Housing Systems Business Division, Eco Solution Company 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 research interest is the ability of the water-saving toilets with a splash-preventing function.

Evaluation Index for the Power Saving Performance of Water Supply Pump

K. Sakaue (1), S. Okauchi (2), G. Wu (3), T. Mitunaga (4),

K. Fujimura (5)

(1) sakaue@meiji.ac.jp
(2) okauchi@kajima.com
(3) kure@kanto-gakuin.ac.jp
(4) mitunaga-t@yamashitasekkei.co.jp
(5) kazuya.fujimura@mj-sekkei.com

Abstract

In Japan middle and high-rise buildings have traditionally relied their water supply on the elevated tank system and the booster pump system, which utilize receiving tanks. In 1995 a direct connection system without a receiving tank was given approval. power saving performance of water supply pump becomes an important issue in selecting the type of water supply system to be used. However, no valid evaluation index for power saving performance of water supply pump has been established.

In this study the authors have analysed water supply and power consumption data obtained from different types of water supply systems before switching over from one to another in a middle size multifamily dwelling, and proposed UWPC (unit of water-power consumption) as an index for power saving performance of water supply pump. The authors have also evaluated power saving performance of water supply systems using UWPC to validate their applicability.

Keywords

Water supply system; index for power saving performance; unit of water-power consumption; apartment house

1. Introduction

Water supply system in buildings can be divided into the direct connection system and the receiving tank system. Traditionally in Japan, the direct connection system has been used in low-rise buildings, and the boost pump system and the elevated tank system in middle to high-rise buildings. The use of storage tanks requires sanitation control to keep water quality in tanks in check, but thorough control had not been carried out for systems with small receiving tanks. To remedy this situation, the use of the direct connection system was approved in 1995. Since then the system has gained popularity as it eradicated space for storage tanks and need for sanitation control, and contributed to saving power. However, we can’t say that this power saving features of the system has been well verified.

Though power saving features of water supply pump play an important role in the overall scheme of energy saving of plumbing systems, equipment efficiency has been the only useable element to evaluate the performance of water supply pump.

In this study the author have proposed UWPC[kW・h/m^3] as a new performance index. Here, UPWC is defined as the ratio of power consumption to water supply amount per day. UWPC was applied to water supply amount and power consumption data of a middle size multifamily dwelling where water supply system had been switched from the elevated tank system to the direct connection boost pump & elevated tank system, and the validity of UWPC as an index was examined.

2. Measuring water supply amount and power consumption in a multifamily dwelling

It is desirable to be able to have different water supply system in the same building and situation in terms of an ideal environment to evaluate the power saving performance of water supply system. We measured water supply amount and power consumption in a middle size multifamily dwelling, where water supply system was switched over from the elevated tank system to the direct connection boost pump & elevated tank system.

2.1 Outline of target building and switchover of water supply system

A middle size multifamily dwelling in the suburb of Tokyo was selected as the target building. The outline of the building is shown in Table 1. In this building water supply system was changed from the elevated tank system to the direct connection boost pump & elevated tank system. Water supply system diagram before and after switchover is shown in Figure 1, and the specifications of water supply apparatuses in Table 2.

2.2 Measurement

Table 1 Building outline

building use	apartment house (63vunits), 3 stores (2 restaurants)
scale	RC construction, residence: 11 F, PH: 2 F
completion	1970 (47 years old)

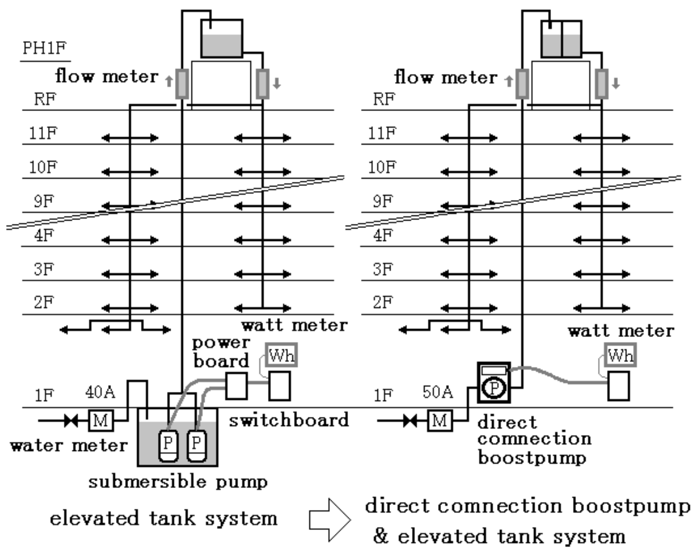

Figure 1 Water supply system diagram before and after the switchover

Table 2 Specifications of water supply apparatuses

item	before switchover	after switchover
Water supply system	elevated tank system	direct connection boost pump & elevated tank system
capacity of elevated tank	FRP, D2m×W3m×H2m	FRP, D2m×W3m×H2m, 2tanks
diameter of service pipe	40A (40mm)	50A (50mm)
capacity of lifting pump	submergible pump 60A-325L/min, 7.5kW, 2 units	booster pump 40A-167L/min, 3.7kW, 2 units

Measurement of water supply amount and power consumption was made before the switchover August 8 ~ August 16, 2017, and after the switchover September 5 ~ September 12, 2017. Ultrasonic flow meters were attached to the lifting pipe and feeding pipe, and flow rates were recorded every second with a data logger. A watt meter was attached to the switch board for water supply pump, and power consumption was recorded every second. The positions of the measurement devices are shown in Figure 1. Data were also collected from the water meter attached to the service pipe after the switchover.

2.3 Results of measurement and consideration

2.3.1 Measurement before and after the switchover

Instantaneous water supply amount and pumped water amount were different, but the total water supply amount from the time when the elevated tank was filled and the pump turned off to the time when the pump turned off again 24 hours later matched the total amount of water pumped up during the same hour.

The measurements of water supply amount and power consumption before and after the switchover of the water supply system are shown in Tables 3 and 4. Water supply amount before the switchover was 13.1 ~ 23.7 (Avg. 20.0) m^3/d, after the switchover was 18.7 ~ 23.02 (Avg. 20.0) m^3/d. Power consumption before the switchover was 3.92 ~ 5.51 (Avg. 4.76) kW･h/D, after the switchover was 3.56 ~ 4.39 (Avg. 4.05) kW･h/d. There were 63 households, one general store, and two restaurants in this building. Though water supply amount of the restaurants was not measured, it was estimated from their sizes to be about 3.5 m^3. This amount was subtracted from the total water supply amount, and average water supply amount estimate per household of 270L/d was obtained.

Water supply amounts before and after the switchover were approximately the same, but power consumption after the switchover was 10 ~ 20% smaller than before the switchover, which clearly indicates the water supply system after the switchover is more power efficient.

2.3.2 Downsizing water supply pump

The operating conditions of the pump have a bearing on power consumption. We examined the relationship between water supply amount and pumped water amount on

Table 3 Measurements of water supply amount and power consumption before the switchover of the water supply system

date	water supply amount [m^3/d]	pumped water amount [m^3/d]	power consumption [kW□h/d]
2017.8.8-9	24.3	23.7	6.51
2017.8.9-10	18.7	17.9	4.13
2017.8.10-11	23.9	23.1	5.41
2017.8.11-12	23.2	22,9	5.51
2017.8.12-13	17.1	17.2	4.15
2017.8.13-14	21.5	22,2	5.34
2017.8.14-15	15.9	17.1	4.13
2017.8.15-16	15.1	16.1	3.92
average	20.0	20.0	4.77

Table 4 Measurements of water supply amount and power consumption after the switchover of the water supply system

date	water supply amount [m^3/d]	pumped water amount [m^3/d]	power consumption [kW□h/d]
2017.9.5-6	18.7	18.7	3.56
2017.9.6-7	22.0	20.7	3.98
207.97-8	20.4	21.0	4.04
2017.9.8-9	20.5	22.1	4.27
2017.9.9-10	23.4	23.2	4.39
average	21.0	21.1	4.05

the day when a large amount of water was used. The operating conditions of the submersible pump before the switchover and the direct connection boost pump after switchover are shown in Figures 2 and Figures 3. Pumped water amount before the switchover was 325L/min. on average, which was larger than the instantaneous maximum supply amount of about 200 L/min. This shows that the pump capacity was too large. The situation improved after the switchover with the pumped water amount dropping down to the average of 125L/min.

The pump operated 5 times a day and it took the same amount of time for each operation. The reason for this is that long pumping time was not required even during the peak time because of the large pump capacity. And this clearly indicates that a smaller pump can be used to do the same amount of pumping. The diameter and capacity of the submersible pump before the switchover were 65A and 7.5kW. But judging from actual measurements, an appropriate diameter was found to be 40A. Accordingly an appropriate capacity for 40A would be 3.7kW. Power needed to pump: 1 m^3 of water, according to the characteristic curves of pump, calculated to be 0.313 kW/h for 65A-7.5kW pump, and

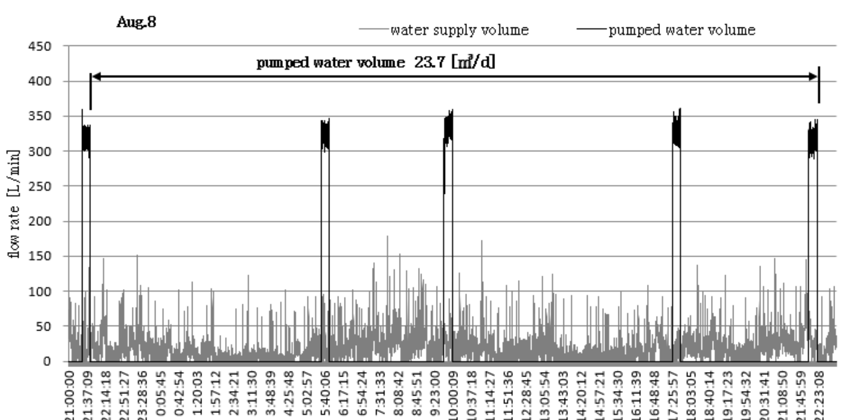

Figure 2 Operating condition of submersible pump before switchover

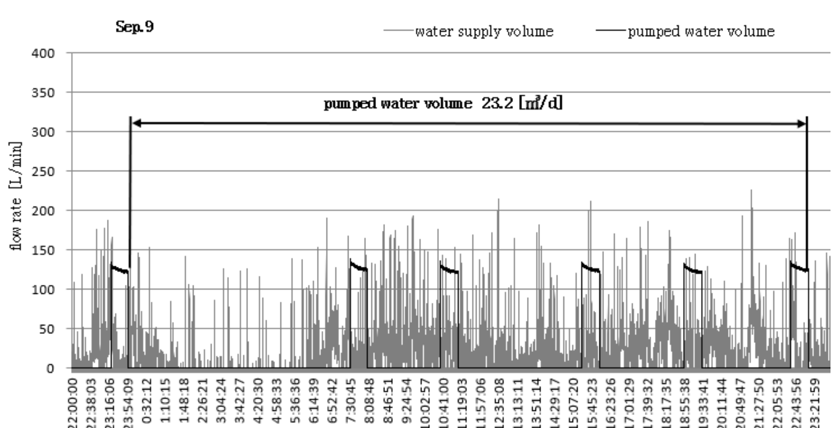

Figure 3 Operating condition of boost pump after switchover

0.266 kW/h for 40A-3.7 kW pump. Therefore, power consumption would be reduced by 15% if a smaller pump were used. In addition, "A" is the Japanese unit of pipe diameter, which is the same as "mm".

The diameter and capacity of the pump after the switchover were 40A and 3.75kW. An appropriate diameter calculated from actual measurements would be 25A, and the capacity in this model 1.1 kW. Power needed to pump: 1 m^3 of water was calculated to be 0.197kW/h with 40A-3.7kW pump and 0.164kW/h with 25A-1.1kW pump. Power consumption would be reduced by approximately 17% if a smaller pump were used.

3. Unit of Power-Water Consumption (UWPC)

UWPC is the ratio of power consumption to water supply consumption (amount) per day. Water supply amount, power consumption, UWPC, and change rate of the submersible pump before the switchover are shown in Table 5, and those of the pump after the switchover in Table 6. Change rate was obtained by dividing the difference between the maximum and minimum values by the maximum value. Water supply amount, power consumption, and UWPC before and after the switchover are shown in Table 7. UWPC of each water supply pump in Tables 5 ~ 7 are shown in Figure 4.

Change rates of water supply amount before and after the switchover were 32.0% and 19.3% respectively. However change rates of UWPC were 5.3% before the switchover and 1.2% after. UWPC before the switchover was 0.238 kW・h/d, and 0.191 kW・h/d after the switchover. There was an improvement of 0.047 kW・h/d in power saving as a result of the switchover. UWPC of the 40A-3.7 kW submersible pump before and capacity after the switchover was 0.191kW・h/d. Though it is said the direct connection boost system is superior in power saving to the receiving tank system, improvement achieved was as small as 5.4%. From these results it has been confirmed that UWPC can be used as an index to evaluate the power saving performance of water supply pumps.

Table 5 UWPC of submersible pump (before the switchover)

aggregation start time (full water time in elevated tank)	pumped water amount [m^3/d]	power consumption [kW・h/d]	UWPC [kW・h/m^3]
2017.8.8 21:44:56~	23.7	5.51	0.233
2017.8.9 22:22:12~	17.9	4.13	0.231
2017.8.10 19:46:39~	23.1	5.41	0.234
2017.8.11 22:37:53~	22.9	5.51	0.241
2017.8.12 21:42:30~	17.2	4.15	0.241
2017.8.13 19:15:52~	22.2	5.34	0.241
2017.8.14 20:42:53~	17.1	4.13	0.242
2017.8.15 19:31:09~	16.1	3.92	0.244
2017.8.16 18:41:25			
average	20.0	4.76	0.238
change rate [%]	32.0	28.0	5.3

Table 6 UWPC of boost pump (after the switchover)

aggregation start time (full water time in elevated tank)	pumped water amount [m^3/d]	power consumption [kW・h/d]	UWPC [kW・h/m^3]
2017.9.5 22:53:12~	18.7	3.56	0.190
2017.9.6 21:22:04~	20.7	3.98	0.193
2017.9.7 23:16:53~	21.0	4.04	0.192
2017.9.8 21:55:38~	22.1	4.27	0.193
2017.9.9 23:56:20~	23.2	4.39	0.190
2017.9.10 11:40:00			
average	21.1	4.05	0.192
change rate [%]	19.3	19.0	1.2

Table 7 UWPC of downsized water supply pumps

small sized water supply pump	Avg. pumped water amount [m^3/d]	Avg. power consumption [kW・h/d]	UWPC [kW・h/m^3]
submersible pump (before switchover)	20.0	1.05	0.202
boost pump (after switchover)	21.1	4.05	0.192

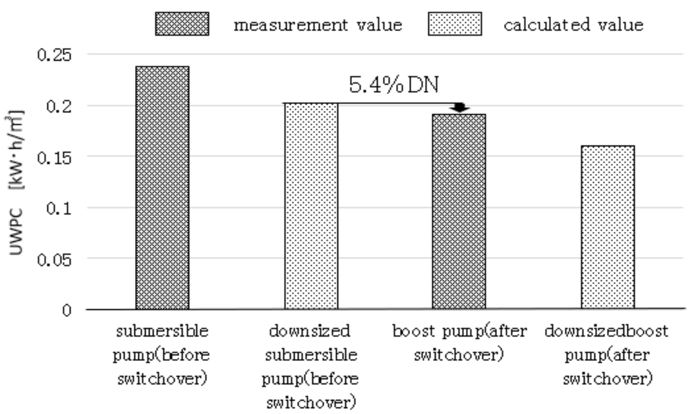

Figure 4 UWPC of each water supply pumps

4. Conclusion

In this study UWPC[kWh/m^3] was proposed as an evaluation index for power saving with water supply amount taken into consideration, and its validity was tested by applying it to actual measurements of water supply amount and power consumption in a multifamily dwelling where water supply system was switched over from the elevated tank system to the direct connection boost elevated tank system. The results can be summarized as follows:

1) Water supply amount per dwelling unit was 270L/d.
2) It was shown that using smaller water supply pumps was feasible. Power consumption

reduction achieved by downsizing of pumps was 15% for submersible pumps and 17% for boost pumps.
3) UWPC (unit of power-water consumption) [kW・h/d] was proposed as an index for evaluating the power saving performance of water supply pumps.
4) UWPC of various downsized water pumps both before and after the switchover of pumps were calculated. The difference in UWPC between the receiving tank system [0.202kW・h] and the direct connection elevated tank system [0.191kW・h] was found to be small.
5) It was confirmed that UWPC could be applied as an index for evaluating power saving performance of water supply systems.

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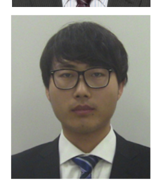
5. Presentation of Authors

Kyosuke Sakaue (Dr. Eng.) is a professor at Department of Architecture, School of Science & Technology, and head of Next Generation Plumbing System Institute, Meiji University. His fields of specialization include water environment, building services and plumbing system.

Shigekazu Okauchi works for Kajima Corp. He manages the construction work of the building.



Guangzheng Wu (Dr. Eng.) is a assistant at Department of Architecture and Environmental Design, College of Architecture and Environmental Design Kanto Gakuin University. He is engaged in research and development of plumbing system.

Takehiko Mitunaga (Dr. Eng.) is a chief engineer at Yamashita Sekkei Inc., He finished the doctor's course in Architecture at Meiji University in Japan. He is engaged in design / research of plumbing system and HVAC system.

Kazuya Fujimura (Dr. Eng.) is a mechanical engineer at Mitsubishi Jisho Sekkei Inc. He finished the doctor's course in Architecture at Meiji University in Japan. He is engaged in research / development of plumbing system.

Development and Spread of Pump-to-Flush Toilet System Corresponding to Global Aging Population

Masayuki Otsuka (1)
(1) dmotsuka@kanto-gakuin.ac.jp
(1) Prof. Dr. Eng., Department of Architecture and Environmental Design, College of Architecture and Environmental Design, Kanto Gakuin University, Japan

Abstract

It is said that the proportion of the world population of those aged 65 and over will rapidly increase in the next half century. Under such a circumstance, there will be a greater burden on carers who look after elderly family members on a daily basis, and it will become even more difficult for those in need of nursing care to go about their day to day activities as they age further. Hence, there is a need for the development and practical application of facility systems that can ease the stress of both carers and those in need. In particular, using a toilet is a frequent daily activity and is hard work for both the one who has an urge to go to the toilet and the one who assists the former. For the one in need of nursing care, it is hard work to walk to the toilet which is away from one's bedroom, and therefore, it would be more desirable if the toilet was closer to the bedroom or installed at the bedside. For the carer, it is hard work to assist the one in need to go to the toilet, but it is also a very stressful task to dispose of waste from a portable toilet in the bedroom, if that is the case, as such an arrangement raises concerns regarding diffusion of bad odour and hygiene maintenance. It is essential, in terms of human dignity, that the elderly remain independent including the ability to use a toilet by themselves.

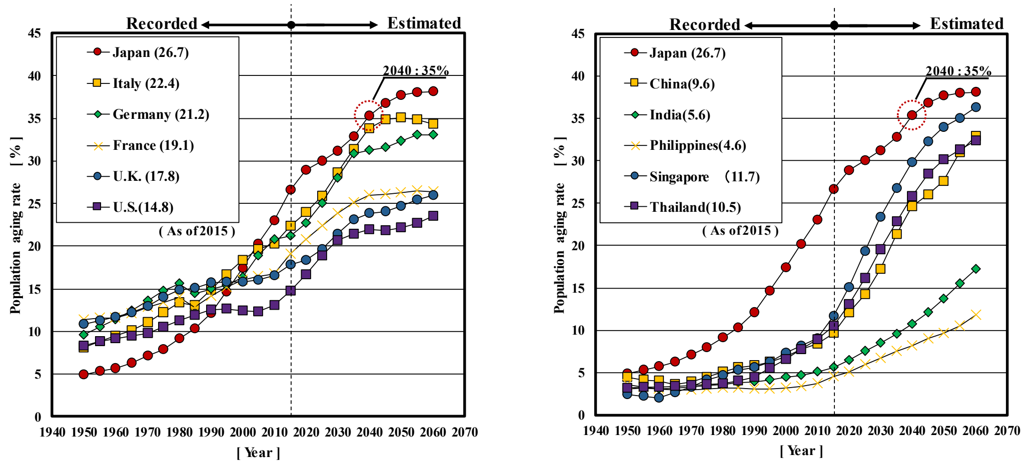
In order to improve such conditions, there are expectations for the development and distribution of a "pump-to-flush toilet" with a force-feed drainage pump which is easy to install at the bedside in a bedroom of an apartment house or a nursing home, and which is configured such that a small-diameter flexible pipe ensures a smooth discharge of waste into a drainage stack. Prior to introducing this technology to high-rise apartment houses, this report evaluates the influence of the technology on the drainage performance of a drainage system and discusses the effectiveness of the technology.

Keywords

Global aging population, Pump-to-flush toilet system for those in need of nursing care, Drainage stack system, Drainage performance

1. Background and objective

Population aging is rapidly increasing in Europe, America and Asia and is becoming a global issue. Japan is in a more serious situation than many other countries, and it is predicted that approximately 35% of the national population will be aged 65 and over by 2040 [1] (Fig. 1). As people become older, they become to need nursing care, and this creates a greater burden on both those in need and their carers in going about their day to day activities. Hence, there is a need for the development and practical application of a facility system that can reduce tasks on both sides.

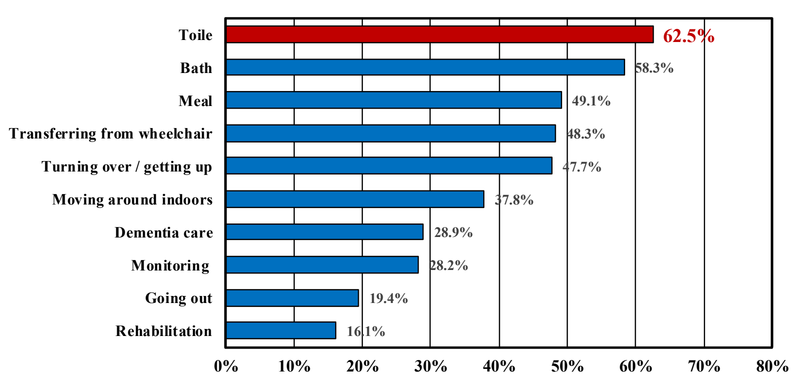


(1) Europe and U.S.A. **(2) Asia**

* The figures in ( ) refer to the ratios as of 2015.

Fig. 1 Transition of the global aging population (Europe and Asia) [1]

In particular, using a toilet is the most stressful and troublesome task of all day to day activities[2] (Fig. 2). Having the ability to use a toilet independently means preserving human dignity. However, it is such a struggle for those in need of nursing care to walk to the toilet that many desire to have toilets much closer to their bedrooms or at the bedside. Moreover, as for carers, it is an oppressive task to empty portable toilets, if that is the case, and to dispose of waste into regular toilets while addressing diffusion of bad odour and ensuring hygiene (Fig. 3).



An interview survey with 696 people who or whose family members have experience in nursing care

Fig. 2 Difficulties and issues surrounding nursing care at home [2]

(1) Japan (2) China

Fig. 3 Example of portable toilets

In order to improve such conditions, the author, in collaboration with a sanitary ware manufacturer, developed a "pump-to-flush toilet system" with a force-feed drainage pump, which is easy to install at the bedside and is configured such that a small-diameter flexible pipe ensures a smooth discharge of waste into the drainage stack or the horizontal drainage pipe of a drainage system. This paper reports the following regarding this new drainage system:

(1) The concept of introducing the pump-to-flush toilet system and the overview thereof
(2) The evaluation of drainage performance and the safety of installing the toilet system to the horizontal fixture drain branch system of a house
(3) The evaluation of drainage performance and the applicability of the toilet system to drainage stack systems of high-rise apartment houses

2. The concept of introducing the pump-to-flush toilet system for the elderly in need of nursing care and the overview thereof

Fig. 4 is a conceptual drawing of a new type of drainage system compatible with next-generation apartment houses with consideration for the elderly in need of nursing care. The concept of the drainage system is based on the following three key points:

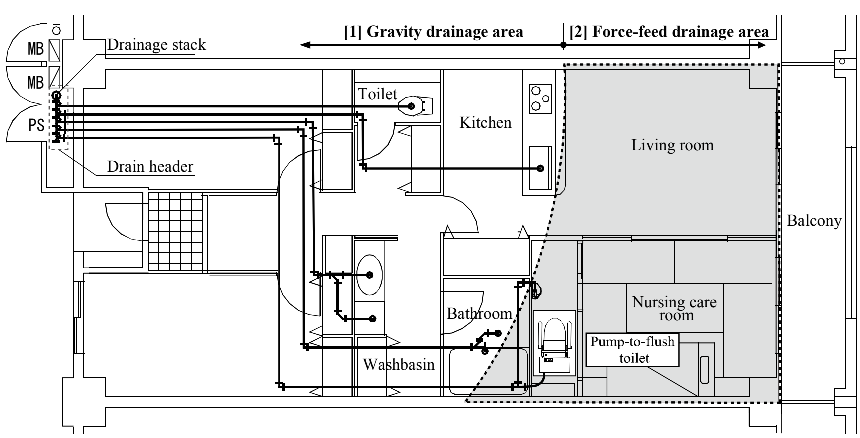
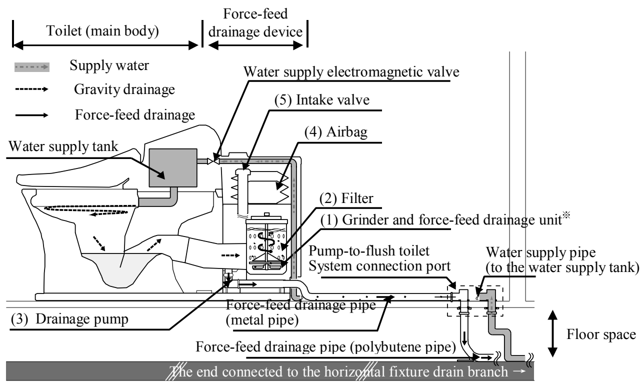


Fig. 4 The concept of the new drainage system for apartment houses with consideration for the elderly in need[3)]

(1) Free planning realised by combining gravity and force-feed drainage systems
Gravity drainage is realised by installing a drainage stack in the pipe shaft of a communal section, and from the drainage stack as the base point, a horizontal fixture drain branch can be connected at a gentle gradient in a floor space, to which a drainage pipe (a pipe diameter 75mm) is connected to discharge wastewater from a conventional type toilet. The area that allows this plumbing is referred to as the "gravity drainage area [1]". Meanwhile, the area, where it is difficult to provide an adequate gradient for gravity drainage in the floor space, is referred to as the "force-feed drainage area [2]" where the pump-to-flush toilet system using a pump-to-flush toilet is applied. The next-generation drainage system is provided with both gravity and force-feed drainage systems.
(2) Plumbing in advance using small-diameter pipes in consideration of a possible future extension of the force-feed drainage system
In order to install the pump-to-flush toilet system in the force-feed drainage area [2], a pipe layout may be planned in advance, where a horizontal fixture drain branch having a small diameter of 25mm is laid in the space between the slab and the floor within an area where nursing care is expected to take place (e.g. a closet as an installation place), so that the pump-to-flush toilet system can be connected to the horizontal fixture drain branch, ready for use when needed.
(3) The main system also as a backup system in case of failure of the sub system
Of the toilets installed in the house, the gravity drainage system using the conventional type toilet functions as a "main system" and the pump-to-flush toilet system functions as a "sub system". It is essential that fail-safe measures are in place so that even if the sub system breaks down, it does not interfere with daily life as long as the main system continues to operate to dispose of waste.

3. Overview of the pump-to-flush toilet system

Fig. 5 shows the structure of the pump-to-flush toilet system. The system comprises a toilet (main body), a force-feed drainage device and a force-feed drainage pipe. Wastewater containing toilet paper and waste is discharged from the toilet into the force-feed drainage device. The wastewater contents are then ground by a grinder/force-feed drainage unit (1) of the force-feed drainage device, passed through a filter (2) and pumped by a drainage pump (3) into a drainage pipe. Moreover, the force-feed drainage device is equipped with an airbag (4) for relaxing positive pressure generated at the time of discharge, and an intake valve (5) is also included in the force-feed drainage device for relaxing negative pressure generated by the pumped wastewater when the drainage pump is in operation. The drainage pipe connected to the force-feed drainage device is a flexible metal pipe. A polybutene pipe is connected to the flexible pipe at one end and the other end of the polybutene pipe is connected to the horizontal fixture drain branch of the gravity drainage system. The toilet uses a nominal amount of 5.5L of water for flushing and is of a water-saving type II according to JIS A5207-2014.



* The nominal amount of 5.5L of flush water does not include any water remaining in the grinder/force-feed drainage unit.

Fig. 5 The structure of the pump-to-flush toilet system3)

4. Drainage performance testing of the horizontal fixture drain branch system

4.1 Experiment overview

(1) Experimental horizontal fixture drain branch system

Fig. 6 and Photo 1 show the experimental horizontal fixture drain branch system when assuming that the system is installed in a house. In the system the drainage pipes of the experimental sanitary fixtures are drawn together into the header (main pipe diameter 75mm, branch pipe diameter 50mm) and are connected to the drainage stack (pipe diameter 100mm).

Fixture used	Gravity type toilet	Bathtub / Washing machine	Washbasin
Experimental drain trap	Toilet trap	Floor drain trap	S trap
Trap seal depth [mm]	55	50	60
Base cross-sectional area ratio	N/A	0.88	1

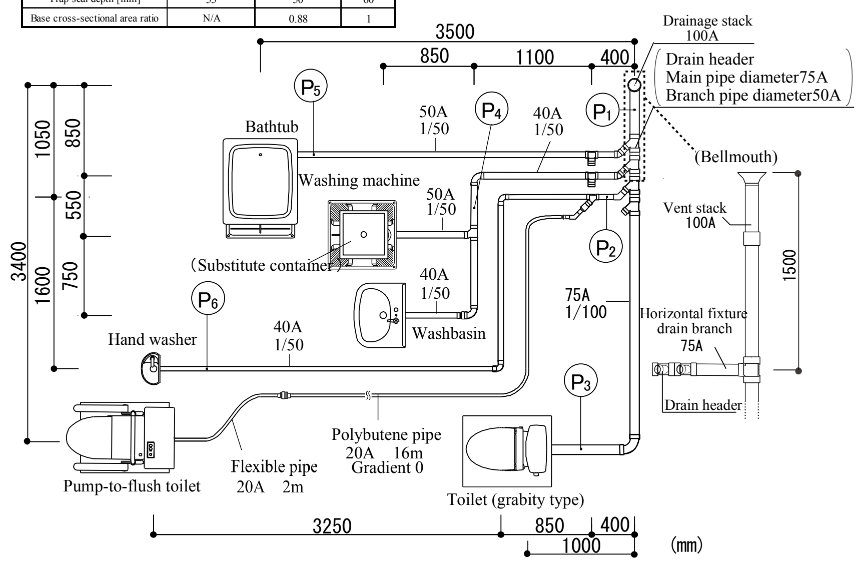


Fig. 6 Experimental horizontal fixture drain branch system3)

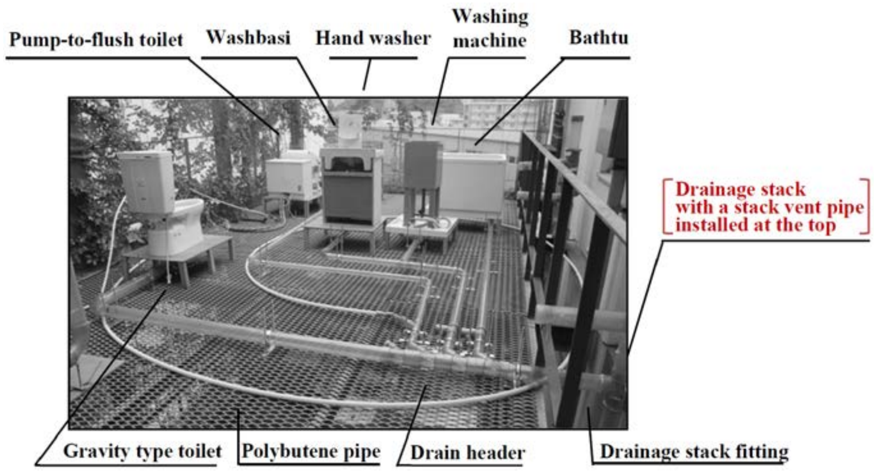
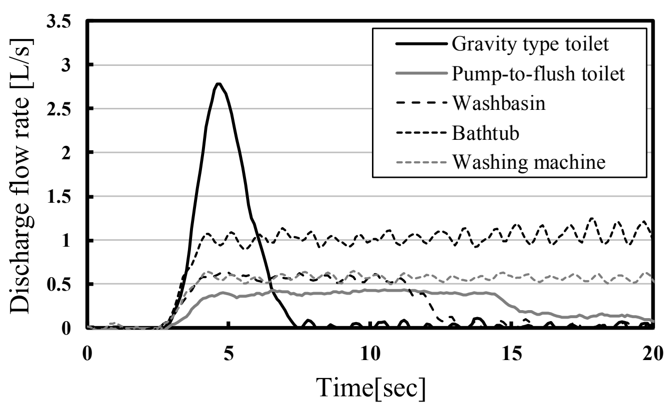


Photo 1 The appearance of the experimental horizontal fixture drain branch[3)]

(2) Experimental sanitary fixtures and drainage load patterns

Fig. 7 shows the waveforms of the discharge flow rates of the experimental sanitary fixtures that are connected to the horizontal fixture drain branch. Moreover, Table 1 shows the discharge characteristics of said sanitary fixtures, and Table 2 shows drainage load patterns using the same sanitary fixtures. The drainage load patterns are applied as “single discharge”, where a load is applied using one sanitary fixture, and as “combined drainage”, where loads are applied using multiple sanitary fixtures. Wastewater is simulated in two ways; by using clean water and by using an experimental waste substitute [note)] (3 folds of a 1 meter-long sheet of 2-ply toilet paper × 6 layers) which is placed in each toilet and flushed with clean water.



※The discharge time lags of the washing machine and the bathtub exceed the time axis scale (20 sec.) and they refer to the numerical values in Table 1, which indicate the characteristics of the flow rate waveforms.

Fig. 7 Fixture discharge characteristics (discharge flow rate waveforms of the experimental sanitary fixtures)[3)]

Table 1 Discharge characteristics of the experimental sanitary fixtures 3)

Fixture※	Fixture discharge volume	Avg. discharge time	Avg. fixture discharge flow rate	Max. fixture discharge flow rate
	W [L]	*td* [s]	*qd* [L/s]	*qmax* [L/s]
Pump-to-flush toilet	5.5	7.9	0.4	0.5
Gravity type toilet	6.0	1.5	2.4	2.7
Bathtub	122.6	73.7	1.0	1.3
Washing machine	29.7	33.1	0.5	0.7
Washbasin	5.0	5.3	0.6	0.6

※The washing machine was substituted by a container. The hand washer (Fig. 5) was not an applicable fixture, hence no measurement. As for the gravity type toilet, a siphonic toilet was used which is of water-saving type II in accordance with JIS A5207-2014. Measurements were made on the pump-to-flush toilet while connected to the force-feed drainage pipe (metal pipe, pipe diameter 19mm, length 2m (standard)).

Table 2 Drainage load patterns3)

	Pattern No. \ Fixture	Pump-to-flush toilet	Gravity type toilet	Bathtub	Washing machine	Washbasin	Waste substitute-containing water
Single drainage	No.1	○					○
	No.2		○				○
	No.3			○			-
	No.4				○		-
	No.5					○	-
Combined drainage	No.6	○	○				○
	No.7	○		○			○
	No.8	○			○		○
	No.9	○				○	○
	No.10	○	○	○			○
	No.11	○	○		○		○
	No.12	○	○	○	○		○
	No.13	○	○	○	○	○	○
Time lag [s]		Start	5	3	2	3	

* ○ indicates a fixture from which a load was applied. As for time lags, drainage delays were timed such that a discharge from the pump-to-flush toilet would collide with discharges from other sanitary fixtures in the drain header.

(3) Measurement items, measurement methods and criteria

Pressure fluctuations in the drainage pipes were measured at points P1-P6 using pressure sensors (Fig. 6), and the seal loss (caused by trap breakage) of the experimental traps was visually measured. The measurement results were examined to see [1] if the inner pipe pressure fluctuations were in the inner pipe pressure value range of ±400Pa and [2] if the trap seal loss values were no more than 1/2 of the trap depth (seal water depth). These criteria are in accordance with SHASE-S 218-2014 “Testing Methods of Flow Capacity for Drainage Systems in Apartment houses” by the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE).

4.2 Experiment results and observations

(1) Inner pipe pressure fluctuations

The drainage load patterns shown in Table 2 were applied and pressure fluctuations in the drainage pipes were measured at the measurement points. From the measured fluctuations, the maximum and minimum values *Pmax*, *Pmin*, were identified per measurement point, and among the *Pmax* values, the maximum system value, *Phmax*, was obtained, and among the *Pmin* values, the minimum system value, *Phmin*, was obtained. Fig. 8 shows the *Phmax* and *Phmin* values in relation to the drainage load patterns. The graph also shows the reference symbols of the measurement points P1-P6

where the *Phmax* and *Phmin* were identified. According to the results of applying both single and combined drainage load patterns, when clean water was applied, *Phmax* was around 10 to 130Pa, and *Phmin* was around -200 to -15Pa. Moreover, when the waste substitute-containing water was applied, *Phmax* was around 10 to 65Pa, and *Phmin* was around -15 to -130Pa. In other words, whether or not the wastewater contained the waste substitute made no significant difference.
Moreover, it was visually observed that when the waste substitute-containing water was discharged from the gravity type toilet connected at the rear of the drain header, the waste substitute collided with drainage from many other fixtures in the drain header and caused temporary blockage before the combined drainage flowed to the drainage stack. Accordingly, it is desirable that the drainage pipe of the gravity type toilet connected to the most upstream side of the drain header is connected at a downstream position from the drain header so as not to be affected by the flow of drainage.

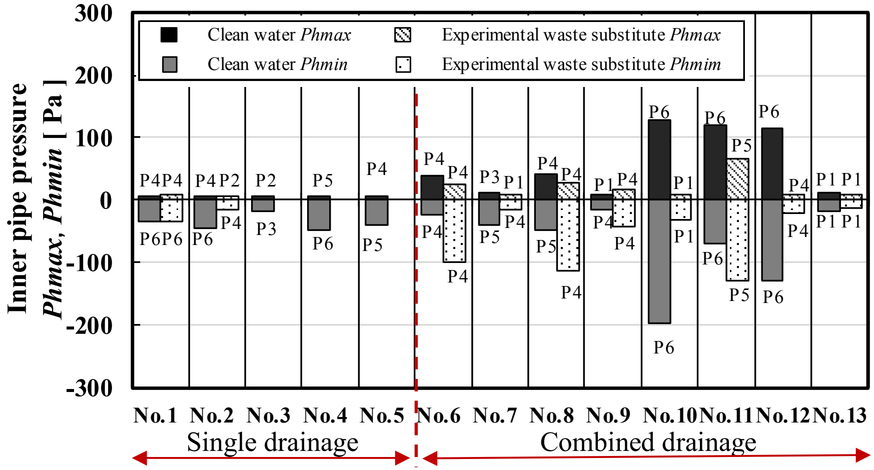


Fig. 8 Inner pressures of the drainage pipes (*Phmax*, *Phmin*) 3)

(2) Trap seal loss

Fig. 9 shows maximum trap seal loss values, ⊿*Hmax*, which were obtained from the sanitary fixtures when combined drainage load patterns No.10-12 were applied by which significant inner pipe fluctuations were caused, as shown in Fig. 8. The graph indicates that the seal loss of the P trap of the hand washer connected to the pump-to-flush toilet and the seal loss of the floor drain trap of the bathtub tend to be significant, although the seal losses are not more than 20mm, and therefore still satisfy the reference values.

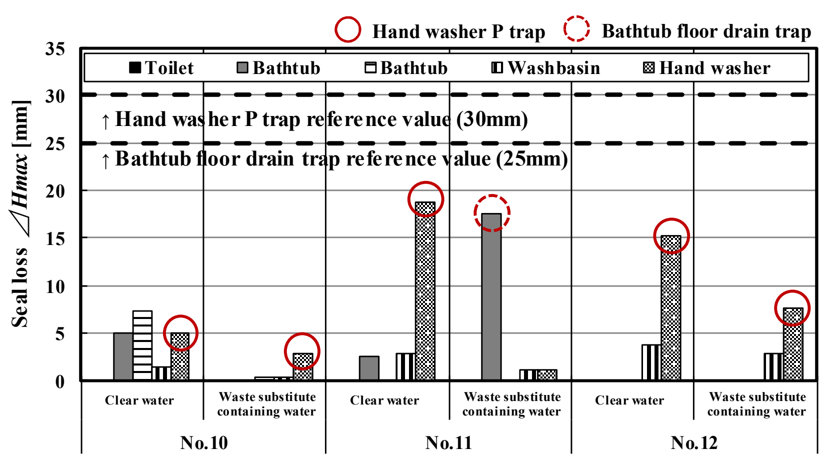


Fig. 9 Seal loss values (⊿*Hmax*) of experimental traps3)

According to the experimental results of inner pipe pressure and trap seal loss, the inner pipe pressure values are approximately -200 to 130Pa, i.e., less than half of the reference value of ±400Pa specified by SHASE-S 218-2014, and the trap seal loss values are also approximately 20mm, i.e., less than half (25 to 30mm) of the depths of the experimental drain traps, which is specified by SHASE-S 218. Therefore, the criteria are satisfied.

5. Drainage performance experiment of the drainage stack system

5.1 Experiment overview

(1) Experimental drainage stack system

Fig. 10 is a drawing of the experimental drainage stack system comprising JIS-DT fittings which is installed to the high-rise construction environment simulation tower at the premises of Kanto Gakuin University. The system is of the stack vent type, wherein a drainage stack has a pipe diameter of 100A, an increaser (100A×125A) is disposed at the base of the drainage stack, and the increaser is connected, at the wider end thereof, through a 90° LL fitting to a house drain (gradient 1/150). Three typical sanitary fixtures are installed at each of the upper 8th and 7th floors; ① a pump-to-flush toilet, ② a gravity type toilet and ③ a bathtub which takes the longest draining time of all, and the water drained from which is most likely to merge with the water drained from other multiple fixtures in reality. The drainage performance was carried out by using these components and by applying different drainage load patterns which are shown in Table 3.

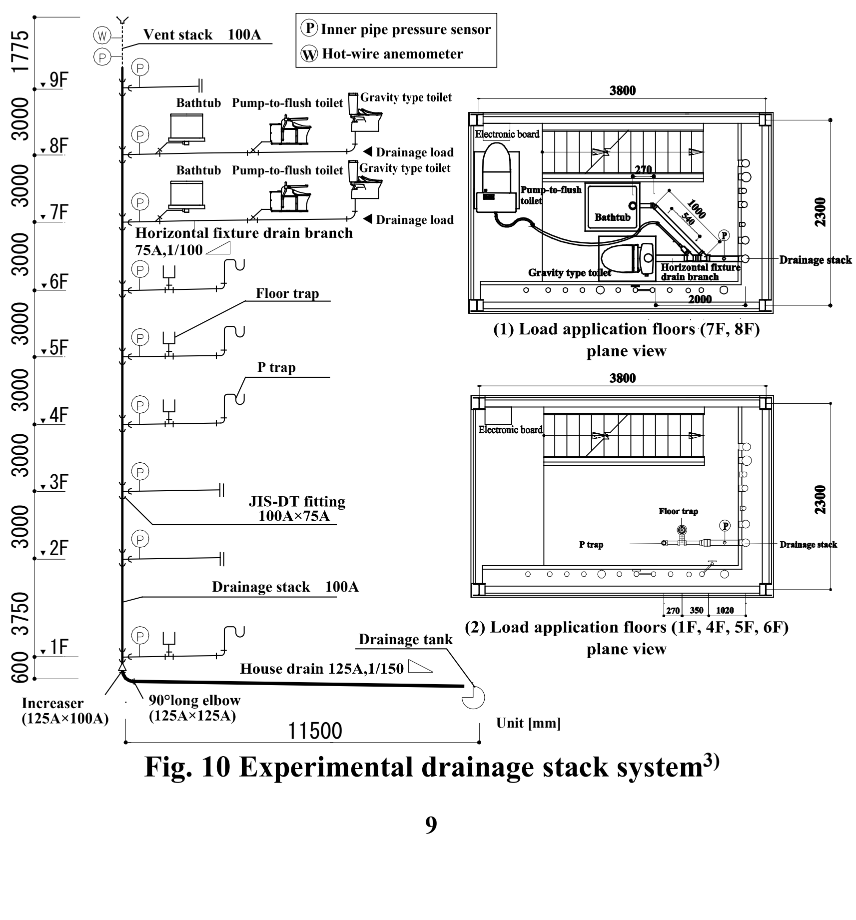


Fig. 10 Experimental drainage stack system[3)]

(2) Drainage load patterns

Table 3 shows the drainage load patterns that were applied from the upper floors. In some cases, a drainage load was applied to the pump-to-flush toilet on the top 8th floor, and drainage loads were then applied to the gravity type toilet and the bathtub on the same floor with a predetermined time lag therebetween. In other cases, drainage loads were also applied from the 7th floor with a set time lag therebetween. With the focus on the maximum value of negative pressure generated at the time of drainage flow merging (the later explained minimum system value, *Psmin*, of the drainage stack system), the time lag, at which said value became maximum under a certain drainage condition, was determined and drainage loads were applied using that time lag.

Table 3 Drainage load patterns to be applied to the drainage stack system[3)]

Pattern No. \ Fixture		8F Pump-to-flush toilet	8F Gravity type toilet	8F Bathtub	7F Pump-to-flush toilet	7F Gravity type toilet	7F Bathtub
Single drainage	No.1	○					
	No.2		○				
Combined drainage	No.3	○			○		
	No.4		○			○	
	No.5	○	○				
	No.6	○	○		○	○	
	No.7	○		○	○		○
Time lag [s]		Start	3	3	1	4	4

*The fixtures from which different drainage patterns were applied are indicated by ○. Draining time lags were set, starting from the toilet (force-feed) on the 8th floor, as shown in the table, and the harshest condition, where inner pipe pressure (*Psmin*) became significant, was determined.

(3) Measurement items, measurement methods and criteria

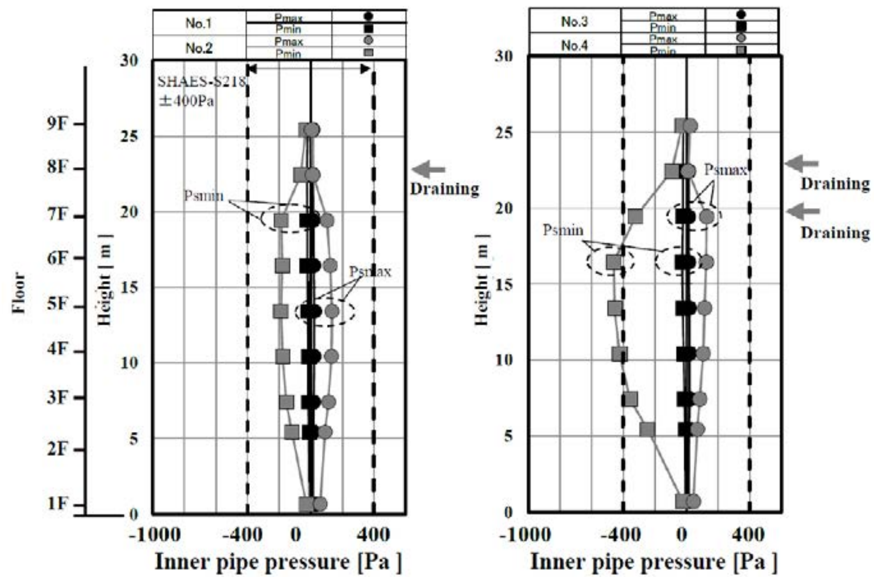
The measurement items and measurement methods refer to 4.1 (3). As shown in Fig. 10, pressure fluctuations in the horizontal fixture drain branches were measured at the measurement points P, and the seal loss (caused by trap breakage) of the experimental traps was also measured. Moreover, the central velocity in the stack vent pipe was measured at the measurement point W, and the measured value was multiplied by a pipe cross-sectional area for air flow rate conversion. Incidentally the criteria also refer to 4.1 (3).

5.2 Experiment results and observations

(1) Comparison of drainage performance influenced by the pump-to-flush toilet and the gravity type toilet

Fig. 11 shows distributions of maximum and minimum inner pipe pressure values, *Pmax* and *Pmin*, which were obtained when the drainage load patterns No.1-No.4 (Table 3) were applied. Fig. 11 (1) compares the results of applying No.1 and No.2 to the pump-to-flush toilet and the gravity type toilet on the 8th floor (single drainage), and Fig. 11 (2) compares the results of applying No.3 and No.4 from the 8th and 7th floors (combined drainage). The waste substitute-containing water was used in both cases, because it has been already demonstrated by the previous study that draining wastewater containing a waste substitute affects inner pipe pressure more than draining clean water. According to Fig. 11 (1), *Psmin* is not more than -25Pa in No.1 and it is not more than -190Pa in No.2, while *Psmax* is not more than 200Pa in both No.1 and No.2 cases.

Moreover, Fig. 11 (2) indicates that *Psmin* is approximately -30Pa in No.3, whereas it is -480Pa in No.4, exceeding the reference value specified by SHASE-S 218-2014. Meanwhile, *Psmax* is not more than 200Pa, which is the same as in Fig. 11 (1). Accordingly, it is considered that the pump-to-flush toilet affects the drainage performance of the drainage stack system less than the gravity type toilet.



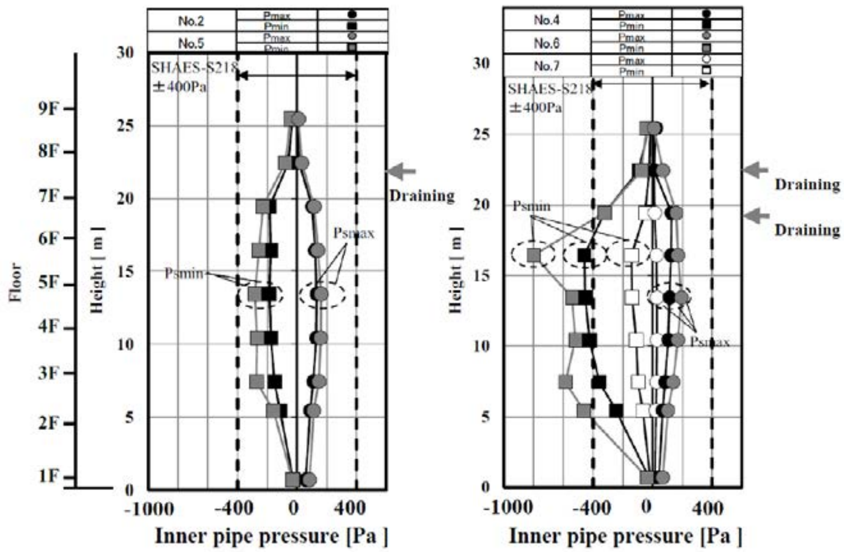
(1) Single drainage (8F) No.1 and No.2

(2) Combined drainage (8F+7F) No.3 and No.4

Fig. 11 Comparison of inner pipe pressure distributions (force-feed and gravity types (waste substitute-containing water)) [3)]

(2) Influence of merging wastewater from the pump-to-flush toilet with wastewater from the gravity type toilet

Fig.12, (1) and (2), compares distributions of inner pipe pressure that was affected by merging wastewater from the pump-to-flush toilet with wastewater from the gravity type toilet. Fig.12 (1) compares the results of applying the drainage load patterns No.2 and No.5 (Table 3) from one floor, and Fig.12 (2) compares the results of applying No.4 and No.6 from two floors. Moreover, Fig.12 (2) also includes the result of applying No.7, by which wastewater from the pump-to-flush toilet was merged with water from the bathtub based on the assumption that in reality, the draining time of the bathtub is long, and while the bathtub is being drained, wastewater from the pump-to-flush toilet very likely merges with the bath water, as explained earlier.



(1) 1 floor (8F)
No.2 and No.5

(2) 2 floors (8F+7F)
No.4 and No.6

Fig. 12 Comparison of inner pipe pressure distributions (gravity type drainage + force-feed drainage (waste substitute-containing water)) [3)]

Furthermore, *Psmax* and *Psmin* values were obtained from Fig. 12 in order to identify pressure fluctuations influenced by the wastewater from the gravity type toilet being merged with the wastewater from the pump-to-flush toilet. The *Psmax* and *Psmin* values are compared in Fig. 13. According to the results, *Psmax* and *Psmin* are -285 to 165Pa, in the one-floor drainage load application, which satisfy the reference value. Moreover, *Psmin* was increased by 100Pa and *Psmax* was increased by 35Pa when the force-feed drainage was added. In contrast, in the two-floor drainage load application using No.6, an extreme drainage load pattern, *Psmax* and *Psmin* are -800 to 190Pa and exceed the reference value of -400Pa. Moreover, *Psmin* was significantly increased by 460Pa, so was *Psmax* by 75Pa compared to the case of the one-floor drainage load application. However, in No.7 where the wastewater from the pump-to-flush toilet is added to the water drained from the bathtub, as shown in Fig. 12 (2), *Psmax* and *Psmin* are -150 to 40Pa. Therefore, it is considered that the drainage performance of the stack vent drainage system using JIS-DT fittings is not adversely affected.

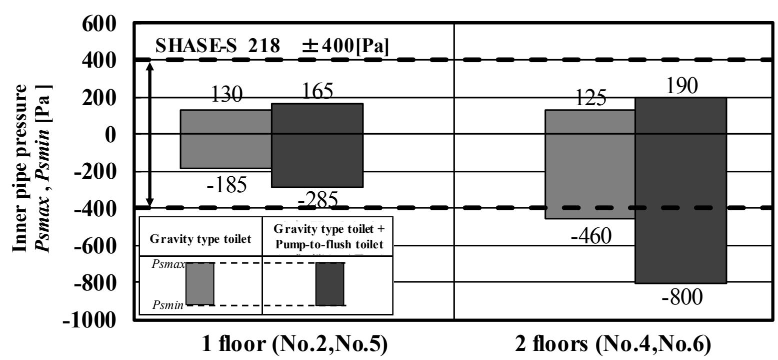


Fig. 13 Comparison of *Psmax* and *Psmin* (gravity type drainage + force-feed drainage (waste substitute-containing water)) [3)]

(3) Overall evaluation of the drainage performance of the drainage stack system

Fig 14 shows *Psmin* and *Psmax* values that were obtained when applying all the drainage load patterns using clean water and waste substitute-containing water (**Table 3**), and **Fig. 15** shows the seal losses ⊿*Hmax* of the experimental traps on the 6th floor where *Psmin* was frequently obtained in the same way. Looking at different two-floor drainage load patterns, No.4 and No.6 for example, in contrast to No.4, in which drainage loads were applied to the gravity type toilets on two floors, in No.6, in which drainage loads were applied to the gravity type toilets and the pump-to-flush toilets on the two floors and merged together, the inner pipe pressure values exceeded the reference value range and the experimental traps broke in both cases of clear water and waste substitute-containing water. Accordingly, as clarified in the reference literature [4], the results of drainage performance testing in accordance with SHASE-S 218 indicate that safety is better ensured by using a special-fitting drainage system with a larger drainage capacity than by using a stack vent system with conventional fittings.

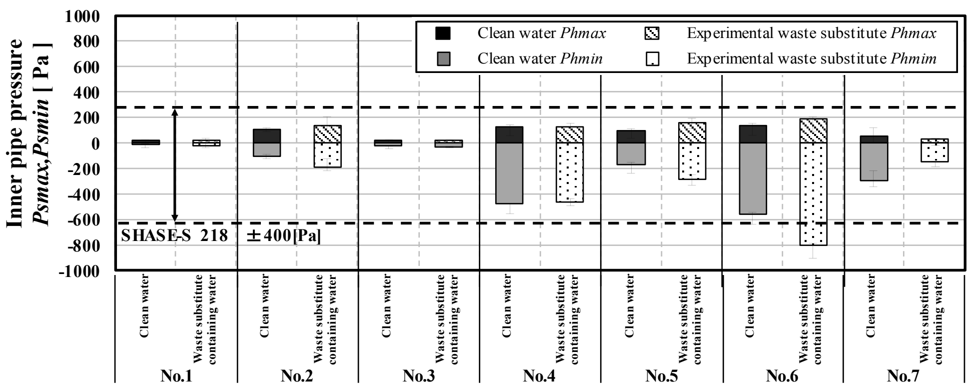
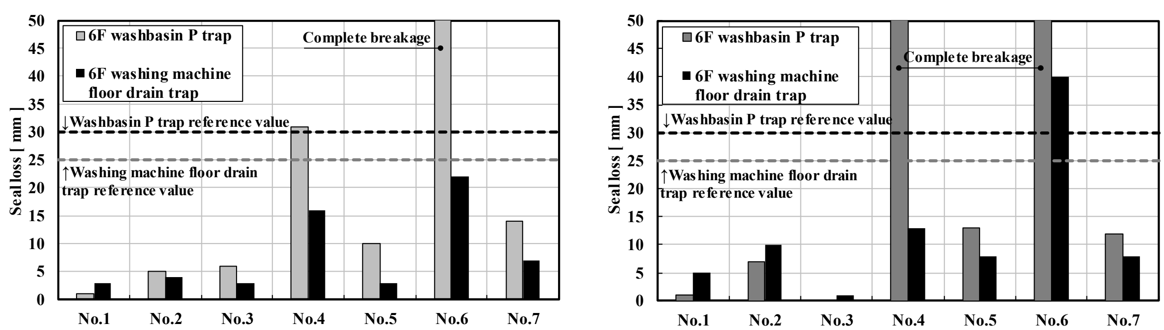


Fig. 14 Comparison of *Psmax* and *Psmin* values in all drainage load patterns[3)]



(1) Clean water **(2) Waste substitute-containing water**

Fig. 15 Comparison of ⊿*Hmax* values in all drainage load patterns[3)]

6. Conclusion

A pump-to-flush toilet system was developed with the intention of reducing the burden and stress on those in need of nursing care and their carers, and said toilet system was evaluated through experiments for its possible applicability to drainage stack systems of high-rise apartment houses. The following knowledge has been acquired from the experiment results:

(1) When the pump-to-flush toilet system was connected to the horizontal fixture drain branch of a house, both single drainage and combined drainage generated by multiple sanitary fixtures never caused induced siphonage to break trap seals, hence having no adverse effect on the drainage performance.

(2) When connected to a drainage stack system, the pump-to-flush toilet system creates much less influence on inner pipe pressure and trap seal loss, which are determination indices, than a toilet that uses gravity for flushing.

(3) When the drainage from the gravity type toilet is combined with the drainage from the pump-to-flush toilet system, it is considered that the application of a special-fitting drainage system with higher drainage performance is preferable for ensuring safety.

Acknowledgement

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Note) The “Methods of Testing Performance of Quality Housing Components, Water Closets, BLT WC: 2015” by the Center of Better Living specifies a waste substitute to be four layers of 0.9m-long folded sheets of 1-ply toilet paper. However, for this study, six layers of 1m-long folded sheets of 2-ply toilet paper, specified by JIS P4501, was used in order to create a severer drainage condition.

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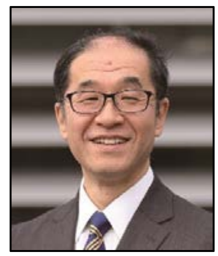
8. Presentations of Authors



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 (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His latest interests are the hybrid drainage system that uses both force feed type and gravity type drainage methods compatible with commercial building conversion.

A Case Study of Corrosion on Type 304 Stainless Steel Piping of Hot Water System Fed with Reverse Osmosis Permeate Water in Japan

K. Hosoya (1), K. Takada (2), L. Zhai (3)

(1) k-hosoya@skk.jp

(2) k-takada@skk.jp

(3) r-zai@skk.jp

(1), (2), (3) Engineering Management Div, Sanken Setsubi Kogyo Co., Ltd, Japan

Abstract

In Japan, type 304 stainless steel is used as a main piping material of central hot water supply system. Japan Stainless Steel Association (JSSA) issued a piping manual which listed welding methods, as well as a water quality guideline of stainless steel piping. However, in buildings where groundwater is treated with reverse osmosis (RO) systems for their hot water systems, even if the permeate water quality conforms to the JSSA guideline, hot water leakage caused by corrosion still occurs on type 304 stainless steel piping. In consideration of this situation, a safety-usage paradigm is proposed in recent years.

In this paper, a typical case of piping corrosion related to RO water is studied, and water quality was evaluated with both the current guideline and the safety-usage paradigm. The safety-usage paradigm is found to be more suitable in evaluating water quality than

the guideline. Since the safety-usage paradigm has not taken influence of sulfate ion and nitrate ion into consideration, to develop measures to prevent corrosion, it is necessary to evaluate level of sulfate ion and nitrate ion which inhibit localized corrosion on stainless steel.

Keywords

Hot water supply system; Stainless steel; Reverse osmosis system; Corrosion.

1 Introduction

The type 304 stainless steel piping is superior in corrosion resistance. Therefore in Japan, type 304 stainless steel is often used as a main piping material of central hot water supply systems[1)]. "Piping Manual for Stainless Steel Pipes for Buildings (Revised edition)" was published in 2011[2)]. In this book, welding methods and a water quality guideline, etc. were listed. "The Guideline for Water Quality of Stainless Steel Piping for Building Equipments" was published by Japan Stainless Steel Association[3)]. Attribute to the issue of both Piping manual and the Guideline for Water Quality, reported leakage of stainless steel piping has decreased.

However, in buildings that groundwater treated with reverse osmosis (RO) systems is used in hot water supply systems, even if the permeate water quality meets the JSSA guideline, hot water leakage caused by piping corrosion still occurs. The safety-usage paradigm of the corrosion-crevie repassivation potential ($E_{R,\ CREV}$) is proposed recently[4)]. In this paper, four cases of piping corrosion related to RO water were studied, and water quality was evaluated with the current guideline and the safety-usage paradigm.

2 Case Studies

2.1 Test Methods

In this paper, four buildings with hot water system were studied as examples to examine the quality of tap water and corrosion forms of stainless steel piping, to compare the applicability of the guide line with the safe-usage paradigm as design manuals.

2.2 Result of case A

In this case, water began to leak around certain welds on the type 304 stainless steel piping of hot water system after three years of the completion of the building. Four years later, tap water fed to the hot water system has been replaced with well water (RO water). Six months after that, hot water leakage caused by pitting corrosion was found on a part of straight pipe[5)]. To find out what has led to the corrosion, water quality was examined. Temperature of hot water was set to be between 50 and 60°C. Figure 1 shows a diagram of the hot water distribution system. Table 1 shows the test results of water quality (in all four cases). Because performance of the RO membrane deteriorates with time, chloride ion concentration of RO water fluctuated between 56 and 83 mg/L. Figure 2 shows the corrosion form of the pipe.

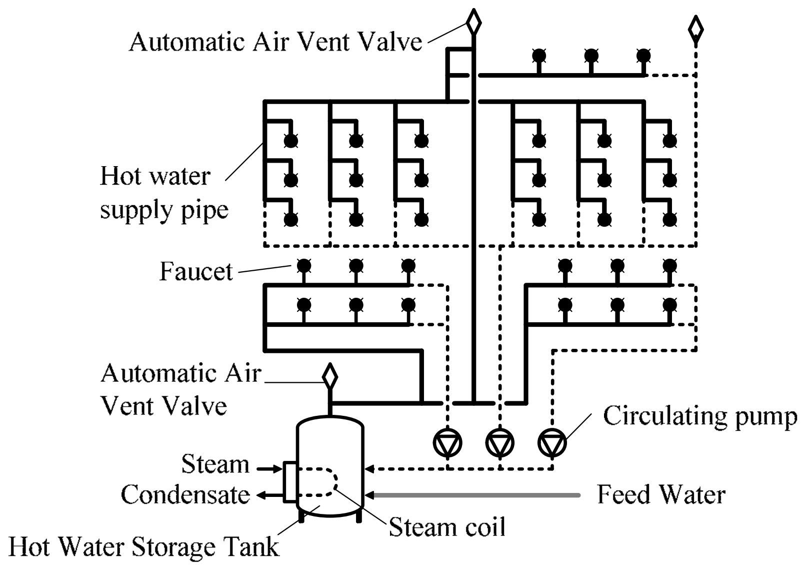
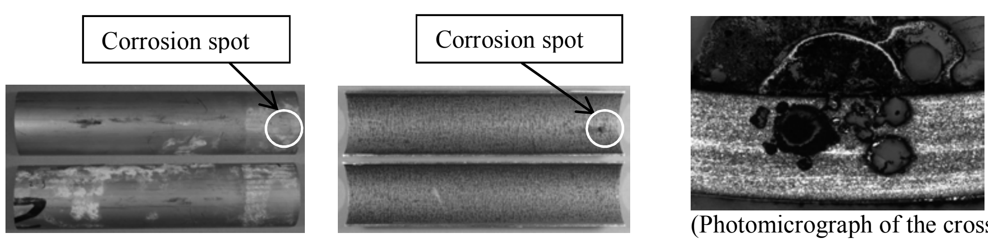


Figure 1- Hot water supply and distribution diagram of case A



(Outer surface of the pipe) (Inner surface of the pipe) (Photomicrograph of the cross section at the corrosion spot)

Figure 2- Corrosion condition of the hot water pipe (type 304 stainless steel)

Table 1- Analysis results of water quality in case A to D

Item	Unit	Case A			Case B	Case C		Case D		
								RO water		
								RO membrane exchange		
		City water	RO water	Hot water	RO water	RO water+ City water	Hot water	Before (D-1)	After (D-2)	Hot water
pH	-	7.0	6.5-7.6	-	7.7	7.3	-	7.57	7.61	7.4
Conductivity	mS/m	14.0	-	-	44.1	25.4	-	10.0	4.55	4.4
Alkalinity [pH4.8]	$mgCaCO_3$/L	22	8.5	-	66	33	-	10	10	10
Ca-hardness	$mgCaCO_3$/L	30.5	-	-	33.7	31.3	-	4.9	5.8	7.3
Total-hardness	$mgCaCO_3$/L	46.5	1.6	-	60.0	48.3	-	5.0	6.0	7.7
Molybdate -reactive silica	$mgSiO_2$/L	10.7	2 >	-	28	13	-	-	-	-
Sulfate ion	$mgSO_4^{2-}$/L	21.3	1.2	-	17.1	2.6	-	-	-	1>
Chloride ion	$mgCl^-$/L	14.7	56-83	-	75	40	-	24.8	10.6	9
Nitrae ion	$mgNO_3^-$/L	-	-	-	1.3>	8.0	-	-	-	-
Total dissolved solid	mg/L	-	140	-	-	-	-	51	27	-
Residual chlorine	$mgCl_2$/L	0.4	0.25	0.15	0.25-0.4	0.5	0.3-0.4	0.1-0.8	0.2-0.4	0.08-0.11
Dissolved oxygen	mgO_2/L	-	8-9	7	-	-	-	-	-	-
Total organic carbon	mgC/L	-	-	-	-	-	-	-	-	0.3>

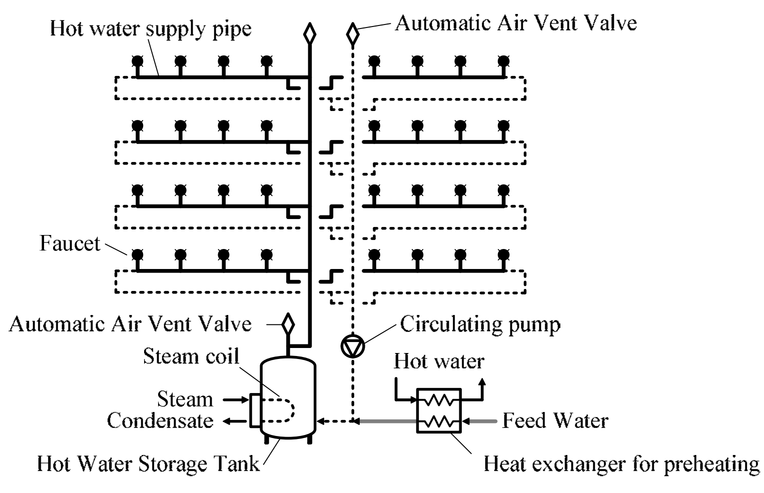


Figure 3- Hot water supply and distribution diagram of case B

2.3 Result of case B

One year after the completion of the building in case B, leakage occurred at the mechanical coupling of type 304 stainless steel piping of the hot water system (70-80°C)[6]. Figure 3 shows a diagram of the hot water distribution system. Table 1 shows RO water quality fed to the hot water system. Chloride ion concentration of RO water fluctuated between 20 to 100 mg/L. Figure 4 shows corrosion spots on a sample of pipe. In this case, crevice corrosion has spread to the conjunction of the mechanical coupling and the O ring (cf. Figure 5). Besides, corrosion has also been found at a flange part and welds inside the hot water storage tank which is made from type 444 stainless steel (water temperature is controlled to be 65°C) (cf. Figure 6).

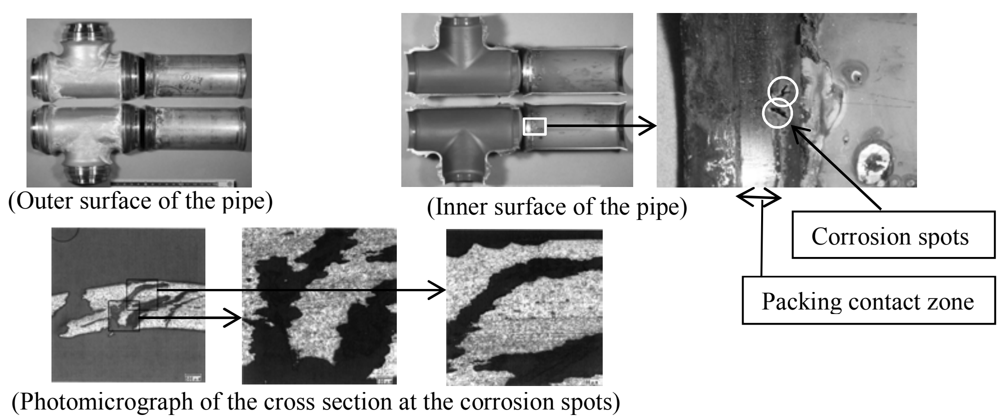


Figure 4- Corrosion condition of the hot water piping (type 304 stainless steel)

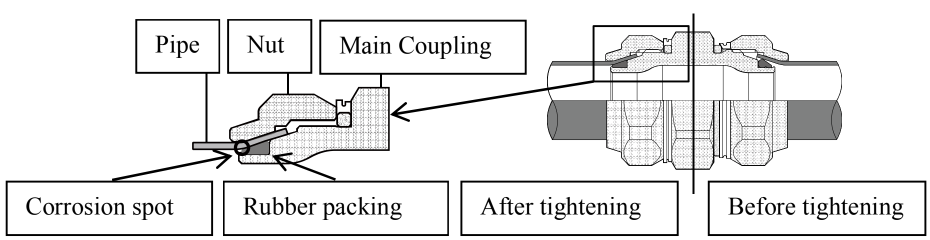


Figure 5- Structure of the mechanical coupling and corrosion condition

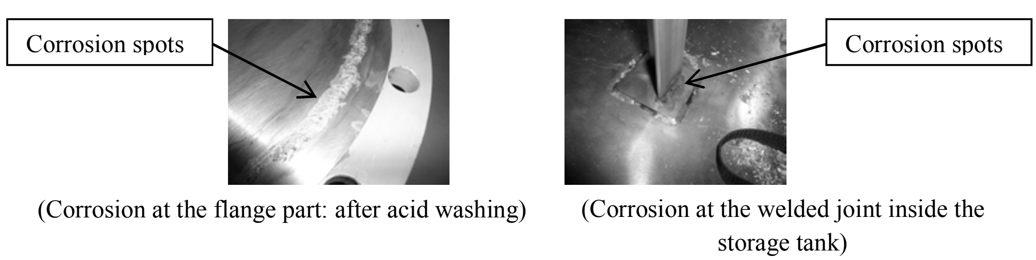


Figure 6- Corrosion condition of the hot water storage tank

（type 444 stainless steel）

2.4 Result of case C

In case C, during the 20 years when tap water was fed to hot water system, leakage caused by corrosion never occurred. However, corrosion on welds of the hot water storage tank (made from type 444 stainless steel) has generated two years after changing the feed water from tap water to RO water (cf. Figure 10)[6]. Fortunately, the hot water piping material is "Heat-resistant hard polyvinyl chloride lined-steel pipe", and no corrosion generated on them. Figure 7 shows a diagram of the hot water distribution system, and Table 1 shows RO water quality which was fed to the hot water system. Residual chlorine concentration in hot water was between 0.3 and 0.4 mg/L, which was found not much less than in feed water.

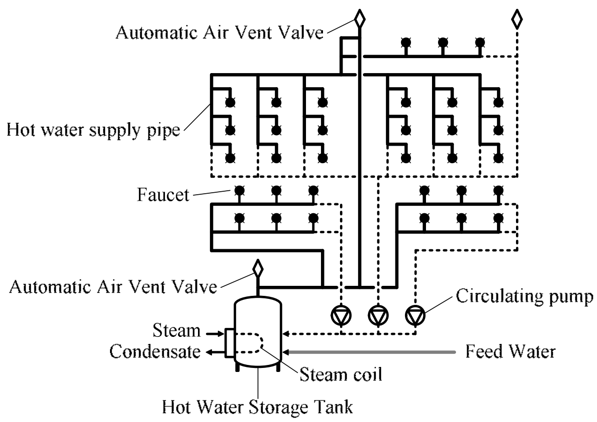
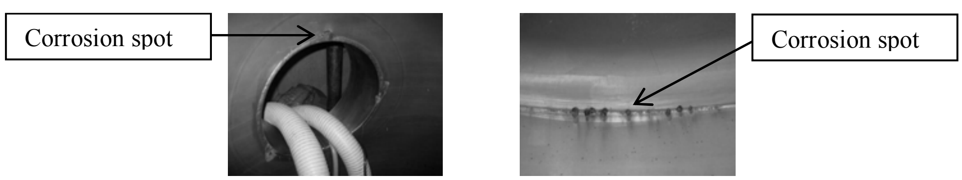


Figure 7- Hot water supply and distribution diagram of case C



(Corrosion on a weld on the manhole) (Corrosion on the welding part)

Figure 8- Corrosion condition of the hot water storage tank (type 444 stainless steel)

2.5 Result of case D

Table 1 shows analysis result of water quality of both RO water and hot water. Figure 9 shows a diagram of the hot water system in case D. In this case, corrosion began to occur one year after the building's completion[7]. After heated to 90°C, hot water was then mixed with tap water and distributed. At the beginning, water temperature of the mixture was set to be 70°C. This has been reset to 60°C after corrosion was found. For performance of the RO membrane deteriorates with time, the chloride ion concentration of feed water fluctuated between 6.1 and 28.5 mg/L. In RO water, the maximum concentration of residual chlorine was 0.8 mg/L, and free residual chlorine concentration was around 0.08 to 0.11 mg/L. Consequentially, in the Natural Coolant CO_2 Heat Pump Water Heater, corrosion occurred at pipes (type 304 stainless steel), welds of the hot storage tank (type 444 stainless steel), and the sub-tank (type 304 stainless steel) (cf. Figure 10). Figure 11 shows corrosion condition at the gap of the mechanical coupling (type 304 stainless steel). Near the curve where a rubber ring was inserted, pitting corrosion and stress cracking corrosion was found. Figure 12 shows the structure of the mechanical coupling and corrosion spots. Figure 13 shows corrosion on a sample of pipe.

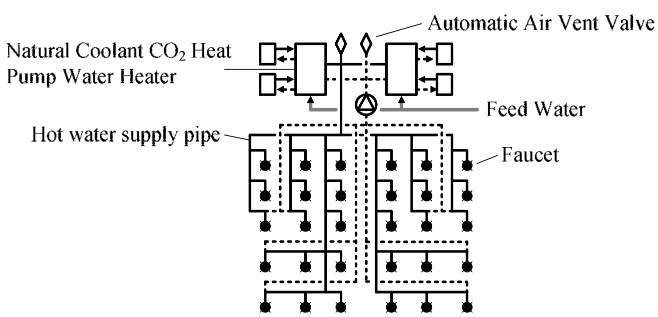


Figure 9- Hot water supply and distribution diagram of case D

(Pipe weldment) (Storage tank weldment) (Sub-storage tank weldment)

Figure 10- Corrosion of the natural coolant CO_2 heat pump water heater

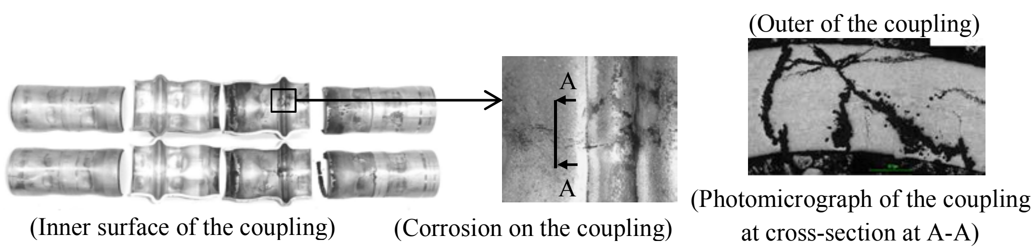


Figure 11- Corrosion condition of the mechanical coupling (type 304 stainless steel)

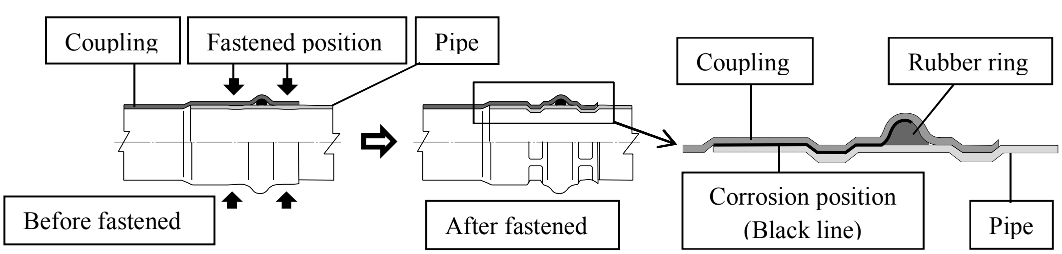


Figure 12- Structure of the mechanical coupling and corrosion spot

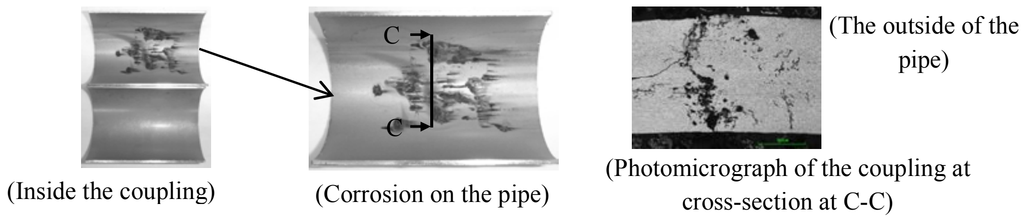


Figure 13- Corrosion on the pipe（type 304 stainless steel）

3 Examination of water quality

3-1 Evaluation with the Guideline for Water Quality Issued by JSSA

The water samples collected from buildings in case A to D were analyzed and evaluated with "the Guideline for Water Quality concerning Stainless Steel Equipment for Building", issued by Japan Stainless Steel Association (JSSA)[3]. Figure 14 and Figure 15 shows the results of evaluation.

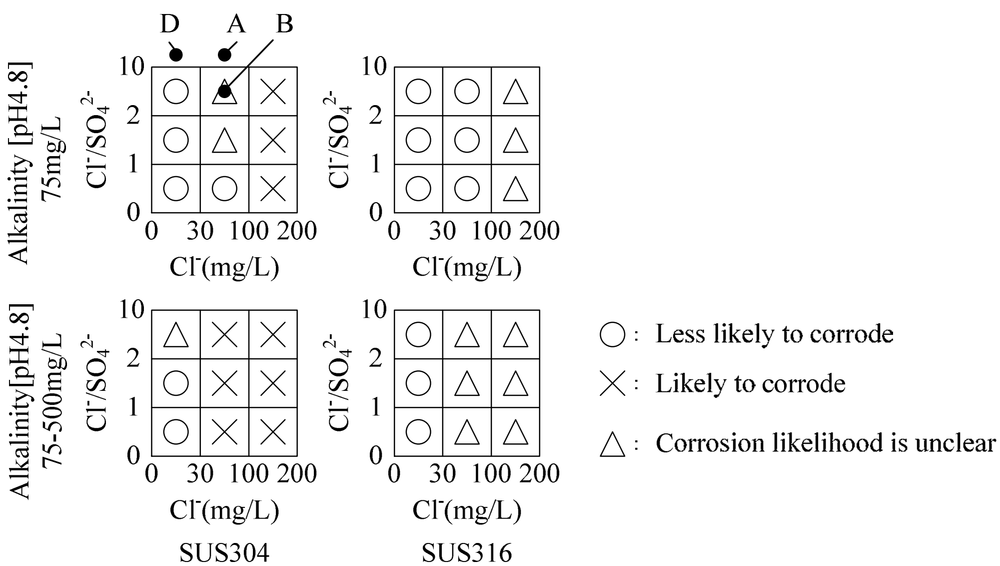


Figure 14- Comparison between water quality for mechanical coupling areas (for hot-water supply and air-conditioning)[3] and water quality of the corrosion cases

In figure 14/15, water quality of sample in each case is plotted in the corrosion likelihood graph, which was provided in the Guideline for Water Quality issued by JSSA. A point of a water sample plotted within the valid range of the graph means the sample can be evaluated with this graph, such as case B. On the other hand, points of case A and D fall outside of the range of the graph, which means their corrosion likelihood was unclear.

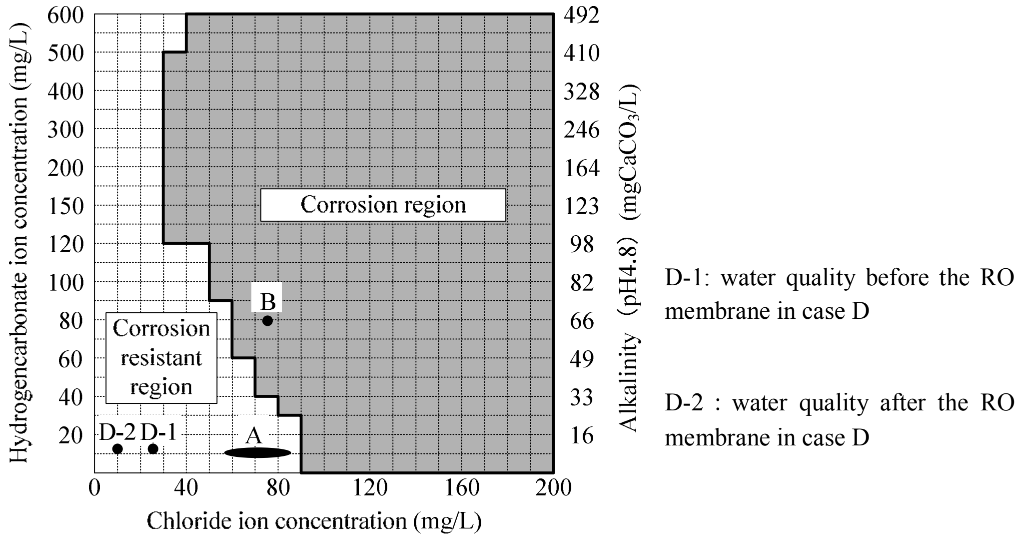


Figure 15- Comparison between water quality for SUS 304 welded coupling areas (for hot-water supply piping)[3] and water quality of the corrosion cases

3-2 Evaluation with the safety-usage paradigm

Figure 16 shows comparison between the safety-usage paradigm[4] of stainless steel and water quality of case A to case D. Water temperature and chloride ion concentration of each case has been plotted on the safety-usage paradigm. If a point of water quality falls above a line of residual chlorine concentration, localized corrosion is likely to occur. To the contract, if water quality is below a line of residual chlorine concentration, it is unlikely to corrode.

In case A, residual chlorine concentration of hot water is 0.15mg/L. Therefore stainless steel would corrode. In case B, since the residual chlorine concentration in tap water is about 0.25-0.4 mg/L, the same substance is presumed to be around 0.1 mg/L after heated. Thus, it is estimated that both pipe (type 304 stainless steel) and hot water storage tank (type 444 stainless steel) are likely to corrode. In case C, since residual chlorine concentration of hot water is about 0.3-0.4 mg/L, the point of water quality falls in the area that hot water storage tank (type 444 stainless steel) tend to corrode. As for case D, residual chlorine concentration of hot water is around 0.08-0.11mg/L. D-1 shows water quality before RO membrane, while D-2 shows that of after RO membrane. According to the paradigm, in D-1, both pipe (type 304 stainless steel) and the hot water storage tank (type 444 stainless steel) would corrode, whereas in D-2, both would not.

We can see that all four cases are plotted within the area of the safe-usage paradigm; therefore the paradigm can be used to evaluate all the four cases.

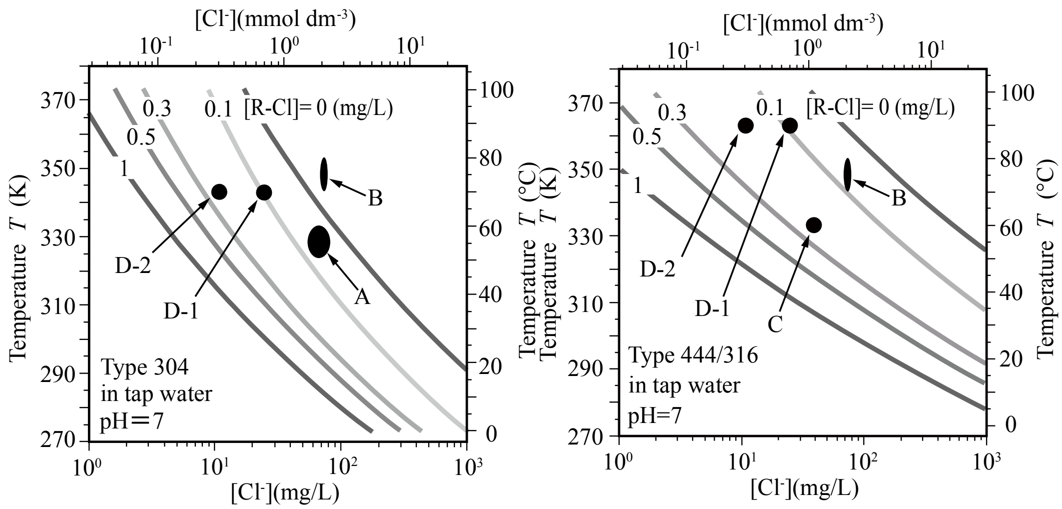


Figure 16- Comparison between the safety-usage paradigm of stainless steel [4)] and water quality of the corrosion cases

3-3 The corrosion inhibition of RO water

Yamaguchi and Yamamoto has proved that residual chlorine reacts with dissolved organic matter in water purification process, piping transfer process, and heating process[8), 9)]. Because RO water is low in organic matter concentration, the decrease in residual chlorine concentration caused by the reaction with organic matter is not much[6), 7), 10)]. As a result, steady-state corrosion possibility of stainless steel grows considerably, and localized corrosion is supposed easily occur[4), 10)]. Furthermore, sulfate ion and nitrate ion which inhibits localized corrosion is lower in RO water than in tap water, so localized corrosion in RO water tends to occur more easily. In the safety-usage paradigm, influence of sulfate ion and nitrate ion has not been taken into consideration. Therefore, it is necessary to additionally evaluate the influence of sulfate ion and nitrate ion when developing measures to inhibit corrosion for stainless steel.

4. Conclusions

In this report, we investigated four cases of corrosion in hot water systems, examined the propriety of the guideline and the safety-usage paradigm and have reached the following findings:

(1) Evaluation with the Guideline for Water Quality of JSSA

Two cases were outside the evaluation range of the guideline (for mechanical coupling), and three cases were inside the corrosion resistant region of the guideline (for welded coupling). The guideline cannot be used for assessing possibility of corrosion.

(2) Evaluation with the safety-usage paradigm

All four typical cases were inside the corrosion area of the safety-usage paradigm. It is considered in most cases, the safety-usage paradigm can be used to assess corrosion possibility.

(3) Measures to inhibit corrosion in RO water

In order to inhibit corrosion of the stainless steel pipe, it is also necessary to evaluate influence of sulfate ion and nitrate ion.

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6 Presentation of Authors

Kiyoshi Hosoya is a chief technical officer at Sanken Setsubi Kogyo Co., Ltd., a member of SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan) and JSCE (Japan Society of Corrosion Engineering).

Koji Takada is a manager at Sanken Setsubi Kogyo Co., Ltd., a member of SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan) and JSCE (Japan Society of Corrosion Engineering).

Liangliang Zhai is a chief technical staff at Sanken Setsubi Kogyo Co., Ltd.

Flow and Seal Loss Characteristics of Siphonic Drainage System with Tail trap

K. Yanagisawa (1), K. Sakaue (2), T. Inada (3),T. Mitsunaga (4)
(1) ce183047@meiji.ac.jp
(2) sakaue@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 the siphonage generated by full flowing through the pipe. Since this drainage system has a strong carrying force and it is possible to install a long distance piping with a small diameter and horizontal pipe, it can be installed costly and freely in piping design. Normally, a trap needed for drainage system is installed in the inflow part near the fixture drain. However, in this drainage system, seal break often occurs due to the influence of the siphonic negative pressure generated by the siphonage. An air admittance valve is used as a method for preventing seal break but we propose a tail trap installed in the tail part.

In this study, we considered the seal loss characteristics of siphonic drainage system with improved tail trap by experiments.

Keywords

Siphonic drainage system; Seal break; Tail trap

1. Introduction

The siphon drainage system derives its power from siphonage generated by the fill flow in the piping. Because of its strong power of transport, it makes possible the installation of small diameter piping with no slope. As it gives freedom to piping design, further expansion in the future is expected. Though water sealed trap in the wastewater drainage system plays an important role in preventing drainage gas from entering indoors, not enough attention has been given to the retention of seal water. Seal break may occur due to negative pressure generated by induced siphonage in trap installed in the inlet part of piping.

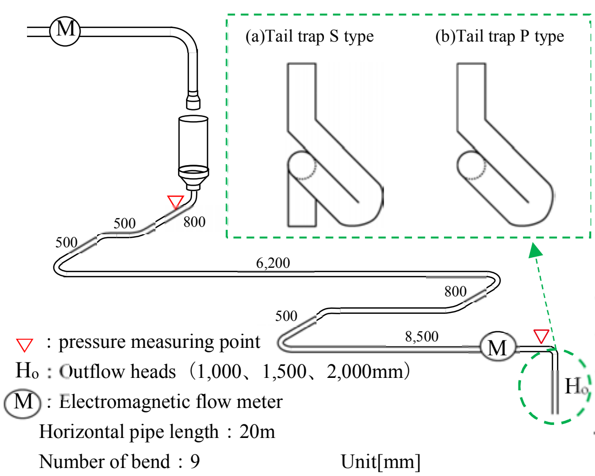
In the previous studies experiments were conducted to clarify the effects of trap placed in the tail part of pipe (referred to as tail trap below) on flow characteristics and seal loss with a view to preventing seal loss when siphonic drainage system was installed. These experiments clearly showed that no seal loss or break occurred in any of the experimental conditions and that tail trap was effective in protecting seal water.

In this study, the authors performed experiments to elucidate the effects of tail trap (S type, P type) on flow characteristics and seal loss characteristics of trap in case such trap was connect with drainage stack.

2. Outline of experiment

2.1 Experimental apparatus

Experimental apparatus and its details are shown in Figure 1. U-PVC pipe (ϕ 25mm) with the inflow part diameter of 100A, horizontal length of 20m, and outflow head including tail trap (S type and P type) of 1,000, 1,500, and 2,000 mm was used. Pressure was measured near the inflow part and the elbow at outflow part. Water supply volume was measured and adjusted with an electromagnetic flow meter placed in the feeding pipe. Discharge flow rate and flow velocity were calculated on the basis of measurements made with an electromagnetic flow meter placed near the outflow elbow. Seal loss when tail traps (S type, P type) were attached was confirmed visually.



Type	Tail trap S type
Diameter	ϕ 25mm
Depth of seal water	6cm

Type	trap P type
Diameter	ϕ 25mm
Depth of seal water	6cm

Figure1 Experimental apparatus

2.2 Experimental conditions

Experimental conditions are shown in Table 1. Two different shapes of tail trap (S type and P type), three outflow heads (1,000 mm, 1,500 mm, 2,000 mm), four patterns of supply flow rate (12, 18, 24, 30 L/min.) were used. Measurements were made twice, 2 minutes each with a sampling frequency of 50 Hz.

Table1 Experimental conditions

Diameter [mm]	Type	Outflow heads [mm]	supply flow rate [L/min]
25	Tail trap S type	1,000 □ 1,500 □ 2,000	12 □ 18 □ 24 □ 30
	Tail trap P type		

※common comdition Material:U-PVC. Horizontal Pipe Length:20m

3. Results and consideration

3.1 Flow phase

Pressure in drain and discharge flow velocity with tail trap S type and P type when outflow head was 1,500 mm and supply flow rate 24 L/min are shown in Figure 2 and 3 as an example of experimental results. For comparison, the same parameters with S trap under the same conditions in the previous study are shown in Figure 4. Flow phase is outlined in Figure 5, and all the phases that occurred were listed in Table 2. Siphonic effect was found to occur in all conditions with tail trap S type and P type, and there was no significant difference in flow phase between the two types of trap. Neither was there any significant difference in flow phase compared to S trap under the same conditions in the previous study. But siphonic negative pressure with tail trap S type and T type tended to be smaller.

The comparison of the S trap piping layout and the tail trap S type piping layout is shown in Figure 6. The tail trap S type is considered to have superior workability to S trap when connected with drainage stack. The same thing can be said to the tail trap P type.

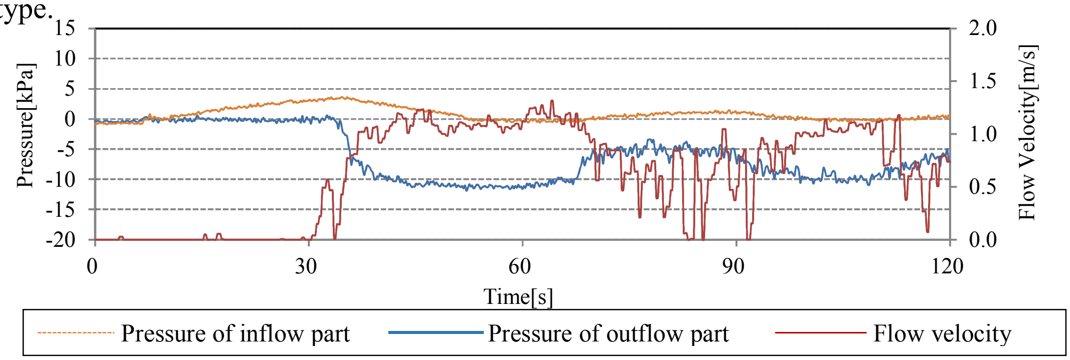


Figure2 Change of pressure in drain and flow velocity
(tail trap S type, outflow head 1,500mm, supply flow rate 24L/min)

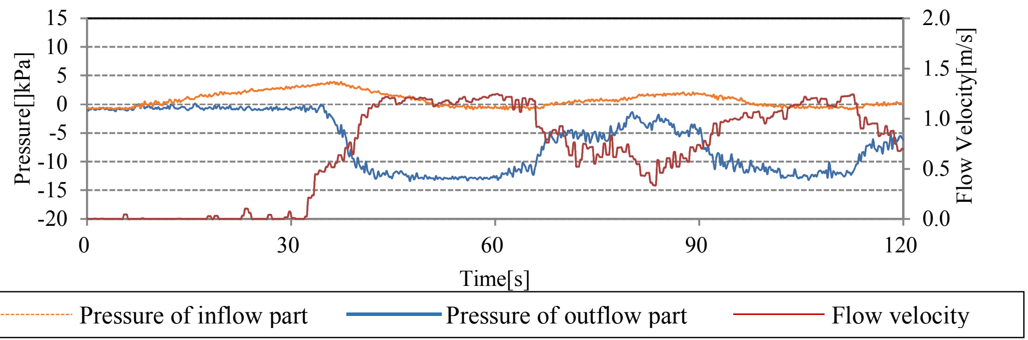


Figure3 Change of pressure in drain and flow velocity (tail trap P type, outflow head 1,500mm, supply flow rate 24L/min)

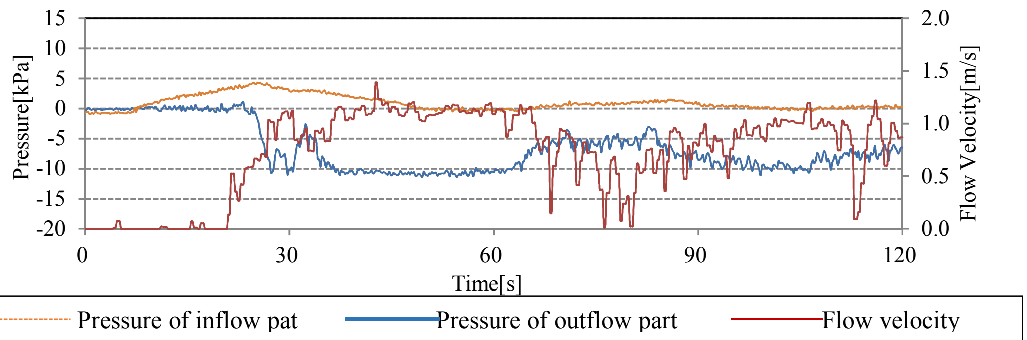


Figure4 Change of pressure in drain and flow velocity (S trap in the tail part, outflow head 1,500mm, supply flow rate 24L/min)

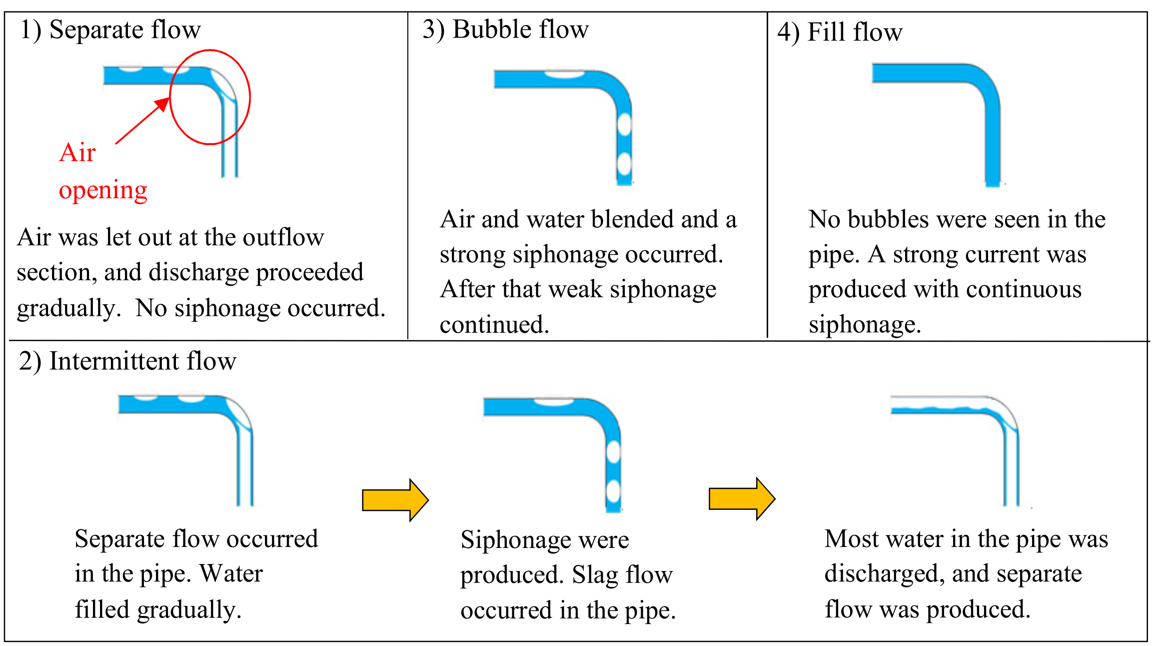


Figure5 Flow phase outline

Table2 Flow phase

Supply flow rate[m/s] \ Outflow head [mm]	Tail trap S type			Tail trap P type			S trap		
	1,000	1,500	2,000	1,000	1,500	2,000	1,000	1,500	2,000
12	△	△	△	△	△	△	△	△	△
18	△	△	△	△	△	△	○	△	△
24	◎	○	○	○	○	○	○	○	○
30	◎	◎	○	◎	◎	◎	○	○	○

△···intermittent flow,○···bubble flow, ◎···fill flow

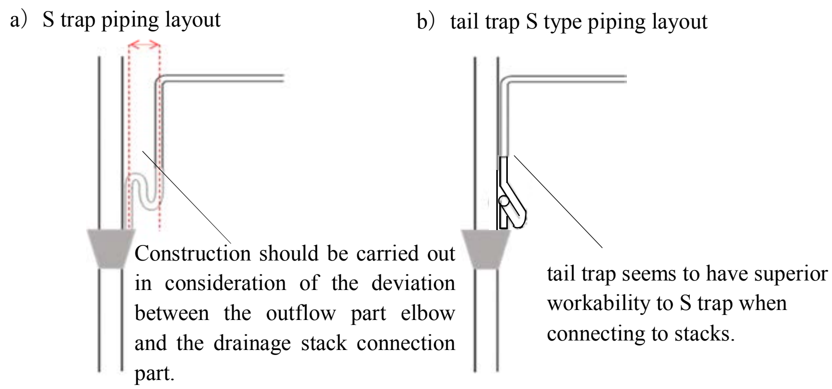


Figure6 The comparison of the S trap piping layout and the tail trap S type piping layout

3.2 Maximum negative pressure and maximum flow velocity

The relationship of supply flow rate and maximum negative pressure and that of supply flow volume and maximum flow velocity are shown in Figure 7. There was no significant difference between S trap and P trap in maximum negative pressure. Maximum negative pressure with tail trap S type and P type tended to be smaler than when S trap was installed at the tail part of piping. The outflow head and flow velocity changed in proportion to each other when supply flow volume was 12 ~ 18 L/min., but they converged as the flow volume increased and maximum flow velocity reached approximately 1.4 L/min. when the supply flow volume was 30 L/min.

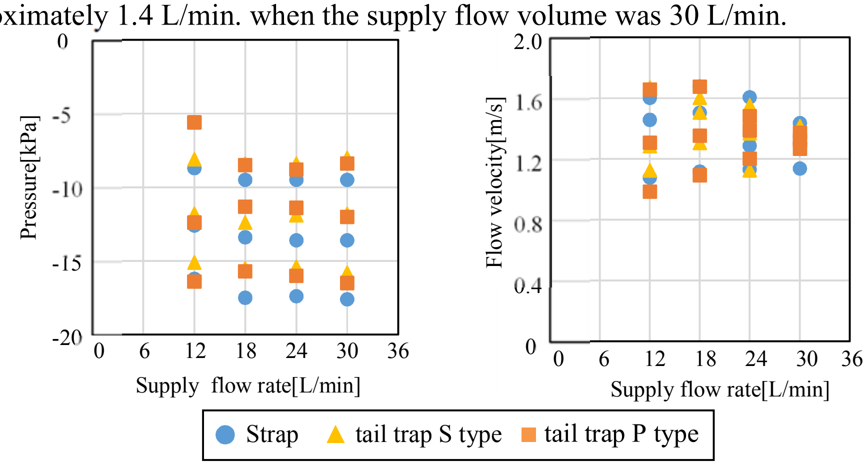


Figure7 Maximum negative pressure and maximum flow

3.3 Comparison of actual measurements with theoretical values

The comparison of actual measurements and theoretical values of maximum negative pressure and maximum flow velocity is shown in Figure 8. There was no significant difference between tail trap S type and tail trap P type in maximum negative pressure. Actual measurements of maximum negative pressure and maximum flow velocity were smaller than theoretical values when tail trap S type and P type were installed. The reason for this is that intermittent flow was generated as the air entered the pipe when siphonage started.

Another reason for the discrepancy between actual measurements and theoretical values seen when tail trap S and P types were installed as opposed to the convergence of the values seen when Strap was installed at the tail part in the previous study is that openings for atmospheric release of tail trap S and T type were positioned higher than those of S trap resulting in shorter outflow head.

Though there was no difference in maximum flow velocity due to the shape of trap, actual measurements of maximum flow velocity were larger than theoretical values because of air entrapped in the piping.

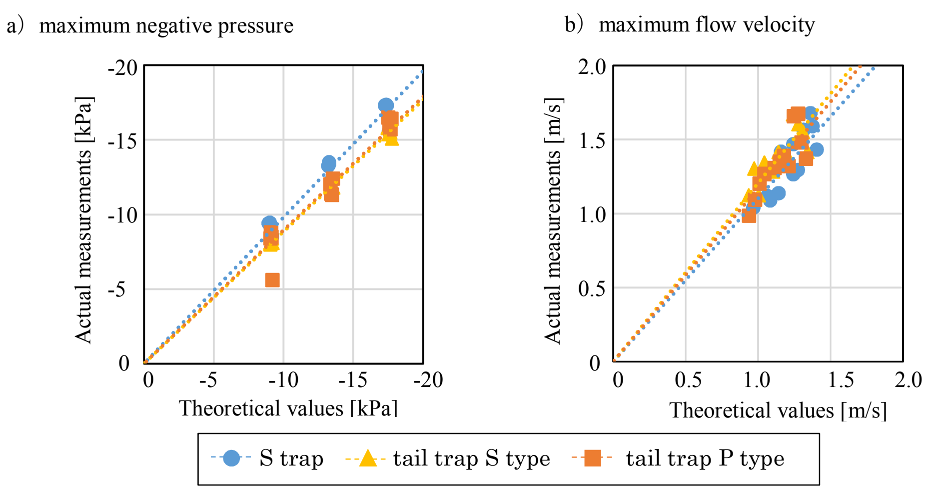


Figure8 Comparison of actual measurements with theoretical values

3.4 Initiation, duration, and cycle of Siphonage

Initiation, duration and cycle of siphonage with tail trap S and P type in the current study and those of S trap installed at the tail part of the piping in the previous study are shown in Table 3 for comparison. It took more time for siphonage to start with tail trap S and P type than with S trap at supply flow volume of 12 L/min. The difference between the shapes of trap lessened as supply flow volume increased. As for duration, there was no difference due to the shape of trap. Siphonage occurred in shorter cycles with S trap, but the difference was not significant.

Table3 Initiation, duration, and cycle of Siphonage

a)Initiation of siphonage

Outflow head [mm] / Supply flow rate[m/s]	Tail trap S type			Tail trap P type			S trap		
	1,000	1,500	2,000	1,000	1,500	2,000	1,000	1,500	2,000
12	84	85	85	94	102	90	60	56	64
18	44	46	22	46	50	45	38	54	32
24	35	35	35	29	31	34	40	55	32
30	30	29	29	22	29	31	30	29	29

Unit[s]

b) Duration of siphonage

Outflow head [mm] / Supply flow rate[m/s]	Tail trap S type			Tail trap P type			S trap		
	1,000	1,500	2,000	1,000	1,500	2,000	1,000	1,500	2,000
12	24	20	20	—	—	19	29	23	18
18	37	28	30	35	31	29	36	27	24
24	◎	◎	◎	◎	◎	30	◎	33	30
30	◎	◎	◎	◎	◎	◎	◎	◎	◎

Unit [s]

"—"…unreadable、"◎..Full-flow drainage continues after siphonage

c) Cycle of siphonage

Outflow head [mm] / Supply flow rate[m/s]	Tail trap S type			Tail trap P type			S trap		
	1,000	1,500	2,000	1,000	1,500	2,000	1,000	1,500	2,000
12	—	—	—	—	—	—	—	—	—
18	63	61	64	65	61	58	57	54	53
24	◎	◎	◎	◎	◎	52	◎	55	53
30	◎	◎	◎	◎	◎	◎	◎	◎	◎

Unit [s]

"—"…unreadable、"◎"…Full-flow drainage continues after siphonage

3.5 Behavior of seal water

The behaviors of seal water with tail trap S type are shown in Figure 9. No seal loss occurred in any of the experimental conditions with tail trap S or P type. This seems to be the case as the tail part of piping is less affected by negative pressure than the starting part. Temporary seal break due to self-siphonage after discharge was completed was observed, but it did not lead to seal loss as the break was re-sealed by tail flow. The behaviors of tail trap S and P type were roughly identical to those of S trap installed at the tail part of piping. Therefore it is reasonable to think that tail trap S and P type can be used in the siphonic drainage system.

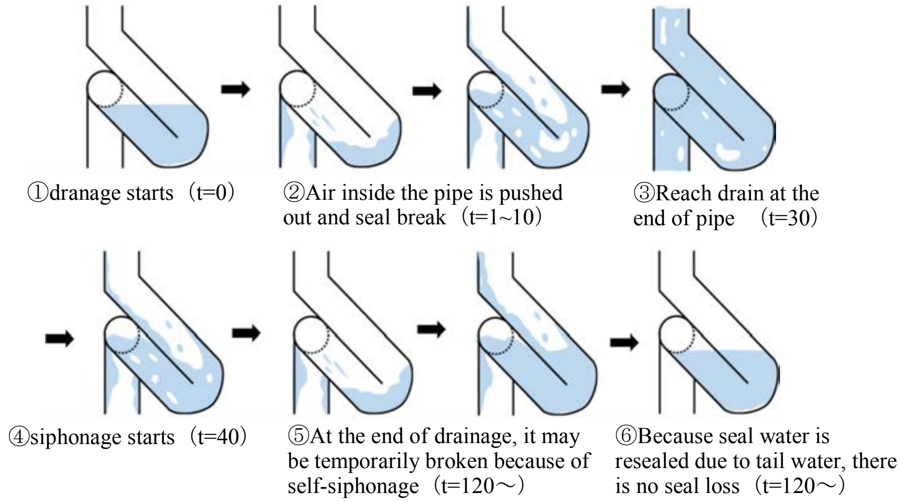


Figure9 Behavior of seal water

4. Conclusion

The findings from this study can be summarized as follows:

1) There was no severe disruption in flow phase in any of the experimental conditions using tail trap S type or tail trap P type in 20 m piping. Neither was there any significant difference from when S trap was installed in the tail part.

2) Maximum negative pressures when tail trap S type and P type were installed were lower than when S trap was installed at the tail part of piping. There was no significant difference in flow velocity attributable to the shape of trap.

3) When theoretical values and actual measurements were compared, there was no significant difference in negative pressure and flow velocity between tail trap S type and tail trap P type.

4) The effects of trap shape on the time until siphonage was initiated became less apparent as supply flow volume increased. As for duration and cycle of siphonage, there was no significant difference due to the shape of trap.

5) No seal loss occurred in any of the experimental conditions when tail trap S type or P type were installed, and the behaviors of seal water were identical to those of S trap installed at the tail part of piping. Therefore it was clearly indicated that tail trap S type and P type can be used in the siphon drainage system.

5. Presentation of Authors

Kanako Yanagisawa 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.) 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.

The issues and application of same floor drain system in the building of social housing

Chao-Jung LEE (1), Cheng-Li Cheng (2), Wan-Ju Liao (3)

(1) m10713008@gapps.ntust.edu.tw

(2) CCL@mail.ntust.edu.tw

(3) annie5064@gmail.com

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

(3) National Kaohsiung University of Science and Technology, Department of Construction Engineering

Abstract

The social housing policy is implemented by Taiwan government recently with the goal to complete 200,000 public housing in eight years. Under the situation that social housing is determined for rent and with public duty for the life cycle maintenance, thus it is important for the government to plan and design well in the earlier stage of construction for water supply and drainage system. Plumbing system is an important part of residential facilities. The rationality of its design greatly affects its replacement and maintenance in the building life cycle. The construction life cycle of building is longer than that of the water supply and drainage equipment. Hence, it inevitably needs to be repaired and maintained during the life cycle of the building. 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 study simulates the renewal of the plumbing system in its life cycle and compare the cost of traditional construction with that of same floor drain practice. The issues would include the work periods, materials and the use of the construction methods. As the results, the feasibility of same floor drain would be proved and concluded as application in the building of social housing.

Keywords

social housing; same floor drain; life cycle cost; building drainage system

1 Introduction

Social housing is a crucial policy for government to help the economic vulnerable group in society to process a basic dwelling. The service objects of society are including social vulnerable group and young generation just employed. According to statistic data, the needs of social housing is far over the existing facilities. The function of social housing is to bridge the people from no dwelling to process a housing in transition period. Therefore, the operation mechanism for social housing is rental with no sell out. The mechanism of flow and replacement should be considered for its features. Government would be the owner and with responsibility to maintain the social housing in its lifecycle maintenance. As the vision of social housing, the hardware should be fitting the construction needs, and its software should be considered for the lifecycle maintenance and security of environmental healthy. The social housing policy is implemented by Taiwan government recently with the goal to complete 200,000 public housing in eight years. Under the situation that social housing is determined for rent and with public duty for the life cycle maintenance, thus it is important for the government to plan and design well in the earlier stage of construction for water supply and drainage system.

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. Conventional 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. Firstly, the current practical drainage issues in domestic social housing would be investigated. Questionnaire and statistical analysis would be used to figure out the feasibility and design strategy for same-floor drain technology. Furthermore, the life cycle cost would be explored which would improve the building drainage system design regulation and decision making for social housing.

2 Review and methodology

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. 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). 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.

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 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.

This study uses net present value (NPV) to analyze the life cycle cost of the sanitary system. The analysis method uses the cost which are initial cost, and maintenance or repair costs during the 50-year period of use in discounted rate into the NPV, and add up to become the total cost of the life cycle. The life cycle cost analysis of this study with conditions of four bathrooms space size unified set to 160cm x 220cm x 250cm. Bathroom equipment use the same type of bathroom equipment, according to the manufacturer price of cost price and installation fee for comparison. Analysis objects are traditional piping system, wall piping system, raised floor piping system and descended floor piping system. Life cycle of service life is 50 years of service life in the whole life time. Initial cost includes 4 sanitary systems in initial construction cost. Bathroom construction and repair projects include 4 types of bathroom refurbish update the bathroom equipment and pipeline, repair the bathroom equipment pipeline in two categories. Refurbish or repair costs is the cost of pipeline repair for sanitary systems. Refurbish frequency set as once every 10, 15, 20, 25, 30, 45, and 50 years. The study calculated and analysis the life cycle cost in every frequency of refurbish or repair. The equations of NPV and LCC are as the following:

$NPV=\Sigma_{i=1\sim n}(Ci\text{-}Bi)/(1+R)^i$……………….……………………..………(1)

$LCC=I_o+\Sigma_{i=1\sim n}(Ci\text{-}Bi)/(1+R)^i$ ………………………………………(2)

NPV: net present value

LCC: Building life cycle cost

I_o：Initial cost

B_i：Income for the i-year (this study is set at 0)

C_i：Refurbish or repair costs for the i-year

N：50 years of service life in sanitary system

R：discounted rate, this study took 1.9% and 5.0% and calculated the life cycle cost respectively.

3 Technical issues for same floor drain

Currently, the same floor drain technology about construction includes bring down slab, inside wall and lift up floor as shown as figure 1.

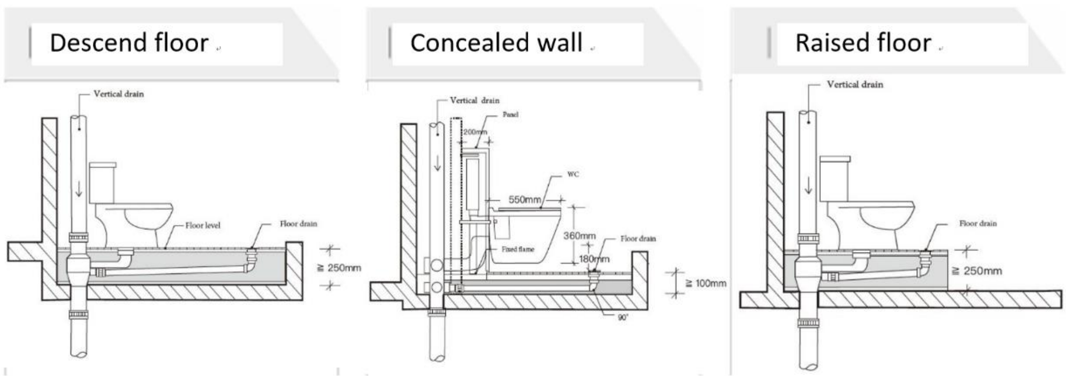


Figure 1 - Conceptual solutions for same-floor drain construction

3.1 Descend floor

The solution of descend floor is to bring down slab of construction for create a space with net depth of above 250mm for the piping allocation. The descend floor should be casted with the construction and consider the water proof to prevent the leak of water. The practical construction of completed surface would be light deck covering the space or fill with light concrete material. The construction is shown as Figure 2.

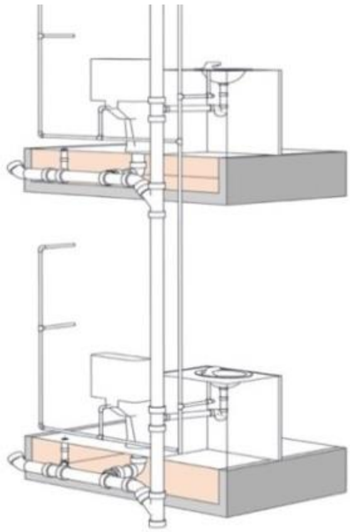


Figure 2 – Descend floor construction and planning

The strengths of descend floor solution are piping equipment allocated in the descend space with clarity and flexible maintenance, convenient for the construction and repair work. The weaknesses of this solution are cost up, floor load increasing and accumulated water in the descend space should be drain out beforehand. This construction should be well planned in advance.

3.2 Concealed wall

The concealed wall of solution is to construct a space behind the wall and allocate the piping equipment inside the concealed space. The piping system and water tank would be organized and planed in this concealed space. Meanwhile, water closet and basin would be hand on the wall with clean inside space. However, the floor drain and trap should be considered with limited space for setting up. The construction is shown as Figure 3.

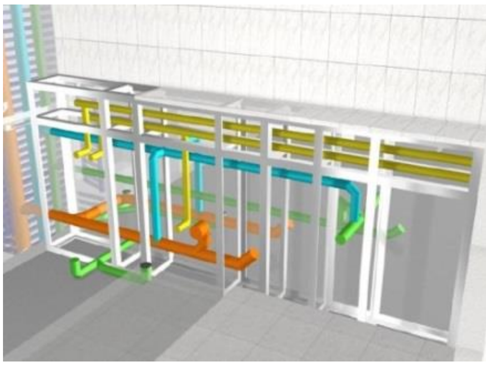


Figure 3 - Construction of concealed wall

The strengths of concealed wall solution are flexible space for allocation of water equipment, convenient for maintenance and reduce the drain noise. This solution is suit for the public toilet, dormitory and residential buildings. The weaknesses are cost up and the difficulty of floor drain setting with limited space.

3.3 Raised floor

The solution of raised floor is to allocate the piping system with 250 mm above the slab and construct a raise floor to contain the piping space.

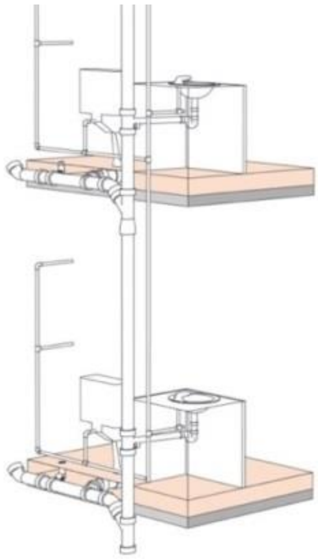


Figure 4 - Construction of raised floor solution

Due to the less limitation of space and construction, this solution is well adopted for retrofitting work with no choice to fix the existed piping problem. The construction is shown as Figure 4. The strengths of raise floor solution are flexible construction and less limitation on space. The renewal work is suit for this solution and well adopted currently. The weaknesses are allocation of equipment should be raised together and decreasing the ceiling height.

4 Building life cycle cost analysis

4.1 Initial cost of sanitary systems

The initial cost of sanitary system is mainly divided for two parts, one is the construction and pipeline, the other is sanitary equipment costs. The concealed wall piping system using wall-mounted toilet and special floor rainwater head, so the equipment cost has slightly different. According to the cost investigation and estimation, the traditional piping system which cost 72,300 NTD is the lowest initial cost in the comparison; the raised floor piping system cost 90,700 (+25%) NTD; descend floor piping system cost 104,000 (+43%) NTD; and concealed wall piping system cost 123,000 (+70%) NTD is the highest one.

Table 1 - Initial construction cost of four sanitary systems

Unit price analysis	Sanitary system	TPS	CWPS	RFPS	DFPS
Construction and pipeline costs		33,870	64,670	50,470	63,770
Water supply equipment	Washbasin faucet	4,000	4,000	4,000	4,000
	Bathroom faucet	5,000	5,000	5,000	5,000
Water container equipment	Toilet	7,200	25,300	7,200	7,200
	Washbasin	2,580	2,580	2,580	2,580
	Bathtub	6,500	6,500	6,500	6,500
Drainage equipment	Floor rainwater head	2,000	3,800	3,800	3,800
Other equipment	Mirror	3,800	3,800	3,800	3,800
	Fan	2,000	2,000	2,000	2,000
	Clotheshorse	1,200	1,200	1,200	1,200
	Two-bar towel rack	550	550	550	550
	Toilet paper holder	400	400	400	400
	Door	3,200	3,200	3,200	3,200
Total cost of sanitary equipment		38,430	58,330	40,230	40,230
Initial cost		72,300(±0%)	123,000(+70%)	90,700(+25%)	104,000(+43%)

Note. Unit : Taiwan Dollar (NTD), TPS : traditional piping system, CWPS : concealed wall piping system, RFPS : raised floor piping system, DFPS : descended floor piping system.

4.2 Estimate the cost of sanitary refurbish and repair

The estimation cost of 4 systems as refurbish for renewal bathroom equipment and pipelines are shown as Table 4. The results reveal that concealed wall piping system cost 87,998 (+33%) NTD is the highest repair cost for refurbish; the traditional piping system cost 66,298 (-0%) NTD; descended floor piping system cost 61,930 (-6%) NTD; and raised floor piping system cost 57,200 (-13%) NTD is the lowest one.

Table 2 - The comparison table of renewal bathroom equipment and pipelines

Project			TPS	CWPS	RFPS	DFPS
Interior	Clear dimension of interior space (m^3)					1.6 * 2.2 * 2.5 = 8.8
Material cost	Floor	Tile floor	4,700	4,700	4,700	4,700
	Ceiling	PVC ceiling	3,168	3,168	-	-
	Wall	Adhered brick	20,000	20,000	20,000	20,000
		Inside wall Steel structure	-	5,000	-	-
	Door and metals					3,200
	Bathroom equipment		35,230	55,130	32,500	37,230
	Total		66,298	87,998	57,200	61,930
Price comparison	Comparison with TPS		± 0	+ 21,700	- 9,098	- 4,368
	Percentage (%)		± 0	+ 33	- 13	- 6

Note. Unit : Taiwan Dollar (NTD), TPS : traditional piping system, CWPS : concealed wall piping system, RFPS : raised floor piping system, DFPS : descended floor piping system.

Table 3 - The Comparison table of sanitary system repair cost

Project	Construction Project	TPS	CWPS	RFPS	DFPS
Toilet pipeline leaking	Removing tiles	2,000	1,500	1,000	2,000
	Remove toilet pay (NT$ person/day)	1,000	1,000	-	1,000
	Install toilet pay (NT$ person/day)	1,000	1,000	-	1,000
	Knocking down concrete (NT$ person/day)	2,500	-	-	-
	Install wages (NT$ person/day)	2,800	3,000	2,500	2,800
	Tile cost	1,056	825	1,000	1,056
	Waste deliver cost	3,500	-	-	-
	Total	13,856	7,325	4,500	7,856
	Percentage (%)	± 0	- 47	- 67	- 43

Note. Unit : Taiwan Dollar (NTD), TPS : traditional piping system, CWPS : concealed wall piping system, RFPS : raised floor piping system, DFPS : descended floor piping system.

The estimation of the cost as repairing for equipment and piping problem in the four system are shown in Table 3. The results reveal that the repair cost of the traditional piping system is the highest with 13,856 NTD, followed by the raised floor and descend floor piping system, which was 4,500 (-67%)NTD and 7856 (-43%) NTD. The lowest cost of repairing piping system is the concealed wall system with 7,325 (-47%) NTD.

4.3 Life cycle cost analysis of sanitary systems

The calculation of the NPV (net present value) of the initial cost with four systems and the life cycle cost of the whole construction and repair are shown in Figure 5 and Figure 6. The life cycle cost of renewal bathroom equipment and pipeline construction with discount rate of 1.9% reveals the life cycle cost of traditional bathroom is much lower than that of concealed wall system and descend floor system. The result shows that the traditional bathroom has an absolute advantage in the initial cost. At a discount rate of 5%, the life cycle cost is lower than that of 1.9%, while the relative relationship of the life-cycle cost is unchanged.

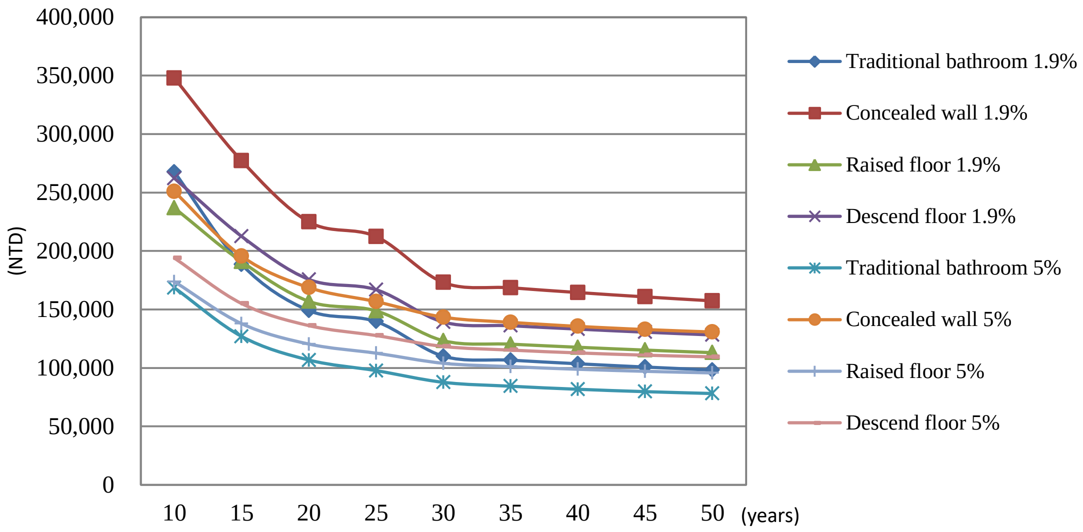


Figure 5 - Life cycle cost of renewing bathroom equipment and pipelines

The life cycle cost of equipment pipeline repair construction with discount rate of 1.9% of the situation in different frequencies reveals the life cycle cost of the concealed wall pipe system is the highest, followed by the descend floor system and raised floor system. The result shows that the traditional bathroom initial cost has advantage as well. At a discount rate of 5%, the life cycle cost is lower than that of 1.9%, while the relative relationship is almost the same trend.

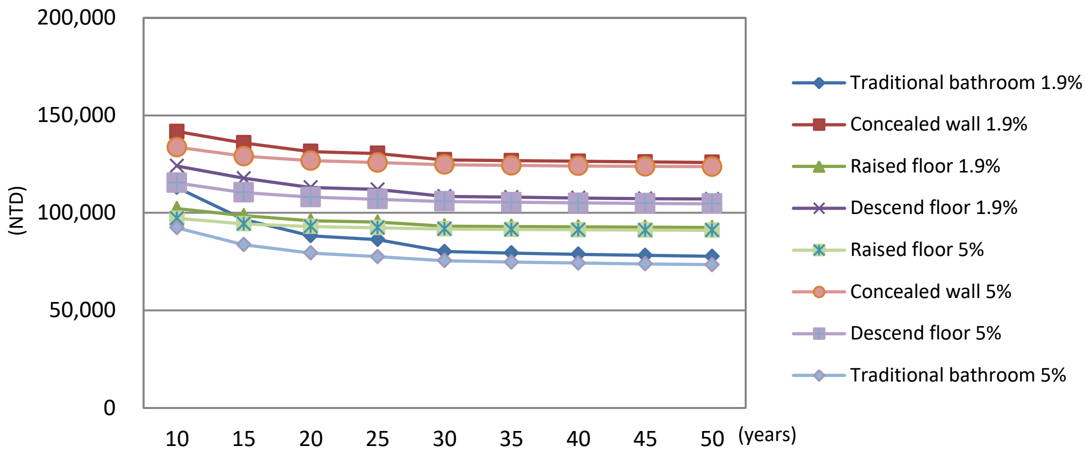


Figure 6 - Life cycle cost of bathroom equipment pipeline repair

4.4 Discussion

The results of the cost analysis of the four sanitary systems, such as the initial cost, the repair cost and the net present value of the life cycle cost are combined into Table 4. The results show that the overall performance of traditional bathrooms in terms of cost and efficiency is relatively lower. It has the advantage in terms of initial costs, construction costs, and life cycle costs except equipment pipeline repairs and renewal. Because the traditional sanitary system has an advantage in initial cost, coupled with its feature fits with the expectations of designers and builders, therefore the traditional construction system is still the most commonly used sanitary system currently.

The concealed wall system has a nearly 50% savings over traditional sanitary systems on the equipment pipeline repair cost and has the advantage previously claimed. In addition, it also has the best performance in terms of repair time and the elasticity of the configuration of sanitary appliances. However, its initial cost and construction cost are 27-70% higher than that of traditional bathrooms, and the net present value of total life-cycle cost is also 45-65% higher. The raised floor system performed well in terms of repair costs for equipment pipelines with saving nearly 70% more than traditional sanitary systems, and it also had the rational performance in terms of construction time. Although the initial cost of the descend floor system is 43% higher than the traditional bathroom, however, if the numbers of bathroom space increased, the initial cost would be decreased more than the traditional construction system. Furthermore, the equipment pipeline repair costs of descend floor system compare to traditional systems could save nearly 43% of the cost. That is to say the descend floor system has more cost advantage and potential to compete with the traditional construction system.

Table 4 - Cost-benefit comparison table for four sanitary systems

Cost-benefit analysis	TPS	CWPS	RFPS	DFPS
cost analysis				
initial	72,300 (±0%)	123,000 (+70%)	90,700 (+25%)	104,000 (+43%)
renewing bathroom equipment and pipeline	66,298 (±0%)	87,998 (+33%)	57,200 (-13%)	61,930 (-6%)
bathroom equipment pipeline repair	13,856 (±0%)	7,325 (-47%)	4,500 (-67%)	7,856 (-43%)
Life cycle cost 15 years, 1.9% discount rate	160,000-200,000 (±0%)	250,000-330,000 (+45~65%)	170,000-250,000 (0~26%)	170,000-260,000 (0~27%)
Benefit Analysis				
Repair time	1-2days	0.5-1 days	0.5-1 days	1-2 days
Construction time	14-20 days	10-13 days	6-8 days	10-13 days
Space occupied by pipelines	Less	Medium	Medium	High
Inspection	Hard	Ordinary	Easy	Easy
Precision	Low	Medium	Medium	Medium

Note. Unit : Taiwan Dollar (NTD), TPS : traditional piping system, CWPS : concealed wall piping system, RFPS : raised floor piping system, DFPS : descended floor piping system.

5 Conclusion

Residential buildings allocated the drainage plumbing system under the floor would cause great problems for the maintenance and retrofitting work during the building life cycle. Social housing is processed by government with responsibility of life cycle maintenance. 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. The same floor drain system should be the solution for the owner to perform the life cycle maintenance. This research focuses on the same-floor drain technology and the life cycle cost evaluation for social housing, and surveys on the solutions for building drainage system design. This study simulated the renewal of the plumbing system in its life cycle and compare the cost of traditional construction with that of same floor drain practice. As the results, the feasibility of same floor drain was proved and concluded as application in the building of social housing. The life cycle cost evaluation for the drainage system was reorganized. There are still field procedure and construction method should be integrated and regulated for the same floor drain technology.

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Presentation of Authors

Chao-Jung Lee is the Master student at National Taiwan University of Science and Technology, Department of Architecture. Her research focuses on water resources and Green Building.

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.

Wan-Ju Liao is Ph. D. of National Kaohsiung University of Science and Technology, Department of Construction Engineering ,and Associate Professor at Department of Interior Design, China University of Technology. Her research focuses on Green building and Building water supply and drainage system.

The prediction method of supply water temperature for energy simulation of hot water supply systems

Part 3 A comparison between annual results of measurement and calculation of a building in Kanagawa University

S. Iwamoto (1), A. Dempoya (2), K. Sakaue (3)

(1) iwamotos@jindai.jp

(2) dempoya@kanagawa-u.ac.jp

(3) sakaue@isc.meiji.ac.jp

(1) Dept. of Architecture, Faculty of Engineering, Kanagawa University, Japan

(2) Dept. of Architecture, Faculty of Engineering, Kanagawa University, Japan

(3) Dept. of Architecture, School of Science and Technology, Meiji University, Japan

Abstract

Supply water temperature is one of the important input conditions to evaluate and predict energy consumption[1)]. In small buildings, such as detached houses, a city-pressure water supply system is employed and supply water temperature is equal to city water temperature. A 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. This study focuses on city water and supply water temperature in buildings, for which it shows measurement and calculation results of supply water temperature.

Method: This paper will describe the following:

(1) Summaries of measurements in three buildings by a BEMS in Kanagawa University. Water temperatures, air temperatures around pumps and/or break tanks and pump running data are measured every minute. Water consumption volume of each building is recorded visually every month. This measurement is continuing and results from January to December 2018 are included.

(2) The calculation method[1)] of city water and break tank water temperature is used. And several calculation methods of city water temperature, such as using soil temperature[2)] or outside air temperature, are considered.

(3) A comparison between measurement and calculation results of water temperature is included.

Results and conclusion: The mean absolute temperature difference between measurement and calculation results in C building in Kanagawa University is described in this paper. The calculation results of city water temperature are investigated using several calculation methods. This paper shows that city water and supply water calculation methods are available to estimate supply water temperature in hot water supply systems.

Keywords

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

1 Introduction

Energy consumption for hot water supply systems is high in dwellings, hotels and hospitals and is therefore very important in terms of energy saving in buildings. Moreover, it is affected by making hot water, as well as heat loss due to piping and in heat sources. Heat loss in heat sources is calculated from their efficiency and is sometimes affected by supply water temperature. Therefore, supply water temperature is one of the important input conditions to evaluate and predict energy consumption. Supply water is based on city water and its temperature is an input condition. In Japan, city water is disinfected with chlorine and it is not necessary to measure its temperature. To evaluate energy saving for hot water supply systems, city water temperature should be estimated.

Iwamoto et al. (2017)[1)] showed an overview of the city water system and water supply system for building services in Japan, a calculation method of city water temperature from river water temperature as the water source, a calculation method of break tank water temperature and results of a case study for a business hotel on energy consumption for a hot water supply system through a simulation.

Iwamoto et al. (2018)[1)] summarized measurements for three buildings in Kanagawa University and compared results of measurement and calculation on break tank water temperature in each building to show the validity of the above calculation method.

This paper describes measurement results from January to December 2018 and several calculation methods for city water temperature, as well as comparing measurement and calculation results for water temperature.

2 A summary of measurements[1)]

Measurements are shown in Table 1 for three buildings in Kanagawa University, Yokohama, Japan. The water supply systems in the buildings include break tanks and water temperature, ambient air temperature, signals of pump running and valve open/close are obtained through a BEMS (Building Energy Management System). The Nishiya purification plant in Yokohama Water Bureau supplies city water around the University.

Table 1 – A summary of the measurements in Kanagawa University

Measurement site		Building A	Building B	Building C
Stories		Eight stories and a basement	Four stories	Eight stories and two basements
Purpose of use		Offices and laboratories	Lecture rooms and laboratories	Lecture rooms and laboratories
Water supply system		Break tank and booster pump system		Elevated tank system
Location of Break tank		Basement	Outdoor	2nd basement
Break tank size		3X7X2H	3X7X2H	4X6X3.5H
Water supply quantity [m^3]	Jan.	422	150	1,444
	Feb.	535	76	1,678
	Mar.	261	86	891
	Apr.	483	259	1,131
	May	328	388	1,258
	June	589	503	1,492
	July	615	610	1,647
	Aug.	576	303	1,281
	Sep.	294	237	1,151
	Oct.	325	373	1,402
	Nov.	447	332	1,444
	Dec.	450	308	1,557
	Total	5,325	3,625	16,376
Daily number of water flow [cycle/day]	Max.	1,367	1,263	192
	Average	807	688	95
	Min.	17	39	10
Supply water flow rate [m^3/min.]		0.0181	0.0144	0.4728
Makeup water flow rate [m^3/min.]		0.5		0.1
Minimum / Maximum water volume in break tank [m^3]		12.7 / 34		70 / 72

The break tank for building A is set in a machine room in the 1st floor basement connected to the booster pump system.

The break tank for building B is set outside in the shadow of the other buildings and pumps are set in a machine room on the ground floor.

The break tank for building C is set in a machine room in the 2nd floor basement and the water supply system is an elevated system that easily measures the water supply schedule.

In fact, the water temperatures in the buildings are not so different from each other despite differences in location, water supply system and ambient conditions.

A summary of the measurement is shown in Figure 1. The temperature sensor is set to the downstream side of the pump, as shown in Photo 1 of Figure 1, in each building. Its water temperature acts a substitute for the water temperature in the break tank. The ambient air temperature is measured with a thermostat used in air-conditioned rooms in each machine room where the pumps are located.

All temperatures and signals for running pumps are measured every minute by the BEMS. Used water volume is recorded in each tank by the facility staff of Kanagawa University by visually reading the water meter every month. The makeup water temperature is not measured and is set to the city water temperature, as will be described later.

Water use volume in each building is shown in Table 1. The amount for Building C is very large. The presentable day is set as January 12th, when water usage volume is large in all buildings, and measurement results are shown in Figure 2. In this figure, the pump running signal is shown by a value of 0 or 1.

In building A, shown in Figure 2(a), the pump is running frequently for water pressure without flowing and water temperature is fluctuating a lot. In building C, shown in Figure 2(b), water usage is clear when the pump is running. These tendencies are the same as observed by Iwamoto et al. (2018)[1).

3 A summary of calculation

3.1 Calculation method for city water temperature

Makeup water temperature is equal to city water temperature. City water temperatures are set by following each case shown in Figure 3

City water in Kanagawa University is obtained from Nishiya purification plant and purified water temperature in 2018 is provided by Yokohama Waterworks Bureau[3). A summary of water temperature in Nishiya purification plant is shown in Table 2 and measurement is made once per day and about 240 days per year. This is case1 with interpolation.

In case2, city water temperature calculation by Iwamoto et al.[1) uses the default values and the coefficient of friction d0 is equal to 0.5. The calculation result is also shown in Table 2. The averaged absolute temperature difference is 0.88 deg. C and within 1.0 deg. C.

Photo 1 – 2nd elevated tank in Building C

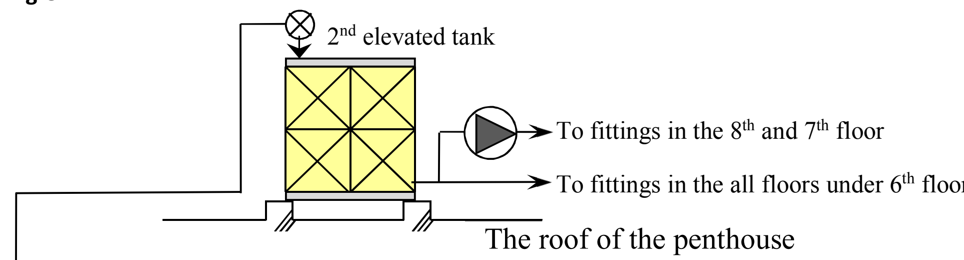


Photo 2 – Pumps and temperature sensors in Building C

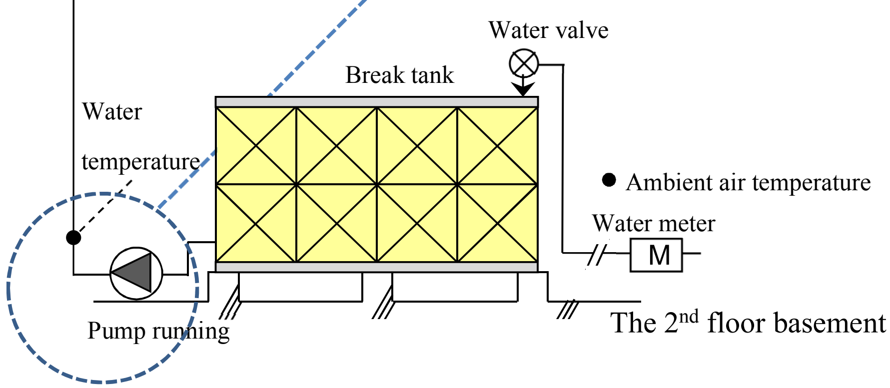
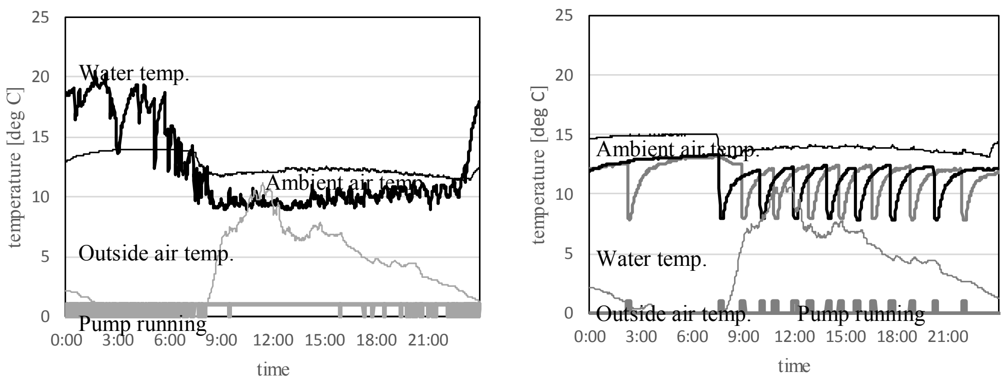


Figure 1 - A summary of measurement in Building C[1)]

Table 2 – A summary of measurement in Nishiya purification plant and city water calculation results

case	water temperature			application	annual averaged absolute difference from case1	averaged daily absolute difference from measurement	reference
	min.	mean	max.				
case1	7.0	16.4	25.4	Nishiya Purification Plant	nothing	0.72	2)
case2	6.3	16.4	26.0	calculation from AMeDAS data	0.88	0.96	1)
case3	3.1	17.1	29.2	calculation from standards	1.92	0.96	3)
case4	7.1	19.7	31.2	calculated soil temperature	3.31	3.58	5)
case5	5.6	16.6	25.9	daily minimum data at C Building	0.62	0.34	



(a) Building A (b) Building C

Figure 2 – Measurement results on Jan. 12th, 2018

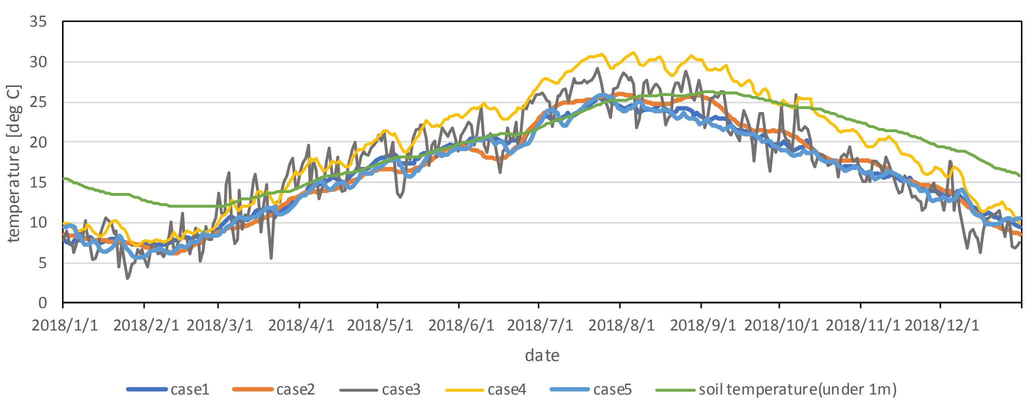


Figure 3 - Setting city water temperatures

In case3, city water temperature is calculated by the following equation used in the standards of energy saving for Japan[3)].

$$t_w = a \times t_a' + b$$

Where,

t_w: daily city water temperature [deg.C]

t_a': daily averaged outside air temperature [deg.C] [4)]

a, b: coefficients, a=0.8516, b=2.473 in Yokohama (the same as in Tokyo)

The averaged absolute temperature difference is 1.92 deg. C and the average temperature difference is 0.7 deg. C corresponded to 2 – 3 % of hot water heat load.

Blokker et al.[5)] showed calculated soil temperature under 1m is a good estimate of city water temperature. Therefore, we conduct the soil temperature calculation as employed by Matsumoto et al.[2)], which is the calculation method used in Japan. Case4 shows a daily averaged calculation result under 0.3 m, with the averaged absolute temperature difference being 3.31 deg. C and the average temperature difference being 3.3 deg. C, corresponding to about 12 % of the hot water heat load. A daily averaged calculation result under 1.0 m is also shown in Figure 3.

In case5, the daily minimum water temperature in building C is used as the alternative city water temperature. The averaged absolute temperature difference is 0.62 deg. C and the average temperature difference is 0.2 deg. C. This shows that daily minimum water temperature in the break tank is a good alternative for city water temperature in building C, where potable water is very frequently used every day.

The calculation method of water temperature in the break tank is the same as employed by Iwamoto et al.[1)]. Input conditions needed for this calculation are shown in Table 3.

Table 3 – Input conditions for calculation[1)]

Item	Application
Supply water flow rate	Constant values shown in Table 1
Water supply schedule	Estimated schedules with measurement results
Makeup water flow rate	Constatnt values shown in Table 1
Makeup water temperature	Set in Table 3
Ambient air temperature around break tank	Measurement values
Overall heat transfer coefficient of break tank panels [W/m^{2}K]	Values 1.99 attached to water, 1.32 attached to air layer in machine room. Values 2.99 to water, 1.32 to air layer outdoor.
Water volume control in break tank	Maximum and minimum values shown in Table 1

The water supply schedule is determined from measurement results. The estimated amounts of supply water flow are shown in Table 1 and the supply water flow rate is set to water usage volume divided by the amount of supply water.

3.2 Calculation results

3.2.1 Averaged absolute temperature differences between measurement and calculation results

Annual averaged absolute water temperature differences between measurement and calculation results for building C in each case are shown in Table 2. They are within about 1 deg. C, except in case 4.

3.2.2 Daily minimum water temperature

Figure 4 shows the daily minimum water temperature of the measurement and calculation for each case. The calculation results agree with the measurement results for the daily minimum water temperature in case1; this calculation method is useful to determine energy consumption for a hot water supply system. However, the difference between measurement and calculation is greater than 1 °C; moreover, the calculation temperature is always greater than the measured temperature.

In Japan, at least in Yokohama, soil temperature is not a suitable alternative for city water temperature, but the temperature of river water as a water source is useful.

Figure 5 shows comparisons of the measurements and calculations of the daily minimum water temperature for each building. The calculation results agree with the measurement results except for a few points for Building B, the same finding as shown by Iwamoto et al.[1].

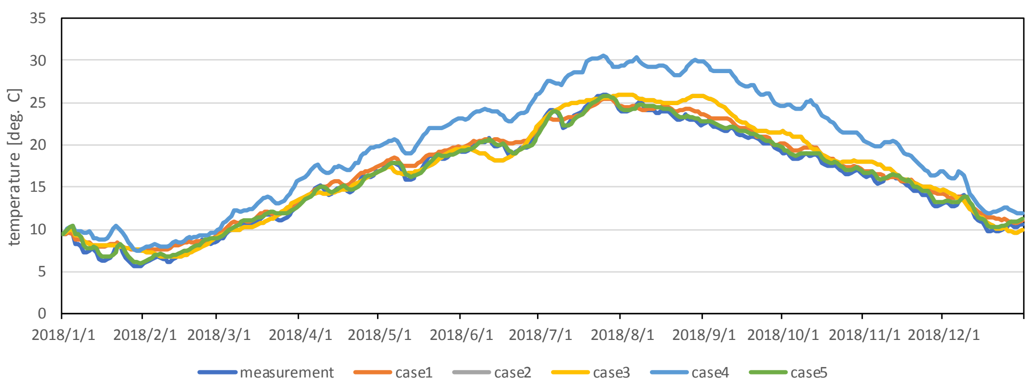
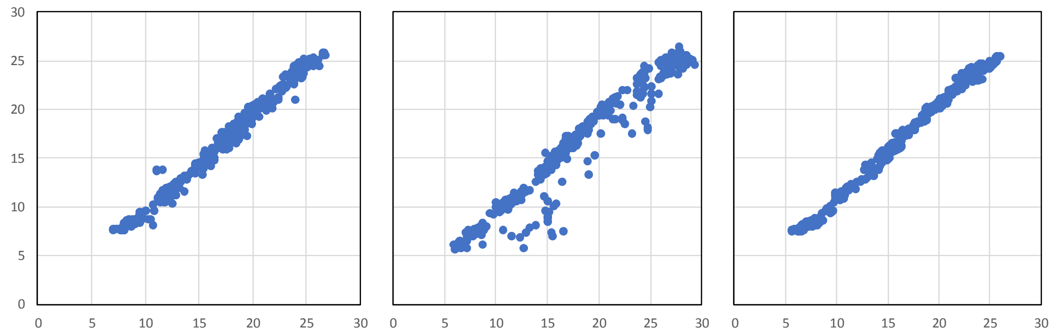


Figure 4 – Daily minimum water temperature for measurements and calculations in building C



(a) Building A (b) Building B (c) Building C

Figure 5 – Comparisons of daily minimum water temperature for measurement and calculation; the x-axis shows measurements, and the y-axis shows calculation values

4 Conclusion

This paper has presented the following findings:

(1) We measured the tank water temperature for a year and tried to show the validity of the calculation method by comparing measurement and calculation results.

(2) In building C, averaged absolute water temperature differences between measurement and calculation results in 2018 are within 1 deg. C. This calculation method seems to be reasonable when calculation conditions shown in Table 3 are sufficient.

(3) A comparison of daily minimum water temperature for measurement and calculation in each building shows a good level of agreement and this calculation method is useful to obtain daily minimum water temperature to evaluate energy consumption in hot water supply systems.

(4) Several calculation methods and calculation results for each method for city water temperatures are shown in this paper.

We plan to measure the tank water temperature over more than a year and try to show energy consumption for hot water supply systems using this supply water temperature.

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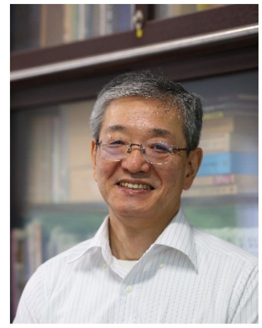
6 Presentation of Authors

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 water environment, building services and plumbing system.