WATER SUPPLY AND DRAINAGE FOR BUILDINGS

CIB W062

38th INTERNATIONAL SYMPOSIUM

AUGUST 27th – 30th 2012

EDINBURGH, SCOTLAND

Proceedings
of
CIB W062 38th International Symposium
on

Water Supply and Drainage For Buildings

27th-30th August 2012

Edinburgh, Scotland

Organised by:
The International Council for Research and Innovation,
Commission W062 Water Supply and Drainage for Buildings CIB W062

In association with:
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Date of publication: 27th August 2012

Foreword

The Drainage Research Group from the *Institute for Building and Urban Design* at Heriot–Watt University, is pleased to organise the 38^{th} International Symposium on Water Supply and Drainage for Buildings, in conjunction with the *Conseil International du Batiment* (CIB) Working Group 62, in Edinburgh from August 27^{th} to August 30^{th} 2012. The symposium has been partially financed by the generosity of sponsors.

The proceedings contain 51 papers reflecting current research on areas ranging from: hot and cold water supply and demand; above ground and roof drainage; rainwater and wastewater re-use; public health engineering; sanitary appliance provision; modelling; and codes and standards. The organisers would like to thank all authors for their contributions and are pleased with the breadth and extent of the research reported herein. The proceedings are organised into four sessions: *'Sustainability, rainwater and re-se of wastewater'*; *'Drainage and sanitation'*; *'Water demand and supply*' and *'Water and energy efficiency'.*

For the second year running the CIBW062 community mourns the loss of a symposium stalwart. Dr. Lawrence (Larry) Galowin died in May 2012, only 15 months after the loss of Professor John Swaffield in 2011. Larry's significant contribution to past CIBW62 symposia is recognised this year by the dedication of the session on 'Water Demand and Supply' to his memory. It is fitting then, that at this symposium, two of the areas in which CIBW62-inspired research has excelled for nearly 40 years be named after two of the 'founding fathers' of the engineered design of drainage and water systems, and whose collaboration had a such a focus in Edinburgh. The 'Lawerence Galowin session on Water Supply and Demand' in addition to the 'John Swaffield session on Drainage and Sanitation', inaugurated in Aveiro in 2011, are fitting tributes to the memory of these two CIB members whose contributions will be sorely missed.

We would like to thank the organising committee, and the international scientific committee, for their advice on contributions to these conference proceedings.

Finally, we would like to gratefully thank all those organisations and commercial companies for their generous contributions and sponsorship of this symposium.

Karel De Cuyper
Coordinator of CIB W062

Lynne Jack
Organiser

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The Activities of the Rainwater Management Center at the Technical University of Kosice

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Abstract

Precipitation monitoring is very a common process all around the world. In Slovakia monitoring is provided by Slovak Hydro-meteorological Institute. The Institute operates several hydro – meteorological stations, in Košice. Stormwater is one of the modern cities water management problems and sustainable approach in the urban drainage, can contribute to the improvement of the actual situation. Since the precipitation has the major influence on rainwater harvesting potential and its effectiveness, we want to describe our precipitation monitoring methodology, type of rain gauge and its location and first measured data in TUKE campus. This paper briefly describes goals of our research center at the Faculty of Civil Engineering in Slovakia.

Keywords

Precipitation; rain gauge; sustainable storm water management; Rainwater Management Center

1 Introduction

The contemporary world has paid great attention to rain water management issue, on the one hand due to increased flooding of urban areas (climate change), on the other hand there is water consumption. Consumption of drinking water for non-potable purposes is enormous, and despite the fact that in our conditions there is enough water, we ought to treat our natural resources more responsibly. These and other aspects have prompted us to create Center for Effective Rainwater Harvesting Utilization with the Purpose of Energy Demand Minimization at our campus. There are altogether 4 stations measuring precipitations in Kosice. We have yet processed five year data from the station Kosice – city centre and Kosice – airport, obtained from Slovak Hydro-meteorological Institute. The reason why we carry out our own measurements is that the measured data all around the city vary and for the research purposes we have to obtain as accurate data as possible which means obtaining data as close to experimental area as possible. New approaches to the rain water management will also be reflected in our water management. This topic is so broad that it brings about many new issues and problems; from the impact on human health through social and community aspects to many aspects of environmental impacts, which will need to be paid more attention.

2 Rainwater Management Center

For our research purposes and under the auspices of the project "Increasing of the rain water management efficiency for the purpose of energy demand minimization" and "Energy Balance Research on Rainwater Management in the Cities of the Future" we have started our own measurements at the campus of the Technical University of Košice (TUKE) (Figure 1). All our devices are located directly at the university campus. The advantage of this location is their vicinity and its good accessibility. We are measuring precipitation amount, roof runoff, groundwater level, water level in the infiltration shaft and qualitative parameters of the storm water. Our rain gauge is located on the roof of the university library.

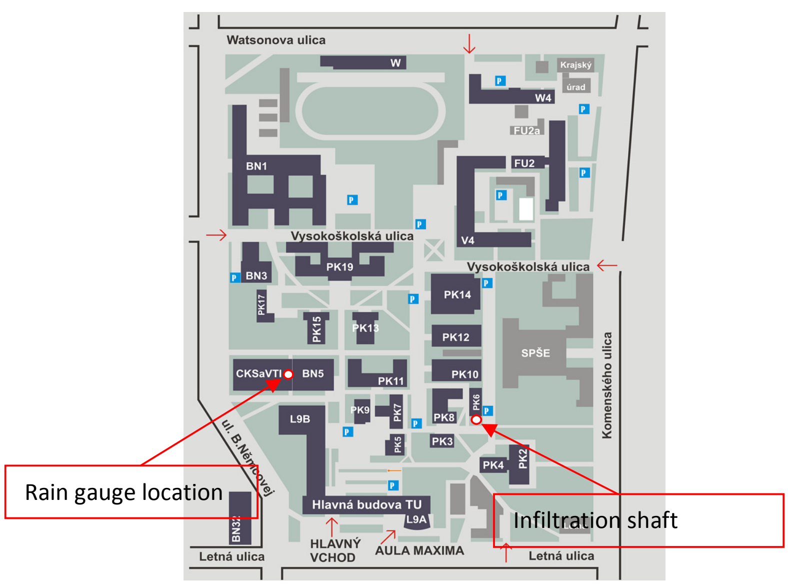

Figure 1 - Location of our research tools

The reason why we decided to place rain gauge at the University campus is because of another parallel research measurements here at the campus. Two infiltration shafts are located in a vicinity of the building PK6 along with the other devices for measuring, which is very close to University library as well. One of the shafts infiltrates runoff from the roof top of the PK6 building and measures amount of runoff, ground water level, infiltration capability. If we want to use this data together, compare them and conclude some relations, all of these mechanisms should be located very close to each other and the timing must be synchronized.

2.1 Rain gauge description

There are general rules of locating gauges but the rules cannot always be fully met in the urban environment [1]. Our rain gauge type MR2H is located on the roof of the university library which is flat and provides good access. Rain gauge is joined with its own concrete foundation using a steel rod. Flat roof helped us fixing the rain gauge into horizontal position which is the first condition for receiving correct data. Rain gauge's (Fig. 2) round catchment area is 200 cm2 and it is calibrated to 0,2 mm for a single tip. The mechanism of measuring of this type is based on tipping bucket which is divided into two parts where one part is filled with calibrated amount of water, then it tips and second half of bucket can be filled with rainwater. Tipping continues during the length of rainfall event. We use recording heated rain gauge for all year round measuring. Its operating temperature is between -30 to +60 °C [3]. Tipping bucket is made of plastic with very thin layer of titanium and it is hanged on stainless steel axial holder, the body of gauge is made of stainless steel and it is insulated. Each tip is recorded and transmitted by telemetric station (Figure 2) which is datalogger together with GSM/GPRS communication module. Data are sent to server every 10 min but for more detailed measuring, this interval changes to 1 minute the moment it stars to rain. One minute interval gives us exact information about the rainfall amount throughout the event, its intensity and duration. Data are then stored at server by data hosting. For various purposes, data can be downloaded from the server at any time in the requested format.

Figure 2 - Open rain gauge and Rain gauge with telemetric station

2.2 Infiltration shafts PK6

Two infiltration shafts are located in a vicinity of the building PK6 along with the other devices for measuring. One of the shafts infiltrates runoff from the roof top of the PK6 building and measures amount of runoff, ground water level, infiltration capability (Figure 3). The shaft is made from concrete rings with a diameter of 1000 mm. The depth of the infiltration pit is 6 m. The hydrogeological survey conducted at the site verified that the depth is gravel with admixture of fine-grained soil, the infiltration coefficient kf was set at $1{,}10^{-3}$ m /s [4,7]. We measure:

- rain water runoff from the roof – flow meter
- water level in the shaft - level transmitter
- ground water level- Levelogger,
- atmospheric pressure– Barologger
- water quality (pH, conductivity) - multi-parameter sensor

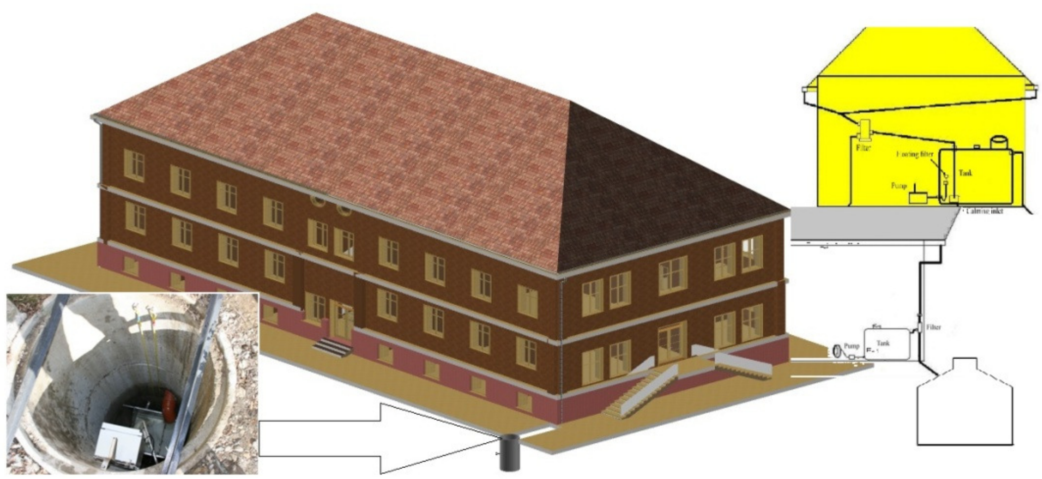

Figure 3 – Building PK6 -2 infiltration shafts

2.3 Roof model

A roof model (in progress) that will help us to analyse the impact of roofs on the quality and quantity of rainwater harvesting(the influence of the roof pitch and surface material) –experiment will be in laboratory conditions and in situ.

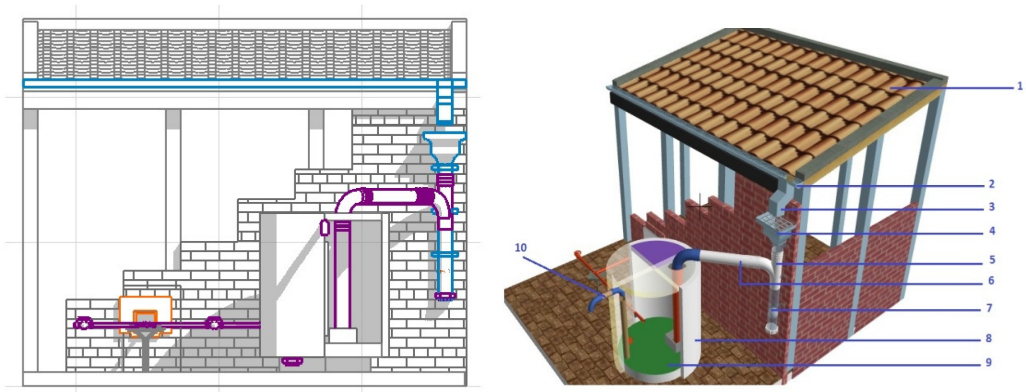

Figure 4 – Model

(1 Roof, 2 Gutter, 3 Gutter, 4 Collector with filter, 5 Storage, 6 Inlet pipe, 7 First flush, 8 Tank, 9 Filter in the tank, 10 Overflow pipe)

3 Precipitation monitoring – first results

Rainfall amounts measured at the TUKE campus from April 2011 to December 2011 are shown in the chart below (Figure 5).

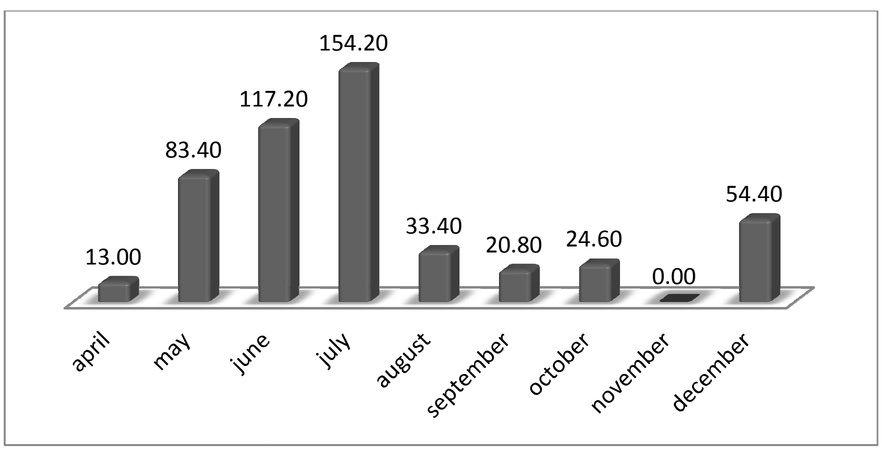

Figure 5 – precipitation measured at the university campus from April to December 2011

During the observed period, the highest total rainfall was recorded in July (Figure 6). The lowest rainfall amount was recorded in November 2011, with the amount of 0,00 mm which is quite unusual as shows Table 1. Data from Košice airport shows the amount of 3,00 mm for November 2011 [5]. This confirms the fact that distribution of rainfall in various parts of the city is different. That is the reason why we should always consider using data from the closest weather station to the place of our interest/design/valuation.

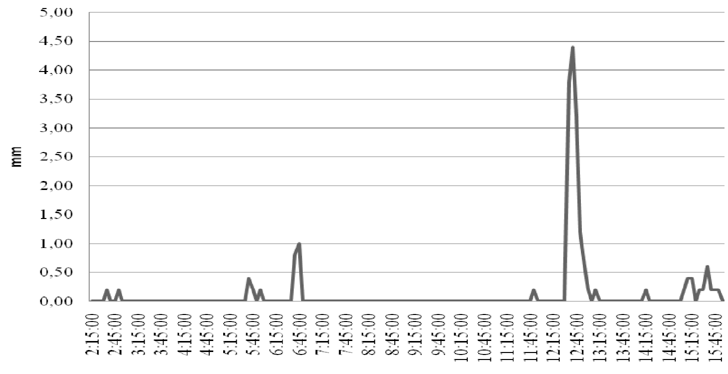

Figure 6 rainfall distribution on 21st of July

Table 1 November precipitation amounts from 2004 to 2008 compared to 2011 (SHMU)

November 2004 - 2008 compared to 2011					
2004	2005	2006	2007	2008	*2011*
49,00	22,90	16,50	27,20	24,80	*0,00*

It is possible to use rainwater instead of potable water anywhere where there is no need for such high quality water for example for flushing toilets, cleaning and maintenance, car washing, irrigation, laundry etc. We have used data measured at the campus of our university to show what would be the rainwater volume (Table 3) obtained from different roof sizes with different runoff coefficients (Table 2).

Table 2 runoff coefficients according to DIN 1989 [6]

roof shape	roof covering	runoff coefficient
flat	metal	0,7
	asphalt	0,6
	plastic	0,7
sloped	roof tile	0,8
	concrete	0,8
	slate	0,8
	wood	0,75
	metal	0,9
	plastic	0,9

The volume of rainwater depends on the area, rainfall, size of the roof and the runoff coefficient. We can calculate it according to the following formula [6].

$$Qm = \psi \,.\, A \,.\, ZM \quad (m3/month) \qquad (1)$$

Ψ – runoff coefficient (-)
A – roof area (m2)
ZM – monthly rainfall (mm/month = l/m2.month)

Table 3 Potential volume of rainwater in m3 from the roofs of different sizes and different runoff coefficients at the TUKE campus

Ψ	roof area m^2			
	10	50	100	150
1,00	*1,54*	*7,71*	*15,42*	*23,13*
0,90	*1,39*	*6,94*	*13,88*	*20,82*
0,80	*1,23*	*6,17*	*12,34*	*18,50*
0,70	*1,08*	*5,40*	*10,79*	*16,19*
ψ	roof area m^2			
	200	250	300	350
1,00	*30,84*	*38,55*	*46,26*	*53,97*
0,90	*27,76*	*34,70*	*41,63*	*48,57*
0,80	*24,67*	*30,84*	*37,01*	*43,18*
0,70	*21,59*	*26,99*	*32,38*	*37,78*
ψ	roof area m^2			
	400	450	500	550
1,00	*61,68*	*69,39*	*77,10*	*84,81*
0,90	*55,51*	*62,45*	*69,39*	*76,33*
0,80	*49,34*	*55,51*	*61,68*	*67,85*
0,70	*43,18*	*48,57*	*53,97*	*59,37*

Every single rainwater harvesting project needs to assess real water demand, calculate the size of the tank, and return on investment analysis as well as cost and water savings.

4 Discussion

We are presenting just first results from the center outputs. We collected new data for the years 2011-2012 that will be processed and presented. Expected benefits of the center are planned at several levels:

- an overview of current rainwater runoff system use in the Slovak Republic highlighting the pros and cons of water reuse and recycling - processing a long-term hydrological amount of precipitation for regional needs.
- at the theoretical level, as determined objectives show, benefits will analyze the quality and quantity of rainwater runoff components (the influence of roof pitch and surface materials)
- clarifying the coefficient of runoff and evaporation rate in order to design an effective rainwater runoff system
- at the methodological level boundary conditions and design guiding principles of rainwater harvesting systems will be defined as well as the principles of rainwater sewerage for building water infiltration into the outcome of a regulation design, implementation and maintenance of the system
- an environmental, financial and energy analysis for rainwater harvesting systems will be processed under the conditions of the Slovak Republic

5 Conclusion

The world access, projects of the European Union and technological institutions is just focused on research in the field of rainwater management; urban sewage network and overall sustainable water management demonstrate that it is necessary to address this issue in details now with regard to future generations that is actually basic idea of sustainable development. The outcomes of the research centre will contribute to knowledge, classification, and a proposal of appropriate measures for dimensioning, designing, installing and operating systems using rainwater and seepage tanks for experimental measurements. The activities of Rainwater Management Center at TUKE will help us to provide own measurements, present the new result and conclusions at the international level.

6 Acknowledgments

This work was supported by the Slovak Research and Development Agency under the contract No. SUSPP-0007-09.

VEGA 1/0450/12
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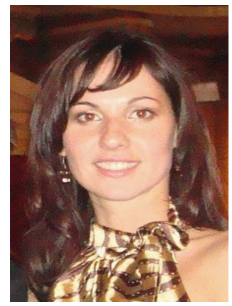
8 Presentation of Author(s)



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Assessment of Low Impact Development (LID) practices simulation applied to two types of buildings in Campinas - SP

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Abstract

The search for technical solutions and methodologies that promote lower environmental, social and economic impacts during the development of built-up areas has been the subject of many discussions and researches. The water management methods in buildings try to reduce these impacts through the adoption of procedures and technologies that improve qualitative and quantitative aspects of the water within the built-up areas. Considering the building systems of rainwater drainage, the adoption of Low Impact Development (LID) practices, like source drainage systems, based on techniques of retention and detention of rainwater, promote the maintenance of water balance in the built-up areas, and can be classified as one of the tools used to improve the environmental performance of buildings. This study aims to evaluate the performance of rainwater building systems simulating the implementation of source drainage systems in two buildings, one at the design phase and other at the occupation phase. The methodology contemplated the study of the characteristics of contribution areas, the analysis of existing drainage solutions and the possible solutions to be implemented. In addition, soil characteristics were evaluated by on-site standards tests. Scenarios were created considering the local hydrological and geotechnical parameters and the implementation of source drainage systems in the buildings. The hydrological behavior of the drainage systems was evaluated using spreadsheet, besides the observation of the surface runoff generated with and without the source drainage systems. The results observed through the simulation of infiltration trenches, pervious pavements, dry wells and detention reservoirs for both buildings shown that the

adoption of LID practices are able to improve the performance of building systems considering the rainwater flow generated by a rain event up to 5 years of return period for the city of Campinas - SP. The simulations using computational tools can contribute to the adoption of constructive solutions that provide aggregation of environmental and economic values.

Keywords

LID, low impact development, source drainage, rainwater infiltration, on-lot drainage

1. Introduction

Nowadays, one of the biggest challenges in the cities is how to deal with population growth and urbanization that cause environmental impacts that go beyond the occupied areas limits. Worldwide, the urbanization process has become bigger in recent decades. In early 2010 the world population concentration in urban areas corresponded to 50.8% of the total population, and it is estimated that by 2030 the concentrated population in urban centers to reach the milestone of 60% total [1].

If the same actual pattern of urbanization occur in the coming decades, the problems related to expansion of the flow of rainwater runoff that cause urban flooding, will worsen further. Each urban area resident generates a impermeable area mean of 49m^2 and, each 10% of impermeable area increase implies in approximately 100% increase in runoff coefficient of flood and in the volume of superficial runoff [2].

Thus, the large population concentration in urban areas implies significant changes in the characteristics of the environment occupied, as men seeks to change the environment they live in the way that best fits their needs. So many imposed changes by rapid urbanization process associated with lack of planning focused on low impact development, almost always come with a number of environmental impacts and urban infrastructure problems. Focusing on urban drainage systems, it can be said that the major impacts are associated to increased frequency and magnitude of floods and deterioration of water quality.

In the search for reducing the impact caused by development of urban areas, many studies have been conducted with the objective of creating and consolidating methodologies and technical solutions that promote a lower environmental impact, social and economic development for the built environment. Among several goals, the methods of water management in buildings try to reduce the impact caused before and after occupation, through the adoption of procedures and technologies that improve qualitative and quantitative water aspects within the built environment.

Considering the building systems of rainwater drainage, the adoption of practices of low impact development (LID); among them, the source drainage systems, based on techniques of retention and detention of rainwater, promote the maintenance of fluid balance in built places, and they can be classified as one of the tools used to improve the environmental performance of buildings. LID strategies aimed to preserve as much the natural soil characteristic and hydrologic balance to reduce impacts caused by the increase of impermeable areas due to the growth of urban population [3].

LID common strategies include: bioretention system, dry wells, permeable pavement, green roof, rain garden, among others. Thus, this study aims to evaluate the performance of water drainage building systems, simulating the implementation of source drainage systems in two buildings, one exists and the another to be built, and thus, to highlight what the *retrofit* or the early planning of drainage building systems can contribute to reducing the environmental impact due to better superficial runoff control and maintenance hydrologic balance.

2. Methodology

The methodology adopted for the development of this study was the choice of two buildings, located in the city of Campinas - SP, one was already built and occupied and the other was in the design phase, in order to evaluate the performance of drainage systems in the source used in these buildings.

For the studies some characteristics of buildings was considerate, such as: contribution areas, existing drainage solutions in the building built, type of runoff surface (grass, cement, roof, etc.), and possible source drainage to be implemented. Moreover, there were evaluated by *in loco* tests local soil characteristics, such as their physical index, coefficient of permeability and infiltration rate, and their structural capacity when subjected to constant changes in moisture content. Building scenarios have been created considering local hydrological and geotechnical parameters and implementation of source drainage systems. The systems behaviors were evaluated by modeling in the SWMM software [4] and in Excel spreadsheet and observation of the runoff generated with and without drainage systems at the source.

2.1 Rain intensity

To determine the rain intensity to be adopted in the design of LID systems, we used the rain equation developed by [5] as shown in Equation 1.

$$i = \frac{2.357.83 \cdot T_r^{0.188}}{(t+20)^{(0,917)}} \quad (1)$$

Where: **i** is the rain intensity in mm, $\mathbf{T_r}$ is the return period in years and **t** is the duration of rain in minutes. According to the authors, this equation is suitable for the determination of rain for Campinas with a return period between 2.33 to 100 years and the duration between 10 to 120 minutes. Thus, we constructed curves of intensity-duration-frequency (IDF) considering rain with a return period of 3, 5, 10 and 20 years and duration between 10-60 minutes. I-D-F curves are presented on Figure 1.

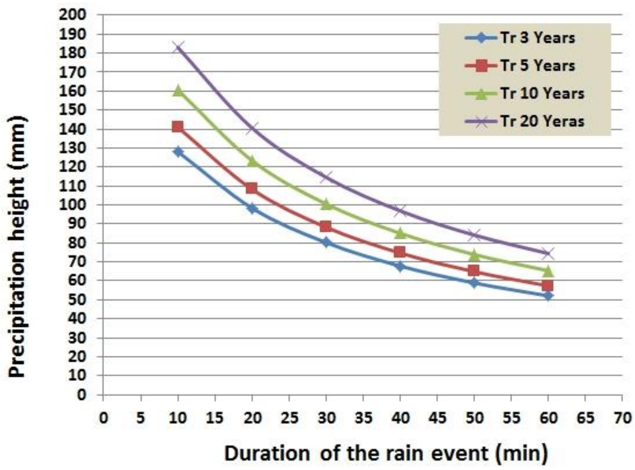


Figure 1: Intensity Duration and Frequency Curves for Campinas according to the rain equation developed by Zuffo and Leme (2005).

In order to give dimension to drainage systems with compatible dimensions with the building units, we chose to adopt a return period of 5 years. The 10 minutes duration was selected considering which would be the worst condition in terms of concentration and volume generated and infiltration capacity of the soil for a time interval. Thus, for dimensioning of used systems in this study, it was used a rain height of 141.1 mm.

2.2 Project flow

To determine the project flow it was used the method rational that is considered suitable for areas of contribution up to 2.0 km^2, as Equation 2.

$$Q = C \cdot i \cdot A \quad (2)$$

Where: **Q** is the project flow in L/h, **C** is the runoff coefficient, **i** is the rain intensity in mm and **A** is the area of contribution in m^2.

Buildings contribution areas were subdivided according to the type of surface. We adopted permeability coefficients presented in [6] and in the perception ability of the researchers. Thus, it was considered the flow coefficients and ratings of areas of contribution to the studied buildings as shown in Table 1.

Table 1: Surfaces classification of study and their respective runoff coefficients.

Nature of Surface	Runoff Coefficient (C)
Roofs and Coverage and Cemented Pavement	0.95
Green areas 1	0.40
Pavement of interlocked blocks	0.75
Green areas 2	0.35
Green roofs	0.65
Permeable pavement	0.75

2.3 Characterization of the study area soil

In order to implement rainwater infiltration systems in the studied areas, there was the characterization of the physical indices of soil at the study area through the removal of samples each 0.50m digging until a depth of 2.0m. *In loco* tests were also performed, according to [7] for assessing the rate of soil permeability according to [8] for evaluating the soil collapsibility.

The tests determined an average infiltration rate of $7.21.10^{-4}$ $m^3/m^2/s$ for the soil of the land on which the commercial building is located and $4.21.10^{-4}$ $m^3/m^2/s$ to the ground where the laboratory building will be built.

The granulometric analysis defined the lot soil of the commercial building as sandy with layers below of 1.5m, with presentation of gravel layers up to 1.5 m depth. Through the unified classification, from the construction to build the soil can be classified as CL - clay of low compressibility in the upper layers, but with a ML class predominance - silt of low compressibility below 1.0m depth.

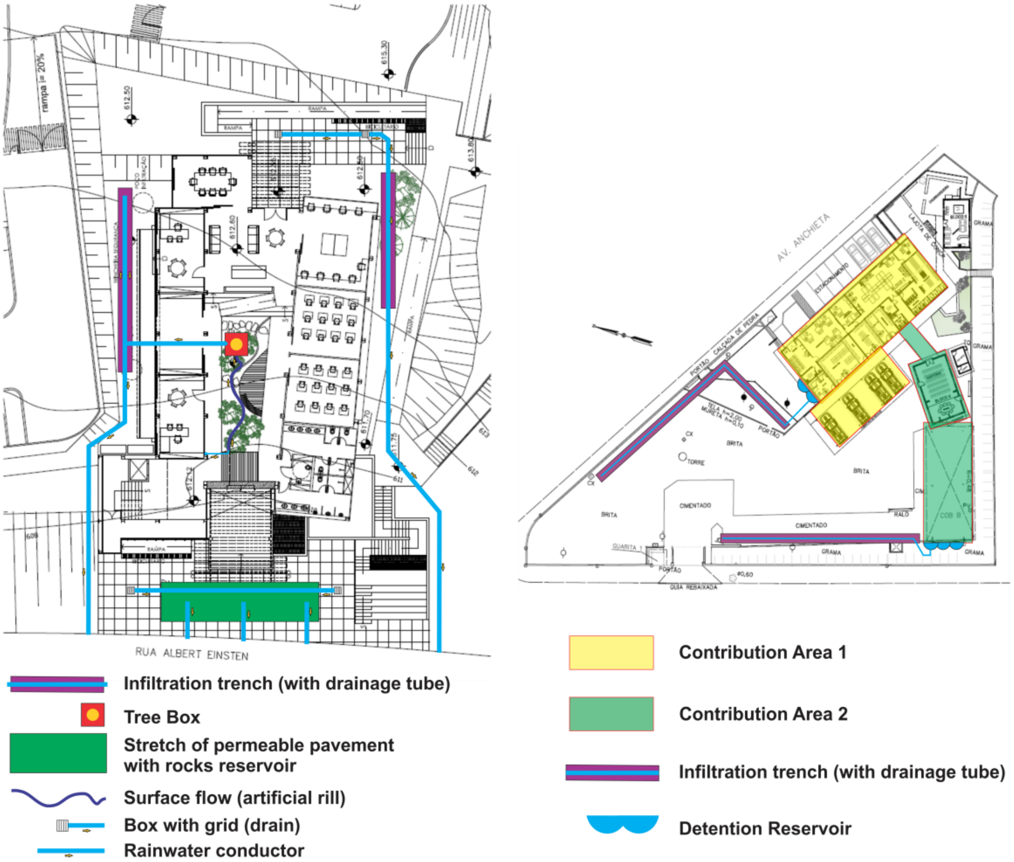
The edometric test did not show that the soil of both buildings have a high potential of collapsibility, and can therefore be used for the deployment of rainwater infiltration systems.

The water table level was also observed during tests to assess possible interferences in infiltration systems. It is recommended that the systems of rainwater infiltration remain at least 1.5m away from the water table level [9]. In the commercial building research, the water table level was observed at 2.5m depth, which prevents the use of deep drainage systems, as they would work drowned leading to greater risk of groundwater contamination. In the building to be constructed, the water table level was below 16.0m, thus demonstrating the possibility of deploying deeper rainwater infiltration systems.

2.4 Drainage solutions in the proposed source for areas of study

After design parameters research, it has been proposed the possible source drainage systems for the management of rainwater originating from each one of the buildings studied. Therefore, it was observed areas of contribution for each infiltration system and the physical space available for the deployment of systems.

Figure 2A shows a sketch of the lot with the ground floor, from the building to the construction and the source drainage systems proposed: (1) box-tree in the center garden, (2) infiltration trenches on both sides of the building and permeable pavement in lower deck of the building. Figure 2B illustrates the existing commercial building, considering the establishment of detention tanks followed by infiltration trenches. In this case, only the roof area was considered in the calculation of infiltration systems, since most part of the pavement is made of interlocking blocks, which are considered semi permeable pavements with low runoff coefficient. In building to be the constructed (Figure 2A), all areas of contribution (cover, vertical walls, floors and surroundings green areas were considered in the calculation of the performance of rainwater infiltration systems.



(A) (B)

Figure 2: Schemes of source drainage systems simulated in (A) laboratory - building to be constructed and in (B) commercial building - existing.

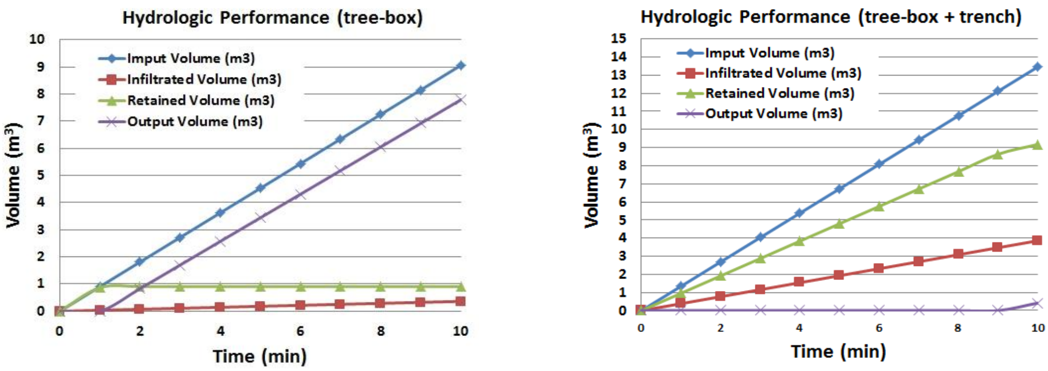
3. Results and discussion

The results were evaluated by observing the input volume of infiltration, retention and output for a time interval of 10 minutes, equivalent to rain design. Figures 3, 4 and 5 show graphs in which it is possible to compare the evaluated systems. Comparing the amount of input and output, it is possible to determine how much water is not longer forwarded to the urban drainage system, and thus, contribute to reducing the runoff peak.

Figure 3 shows the behavior of hydrological systems that receive water from the coverage and the whole left side of the building to be constructed. The system comprises a tree-box positioned in the center garden of the building, followed by an infiltration trench positioned on the outside.

The tree-box, with dimensions of 1.2x1.2m and 1.5m depth and filled with the substrate with a porosity of 45%, was designed to manage 10% of design flow from the coverage of the building. The intention is that this unit will serve only as a demonstration system, since the building is a laboratory window of building systems with high environmental performance. It is possible to observe by Figure 3A that this system contributes very little to control the flow in case of heavy rain, with low retention and extravasations after the first minute of rain project.

The remainder runoff of this unit is routed to the outer trench, positioned on the left of the drawing, whose dimensions are: 0.9x0.6m and 21.0 meters long. Figure 3B shows the hydrologic performance of the whole tree-box and infiltration trench; in this chart it is possible to see that only in the final minute the system started to discharge water in the urban system, being able to manage almost 100% of predicted runoff in project.



(A) (B)

Figure 3: Simulation of the hydrologic performance of the proposed systems for the laboratory (A) tree-box capturing 10% of the design rain flow, (B) whole tree-box and trench dimensioned to 100% of the design rain flow

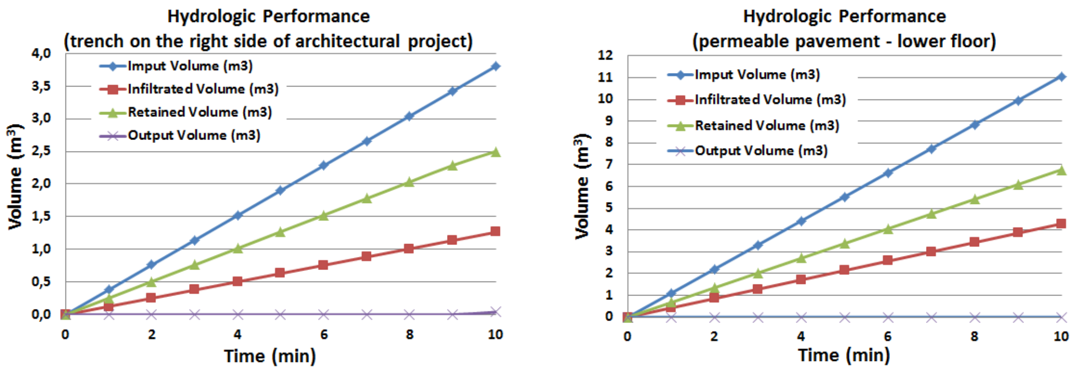
Figure 4 shows the behavior of other systems of infiltration of the building, and the graph in Figure 4A represents the trench positioned on the right side of the drawing and graph in Figure 4B represents the permeable pavement positioned on the lower floor of the building.

In this case, the infiltration trench receives contributions from the back walls and right side of the building, pavement access to the building and the green area located to the right of the building design. The trench has dimensions of 0.6x0.6m and 11m length, filled with a porous material of 50%. The hydrologic performance represented by the graph in Figure 4A shows that the system can control 100% of runoff generated, and the entire volume generated by design rain, infiltrated into the ground on the location.

The permeable pavement receives contributions from all the front of the building (bottom drawing) and the pavement that accesses the lower floor of the building. The base of the permeable pavement is composed of a reservoir of 1.5x15m depth, filled with a porous material of 50%. The hydrologic performance represented by the graph in Figure 4B shows that the system can control 100% of runoff generated, and the entire volume generated by the rain design, infiltrated into the ground on the location.
In all cases, the volume of rainwater retained within the source drainage system will infiltrate over time after the end of the design rain, and in none of them water is accumulated for a period more than six hours.

Finally, Figure 5 shows the behavior of other drainage systems source proposed for the existing building, consisting of two systems containing detention tank followed by infiltration trench. The graph in Figure 5A shows the performance of the group that receives contributions from the main building coverage and from the parking vehicles coverage. The detention tank has-dimensions of 1.6x1.6m and 2.5m high with a 40mm discharge tube.

The water disposed by the detention tank discharges in a trench of 0.6x0.6m and 25m length filled with a porous material of 50%. The hydrologic performance represented by the graph in Figure 5A shows that the system can control 100% of superficial runoff, and the entire volume generated by design rain infiltrated into the soil on the lot.



(A) **(B)**

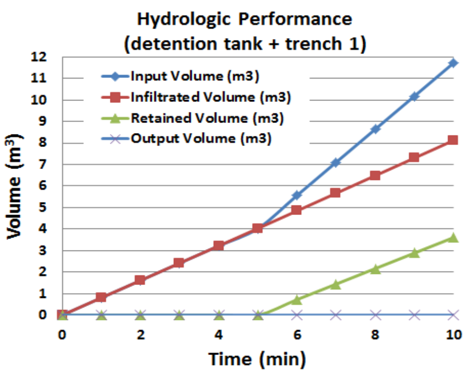
Figure 4: Simulation of the hydrologic performance of the proposed systems for the laboratory (A) infiltration trench on the right side of the building, (B) permeable pavement on the ground floor of the building, both scaled to 100% of design rain flow.

Figure 5B shows the performance of the set that receives contributions from the building coverage and from the parking vehicles coverage.

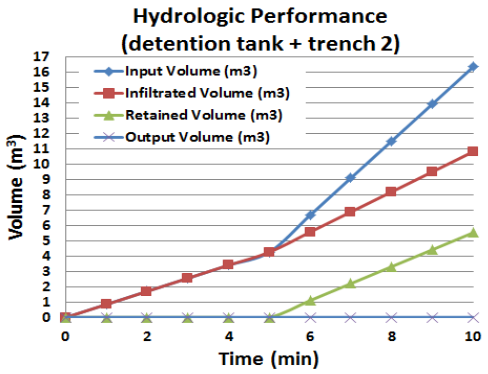
The detention tank has dimensions of 2.0x2.0m and 2.8m high with a DN 40mm discharge tube. The water wasted by the holding tank discharges in a trench of 0.6x0.6m and 25m length. The set performance shows that the system can control 100% the runoff flow generated.

The systems were also analyzed using LID tools and SWMM 5.022 modeling software developed by [4]. The comparison of the hydrographs of superficial runoff with and without the implementation of source drainage systems showed a great improvement in the performance of flow control at the source with the implementation of the proposed drainage systems.

The results showed a slightly lower performance that the studies performed on Excel, showing a reduction of more than 50% in volume of surface runoff generated by the building. However, due to the large number of variables that the system demands, many of them not being available for the study, several have been adopted as default system, which may have resulted in this difference.



(A)



(B)

Figure 5: Simulation of the hydrologic performance of the proposed drainage systems for retrofit (A) detention tank and infiltration trench to the design flow generated by an area of contribution 1, (B) detention tank and infiltration trench to the design flow generated by the area of contribution 2, both scaled to 100% of design rain flow.

4. Conclusions

The large uncertainties by the technical means on the operation and performance of source drainage systems, in many cases, prevent the development practices of low impact development (LID) are addressed with greater reach. Thus, the use of computational tools can help to assess the technical feasibility and performance of these systems, enabling studies of different geotechnical and hydrological scenarios. The use of these tools, besides helping in designing new systems also contributes to a selective planning for the retrofit systems of rainwater in existing buildings. It requires a minimum knowledge of the local parameters and design criteria.

In this study, the results obtained through simulation of rainwater infiltration trenches, permeable paving, tree-box and detention tank for both buildings, demonstrated that the adoption of practices with low environmental impact are able to improve the performance of building systems of rainwater considering the flow generated by rain project up to 5 years of return period for Campinas - SP.

The simulations made by SWMM hydrologic modeling program or with the aid of spreadsheets can contribute to the adoption of design solutions that provide aggregation of environmental and economic values.

Acknowledgments

Authors thanks CPFL - Paulista Company of Power and Light and CAPES - Coordination for the Improvement of Higher Education Personnel for supporting this study.

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Modelling sustainability in water supply and drainage with SIMDEUM®

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Abstract

Energy costs and climate change challenge the water industry to promote sustainability. Sustainability issues for a building's water system are saving of water, materials and energy in the supply of water to a building, reuse of wastewater and rainwater harvesting, heat and resources recovery from wastewater. These applications require insight in the cold and hot water demand of a building or in the characteristics of the drainage loads. SIMDEUM®, an end-use model to simulate residential and non-residential cold and hot water demand patterns, can provide this information. In this paper three successful applications of SIMDEUM for sustainability in water supply and drainage are illustrated. First, SIMDEUM based design rules yield energy efficient designs of water heaters. Second, SIMDEUM assists in a proper choice of storage capacities in grey water recycling and rainwater harvesting systems. It supports minimising urban CO_2 footprint. Third, SIMDEUM is adapted to generate discharge patterns including information on thermal energy and nutrient load, to study possibilities to recover energy and resources from wastewater.

Keywords

SIMDEUM®, cold and hot water demand, energy efficient heater, sustainability, grey water recycling, rainwater harvesting, energy recovery and resources, wastewater

1 Introduction

Water utilities face the challenge of becoming more energy efficient. Energy is the highest operating cost item for most water and wastewater companies. High energy consumption is inextricably linked to climate change. Climate change confronts the water sector with the need to optimise energy use and limit greenhouse gas emissions from their operations (Frijns et al., 2012; Frijns, 2012). Energy efficiency can be achieved by saving energy but also by the recovery of energy from wastewater (Wanner et al., 2005).

It is also expected that climate change will cause scarcity of water in many countries, due to the forecast reduction in rainfall or the alteration of its regime. Population growth, increased consumption and urbanisation will also place increased pressure on water management. Nowadays, cities are highly dependent on external resources, while overlooking local possibilities of self-producing resources by cascading, recycling and recovering. For instance, rain and wastewater are seen as a nuisance and as such is removed from cities instead of valuing its potential as a local resource to optimise the urban water cycle. For reasons of sustainability new concepts are under development to reuse or recycle grey water or to use rainwater. Extensive environmental benefits will also result from a reduced demand on water resources and, where grey water is used, reduced volumes of wastewater going to the sewer (Van Leeuwen et al., 2009; Verstraete et al., 2009).

At the building level sustainability can refer to saving of water, materials and energy in the supply of water to a building, to reuse or recycling of wastewater and rainwater and to recovery of heat and resources from wastewater. To study these concepts of sustainability, understanding the cold and hot water demand of a building on the fixture level or in the characteristics of the drainage loads is required. This knowledge is used for a design of installation and heater capacity based on realistic water demands to have sustainable and energy-efficient designs. Moreover, the information on the fixture level is needed to calculate the desired quantity of grey water for a building (for example to flush the toilets and for irrigation) and the amount of grey water leaving the building (from sinks, dishwasher, bath, and shower). The quantity and quality of the drainage loads, as temperature and concentration of nutrients, is required to study the recovery of heat and resources from water leaving the building through the sewage system.

SIMDEUM® is a model that supports this understanding. SIMDEUM stands for "**SIM**ulation of water **D**emand, an **E**nd-**U**se **M**odel." It is a stochastic model based on statistical information of end uses, including statistical data on water appliances and users (Blokker et al., 2010). SIMDEUM's philosophy is that people's behaviour regarding water use is modelled, taking into account the differences in installation and water-using appliances. This means that in each building, whether it is residential, like a house, or non-residential, like an office, hotel or nursing home, the characteristics of the present water-using appliances and taps are considered as well as the water-using behaviour of the present users. For each person, his presence is modelled and when he uses water and for which reason. The characteristics of each appliance are defined, like the flow rate, duration of use, frequency of use and the desired temperature. The duration and frequency may vary depending on the users: a teenager showers more frequently and longer than an elderly person. Moreover, the duration, frequency and the desired temperature of an appliance depends on the type of appliance (e.g. particular type of washing machine) and the particular application. For example, a kitchen tap can be used for filling a glass (15 s, 0.167 l/s, 10°C) or for washing dishes (45 s, 0.25 l/s, 55°C). SIMDEUM calculates for each appliance at what time it is used, by whom and for which purpose. This results in a demand pattern for cold and hot water at each appliance. By the addition of the demand patterns of all appliances, the demand pattern of a house, office, hotel or nursing home is obtained. The characteristics of the users and the appliances are different for each type of building and are extensively described in Blokker et al. (2010 and 2011). Measurements of cold and hot water patterns on a per second base in different types of buildings show that SIMDEUM renders a reliable prediction of both cold and hot water demand (Pieterse-Quirijns et al., 2011). SIMDEUM's basis gives insight in the reason for which the water is used and at what temperature this water needs to be. Therefore, it also provides information of the wastewater quantity, temperature and quality that will leave the building through the sewage system (e.g. shower water at 35°C with soap residue, or toilet water at 15°C with medicines, hormones and nitrates). In this paper, this information is applied to transform SIMDEUM from a demand model into a discharge model.

The purpose of this paper is to illustrate with three cases the contribution of SIMDEUM in several sustainability issues, in both supply and drainage to buildings:

1. energy efficient design of water heaters
2. grey water recycling and rain water harvesting system.
3. recovery of thermal energy and nutrients from wastewater.

2 Case I: SIMDEUM® in energy efficient design of heaters

2.1 Introduction

Existing Dutch guidelines related to the water demand of residential and non-residential buildings are outdated and do not cover hot water demand for the appropriate selection of hot water devices. Moreover, they generally overestimate peak demand values required for the design of an efficient and reliable water system. Badly designed systems can cause stagnant water with hygienic consequences, and are less energy efficient and therefore more expensive to run.

SIMDEUM simulates the cold and hot water demand of different types of residential and non-residential buildings in a reliable way. As an example, this is illustrated in Figure 1 for an apartment building. Another example for a nursing home can be found in Pieterse-Quirijns et al. (2011). Based on water demand patterns simulated by SIMDEUM, a procedure was developed to derive design rules for peak demand values of both cold and hot water during various time steps (Pieterse-Quirijns et al., 2010). In this procedure, SIMDEUM simulates for each standardised building diurnal water demand patterns, for a specific value of a dominant variable. This dominant variable characterises the size of a building, such as the number of beds in a nursing home. The standardisation of each type of building means that for a specific value of the dominant variable, a building is constructed with the corresponding number of toilets, showers, kitchen personnel, visitors, etc. From the demand patterns at different values of the dominant variable, the maximum peak demand values for cold and hot water are derived. It appears that these peak demand values for several buildings can be described by simple linear relations as a function of the dominant variable. These linear relations function as design rules. The design rules are validated with measurements of cold and

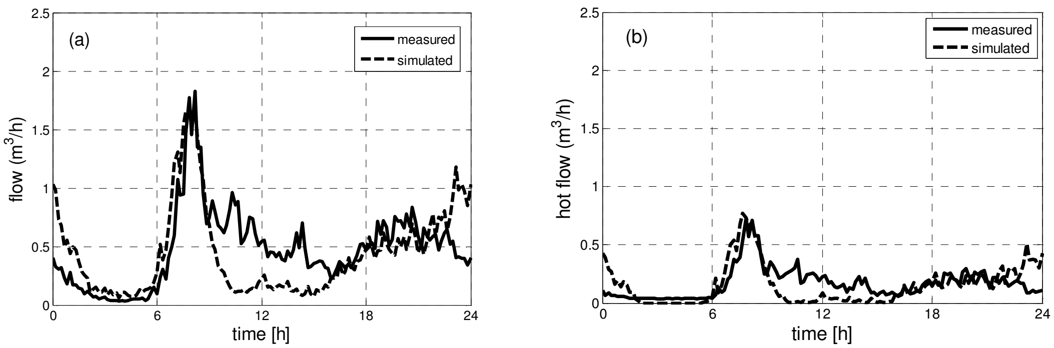

Figure 1 Comparing average measured and simulated demand of cold (a) and hot (b) water of an apartment building

hot water diurnal demand patterns on a per second base for various types of buildings. The validation shows that the design rules yield a reliable prediction of the actual water demand, where existing guidelines and practices overestimate the water demand causing overdimensioned systems (Pieterse-Quirijns et al., 2011). In this case study, the energy-saving consequences for the design of heating systems are illustrated.

2.2 Capacity of heaters

The simulated patterns of hot water demand give insight into the peak demand value of hot water, but also in the maximum hot water use in different time periods, 10 minutes, 1 hour, 2 hours and 1 day. These characteristics of hot water demand are the outcome of SIMDEUM based design rules and can be applied in general design tools to determine the desired volume (V in [l]) and power (P in [kW]) of a hot water charging system (ISSO-55, 2001). The resulting dimensions of the heating systems based on SIMDEUM are compared with dimensions proposed by different suppliers of heating systems, presented in Table 1. To know which dimensions are required to meet the comfort in a building, the measured hot water demands, when available, are also applied in the same design tool for a heating system. The dimensions based on measured hot water demands are also given in Table 1. For a small business hotel, the actual measured hot water demand, during full occupation requires a heating system with a volume of 500 litres and a power of 30 kW. The dimensions resulting from the by SIMDEUM predicted hot water demand are 500 litres and 35 kW. The supplier, on the other hand, proposes for this hotel a heating system of 1000 litres and 200 kW. This comparison shows that SIMDEUM does not underestimate the dimensions of the heating system, while the supplier's overestimation is very large. This tendency is generally found for different types of buildings (Table 1), showing that SIMDEUM based design rules result in heating systems that still fulfil the desired comfort wish, while being more energy efficient.

Table 1 Dimensions of heating systems for different type of buildings, based on measured hot water demand, based on SIMDEUM and proposed by companies

type of building	design based on measurements		design based on SIMDEUM		proposal company	
	V [l]	P [kW]	V [l]	P [kW]	V [l]	P [kW]
apartment building I: standard apartments	500	40	500	60	500	110
apartment building II: luxurious apartments	500	55	500	82	1000	80
hotel I (small business)[a]	500	30	500	35	1000	200
hotel II (large business)	1000	85	1000	60	4000	200
hotel III (tourist)			250	50	740	100
nursing home I: care needed residents			250	30	500	45
nursing home II: self-contained apartments with independent resident			500	25	1000	100

ad [a]: based on measured cold and hot water demand during full occupation.

2.3 Discussion

The reliable prediction of cold and hot water demand by SIMDEUM and the SIMDEUM based design rules yield a significant contribution in the energy efficient design of hot water installations. Especially in non-residential buildings the suppliers of heating systems propose heaters with too large capacities, both in volume and power that do not match with the actual hot water demand. The proposed capacities are 2 and sometimes 4 times larger than needed. Thus, the improved knowledge from the SIMDEUM based design rules will lead to a more energy efficient choice of the hot water systems. An enormous energy-saving is gained here. Moreover, the smaller design of the heating system reduces the stagnancy of water, leading to less hygienic problems.

3 Case II: SIMDEUM® in design of on-site/decentralised grey water recycling and rainwater harvesting systems

3.1 Introduction

In urban areas, provision of water resources and treatment and disposal of wastewater is a major concern. In the transition towards more sustainable urban water systems, increasing attention is given to self-sufficiency (Rygaard et al., 2011). On-site systems for wastewater recycling and rainwater harvesting are options to locally supply water resources for non-potable demand. However, there are no specific guidelines for design of these systems due to the lack of detailed information about temporal variations of water demand at building level.

When analysing residential water demand, it becomes clear that only a small percentage of (high quality: potable) water is used for drinking and cooking. The rest is used for non-potable purposes, mainly for personal hygiene and cleaning, which require lower quality than water that is fit for human consumption. Moreover, residential demand and supply of local resources follows a dynamic pattern fluctuating on time. Temporal fluctuations are given by changes in daily, weekly and seasonal demand and supply patterns. The demand and supply patterns are influenced by the household size and the building characteristics. These temporal variations imply storage to match supply and demand. However, often this dimensioning is based on average data (average household size and average hourly or daily consumption), which results in overestimation of yields. When designing on-site and decentralised systems, understanding these temporal variations is crucial to evaluate storage implications and provide guidelines for design and operation (Agudelo-Vera, 2012).

Different variables determine the actual harvest of local resources: spatial variables depending on building typology (e.g. single houses versus apartment blocks); seasonal and location-bound variables (e.g. yearly rain patterns, depending on locations) and temporal variables (demand and supply patterns that fluctuate through the day – day/night, within the week –working days/weekends, and within the year – seasons) (Figure 2). Our objective was to gain insight into the effect of dynamic patterns on storage capacity.

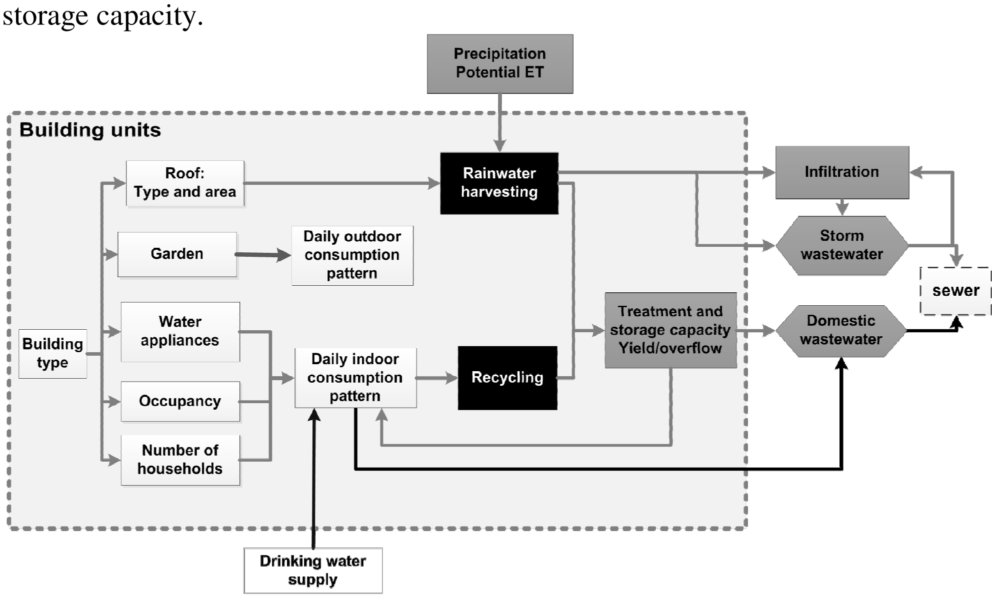

Figure 2 Variables influencing the water cycle at building level.

3.2 Approach

3.2.1 Aggregation of patterns

We focused on supplying non-potable demand (toilet and laundry) by recycling light grey water[1] (LGW) and rainwater harvesting (Figure 3). Two building types were selected: a freestanding house (four-people household) and a mid-rise apartment flat (28 apartments of two-people household). Yearly patterns demands of non-potable water

[1] Wastewater from the shower and bath is referred to as light grey water (LGW). LGW is the cleanest fraction of the residential wastewater.

and patterns of production of LGW at hourly time step were simulated using SIMDEUM. Although the yearly water demand per person is similar for both households, they do not satisfy the superposition principle, meaning that the water demand pattern of the four-people households is not two times the pattern of the two-people households. This non-linearity is, among others, caused by differences in (use frequency of) water appliances related to household size and family composition (adults/children).

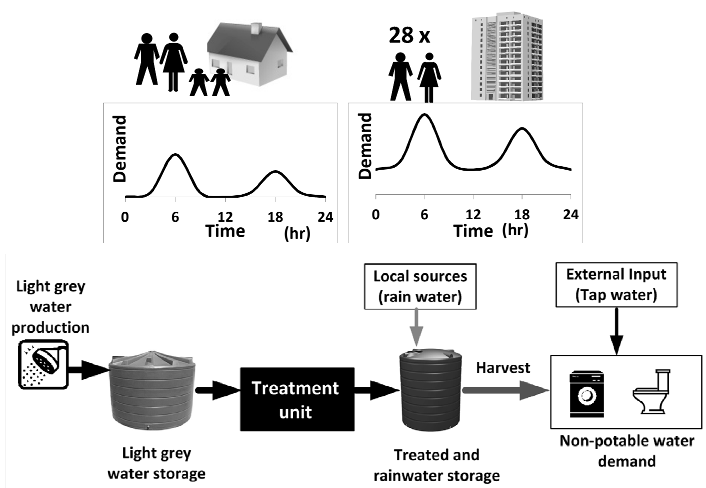

Figure 3 Description of the two building units investigated and the storage and treatment system modelled.

3.2.2 Potential to harvest local resources and storage needs

Residential water flows can vary significantly from day to day. Furthermore, daily water demand is un-evenly distributed during the day. Production of LGW and rainwater harvesting are neither simultaneous nor equal in quantity with actual demands for toilet flushing and laundry machine. Only a percentage of the potential can be harvested – the actual harvest – because of daily water demand patterns and restrictions given by the storage capacity of the subsystem. Therefore, to evaluate the efficiency of the measures and to estimate the storage capacity needed, it is important to investigate also the variations of the daily pattern.

The water balance for the building unit was evaluated for different variables such as tank size, treatment capacity, household size and roof area. A plug-flow reactor was assumed to treat the LGW. Thus, hydraulic residence time – *RT* – and volumetric treatment capacity – *k* – define the volume of the treatment unit. Harvesting of rainwater off a roof can be estimated based on the local precipitation – *P* [mm y^{-1}], the roof area – A_{roof} [m^2] and the runoff coefficient – *RC* [-]. The runoff coefficient is a dimensionless value that estimates the portion of rainfall that becomes runoff, taking into account losses due to spillage, leakage, catchment surface wetting and evaporation. Typical runoff coefficient values range between 0.7 and 0.9 (Farreny et al., 2011). The harvesting potential of rainwater was evaluated for using the rainfall records of the year 2010 (811mm).

3.3 Results and discussion

A proper choice of the storage capacities results in optimisation of local harvest of resources and in minimisation of the overflows. Overflows minimisation will reduce the wastewater production. Selecting the optimal storage capacity involves trade-offs, because it depends on space availability and cost. Moreover, if the storage capacity is small, it will be most of the time full being volumetric effective, but leaving easily excess to overflow. Figure 4 shows that actual recycling and harvesting is a function of the building type (occupancy), storage capacity, and treatment capacity for recycling. Notice that similar on-site systems configuration will perform different according to occupancy.

In Figure 4, three scenarios are plotted: i) recycling, ii) rainwater harvesting and iii) combining recycling and rainwater harvesting. For the scenarios including recycling, two storage units and a treatment unit are required. For rainwater harvesting, a single tank is considered. A comparison between recycling and multi-sourcing shows that for the same storage capacity, recycling is more beneficial. If recycling and multi-sourcing are combined, the maximum yield is achieved with a smaller storage capacity. Comparing the two building units, for a storage capacity of two tanks of 50 litres per person, the yield of recycled water is 39 m^3/year = 10 m^3/ person year for the free-standing house, meanwhile the same storage capacity will yield 709 m^3/year = 12.7 m^3/person per year.

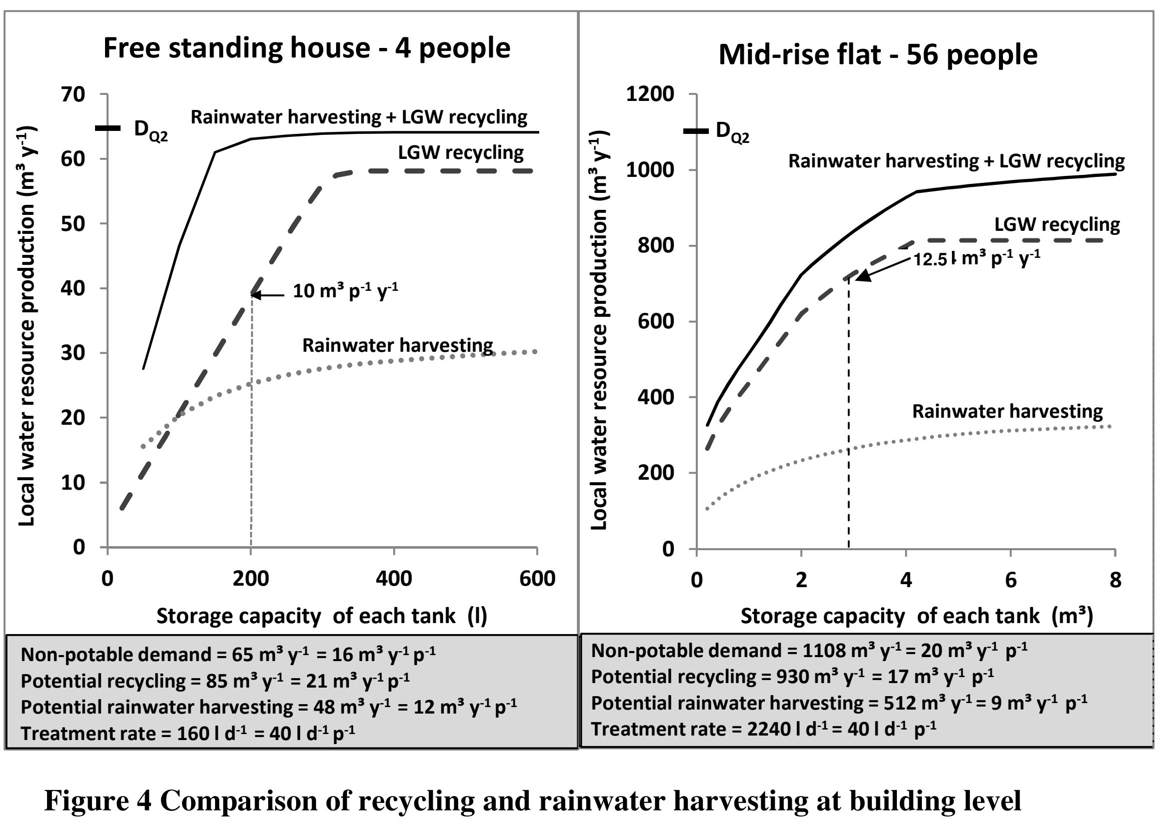

Figure 4 Comparison of recycling and rainwater harvesting at building level

Overall, our results show that there are two types of constraints to satisfy water demand with local resources at the building level. The first type is related to the availability of local resources. Constraints to meet non-potable demand are caused by disparity between grey water production patterns and demand patterns, and to limited availability of rain water related to local context (i.e. climate, roof areas). The second type follows from the first and is caused by practical limitations in harvesting the available resources. In this case, the harvest of available resources are constrained by the storage capacities that are required to cater for the mismatch in water harvested and demand patterns, which is linked to the availability of space in the building unit. Results of the modelling study showed that dimensioning of the storage capacity requires considering treatment requirements, daily water supply-demand patterns and the presence of saving devices, in addition to the physical space available.

This study showed that different building types, displayed different demands and different temporal patterns associated with different occupancies and building characteristics. This is essential information to design and optimise on-site recycling and multi-sourcing measures. Variations in daily production and demand patterns showed large effects on the efficiency of the resources harvested.

SIMDEUM helps understanding of process dynamics relevant for water resources management in the built environment. We have studied the urban water balance at building level and evaluated implementation of various measures: demand minimisation, recycling of light grey water and harvesting of rainwater to supply non-potable demand. SIMDEUM also allows simulation of blocks or neighbourhoods. Simulating residential patterns using SIMDEUM can be used by urban (water) managers and decision makers to better understand the urban water system. Better understanding of urban flows will allow the design of customised solutions for existing and new buildings, because an optimal scale of management of certain flows can be identified. In the future, this type of information can support the implementation of real time control measures to softened peak demands and to achieve smart water grids.

4 Case III: SIMDEUM® in recovery of thermal energy and resources from wastewater

4.1 Introduction

Residential wastewater contains thermal energy and nutrients. These can potentially be harvested. The harvesting process will be more efficient with a good understanding of the quantity and the location and time of the various discharge flows.

The temperature of the discharged water is raised when households heat their drinking water for bathing and cleaning or when the water in the drinking water installation has ample time to approach the room temperature. Especially in the winter when homes are heated and the drinking water enters the home at a relatively low temperature (10 °C, Blokker and Pieterse-Quirijns, 2012) this could be a relevant aspect. Water is used in toilets to discharge urine and faeces. Bathing water and washing water contain soap residues, especially the first rinse. It is possible to quantify when and how much nutrients and thermal energy are being discharged with the residential wastewater with detailed results from SIMDEUM.

4.2 Approach

There are several steps that need to be taken to quantify the energy in the wastewater.

4.2.1 Step 1: discharge intensity and duration

The first step is to adapt SIMDEUM from a demand model to a discharge model. This means adapting the intensity (L/s) and duration (s) of the various end uses to realistic values that describe the discharge of water. The basis is described in Blokker et al. (2010). The discharges that are equal to the demand are for the end uses at the bathroom tap, kitchen tap (except for the sub end use "doing dishes") and shower. The discharge from WC, bath, washing machine, dishwasher and water for manual dish washing are different; the outside tap does not discharge to the residential sewer. Table 2 shows the values for the Netherlands. The duration follows from the demand volumes (intensity multiplied by duration in Blokker et al. (2010)) divided by the new discharge values.

Table 2 Duration and intensity of water discharge for several types and sub types of end uses in the Netherlands, average (μ) and probability distribution function (pdf) (NEN3215, 2011; De Paepe et al., 2003; Persson, 2007).

<table>
<tr><th colspan="2" rowspan="2">End-use type / subtype</th><th colspan="2">Duration</th><th colspan="2">Intensity (L/s)</th></tr>
<tr><th>μ</th><th>pdf</th><th>μ</th><th>pdf</th></tr>
<tr><td>Bathtub</td><td>120 litres</td><td>2 min</td><td>N.A. (fixed)</td><td>1.0</td><td>N.A. (fixed)</td></tr>
<tr><td rowspan="2">Bathroom tap</td><td>Washing and shaving</td><td>40 s</td><td rowspan="2">Log-normal</td><td rowspan="2">0.042</td><td rowspan="2">Uniform</td></tr>
<tr><td>Brushing teeth</td><td>15 s</td></tr>
<tr><td>Dish washer</td><td>Brand and type</td><td colspan="4">Specific dishwashing pattern (3 cycles of water discharged, total 19 seconds, 0.75 L/sec = 14 L)</td></tr>
<tr><td rowspan="4">Kitchen tap</td><td>Consumption</td><td>16 s</td><td rowspan="4">Log-normal</td><td>0.083</td><td rowspan="4">Uniform</td></tr>
<tr><td>Doing dishes</td><td>6 s</td><td>1.000</td></tr>
<tr><td>Washing hands</td><td>15 s</td><td>0.083</td></tr>
<tr><td>Other</td><td>37 s</td><td>0.083</td></tr>
<tr><td rowspan="2">Outside tap</td><td>Garden</td><td colspan="4" rowspan="2">N.A. Water is not discharged to sewer</td></tr>
<tr><td>Other</td></tr>
<tr><td rowspan="2">Shower</td><td>Normal</td><td rowspan="2">8.5 min</td><td rowspan="2">χ^2</td><td>0.142</td><td rowspan="2">N.A. (fixed)</td></tr>
<tr><td>Water saving type</td><td>0.123</td></tr>
<tr><td>Washing machine</td><td>Brand and type</td><td colspan="4">Specific washing pattern (3 cycles of water discharged, total 67 seconds, 0.75 L/sec = 50 L)</td></tr>
<tr><td rowspan="2">WC</td><td>6-litre cistern</td><td>3 s</td><td rowspan="2">N.A. (fixed)</td><td rowspan="2">2</td><td rowspan="2">N.A. (fixed)</td></tr>
<tr><td>9-litre cistern</td><td>9 s</td></tr>
</table>

The frequency of discharge is equal to the frequency of the demand (Blokker et al., 2010). The time of discharge is not always equal to the time of the demand. The bath tub can be emptied 10 minutes to 1 hour after it is being filled. The intake and discharge of washing machine, dishwasher and emptying the sink after doing the dishes also shows a shift in time. The other end uses are typically instantaneously being discharged into the sewer. For the washing machine and dishwasher a supplier has provided us with both intake and discharge patterns. The discharge patterns can thus be used. For the time lag between filling and emptying the bath and kitchen sink there is no information available. Because of the lack of information and the fact that the intake times are already determined through a Monte Carlo simulation, there is no specific time lag being introduced in SIMDEUM for discharge patterns.

4.2.2 Step 2: temperature of discharged water
The second step is to add information on temperature of the discharged water. The bathtub is filled with water at 40 °C, and presumably discharged at 35 °C. The water for showering is 38 °C from the shower head and we measured a temperature decrease of 3 °C from shower head to drain. The washing machine in the Netherlands typically has a programme at 40 °C and 60 °C. This means that the first intake is heated towards the set temperature once. We measured that the temperature of the discharged water of the first release was 35 °C and 52 °C respectively. The water of the second and third release (see also Table 2) has the temperature of the cold water intake. The same is assumed for the dishwasher. The temperature of the discharged water for washing and shaving at the bathroom tap is assumed to be 35 °C, similar to the bath and shower water. The temperature of the discharged water for doing the dishes at the kitchen tap is assumed to be 45 °C, as the intake is assumed to be 55 °C (Foekema and Van Thiel, 2011). The temperature of discharged cold water (at bathroom tap, kitchen tap and toilet) is assumed to be 10 °C at all times. This could be varied depending on the season and residence time in the drinking water installation. The final temperature of the total discharge volume leaving a building is calculated by mixing the discharged volumes of the appliances with the corresponding temperature using an energy balance.

4.2.3 Step 3: nutrient load of discharged water
The third step is to add information on the nutrients in the discharged water. We first will only consider nutrients from urine as they are discharged with a normal flush toilet. Ca. 8.5 to 13 g nitrogen per person per day is being discharged via urine and faeces (Kujawa-Roeleveld and Zeeman, 2006). With an average toilet visit of 6 per person per day (Foekema and Van Thiel, 2011) it is assumed that 1.5 g nitrogen is being discharged per toilet flush. The urine is diluted with 3 L (50% flush of a 6 L toilet cistern) or 9 L (full flush of a 9 L toilet cistern) and a negligible amount of urine.

4.2.4 Step 4: run simulations and analyse results
The fourth step is to do the simulations and analyse the resulting discharge patterns. The simulations are being done as described by Blokker et al. (2010). The results are a set of possible discharge patterns. These can be further analysed on temperature and nutrient load.

4.3 Results and discussion

The adaptations to SIMDEUM to generate discharge patterns including information on the thermal energy and nutrient load have been identified. An example of discharge patterns is shown in Figure 5 for a residential building, without bath. Further analysis of the patterns renders valuable information for recovery purposes. They will also serve to have a more accurate design of the grey water and rain harvesting systems, and to estimate a more realistic peak reduction (in drinking water distribution) and (wastewater discharge) due to local resources.

As residential sewers are unpressurised systems there is a delay between the discharge at the home and the intake at the wastewater treatment plant. In the sewers there is an exchange of thermal energy between the water in the sewer (from all the various sources) and the temperature of the surrounding soil and outside air. Also, there is dilution of the nutrient load. This should be further analysed with the help of a hydraulic model of the sewer system filled with the specific discharge patterns from the new SIMDEUM approach. The extra functionality of the hydraulic sewer model that will allow for the water quality analysis needs to be developed.

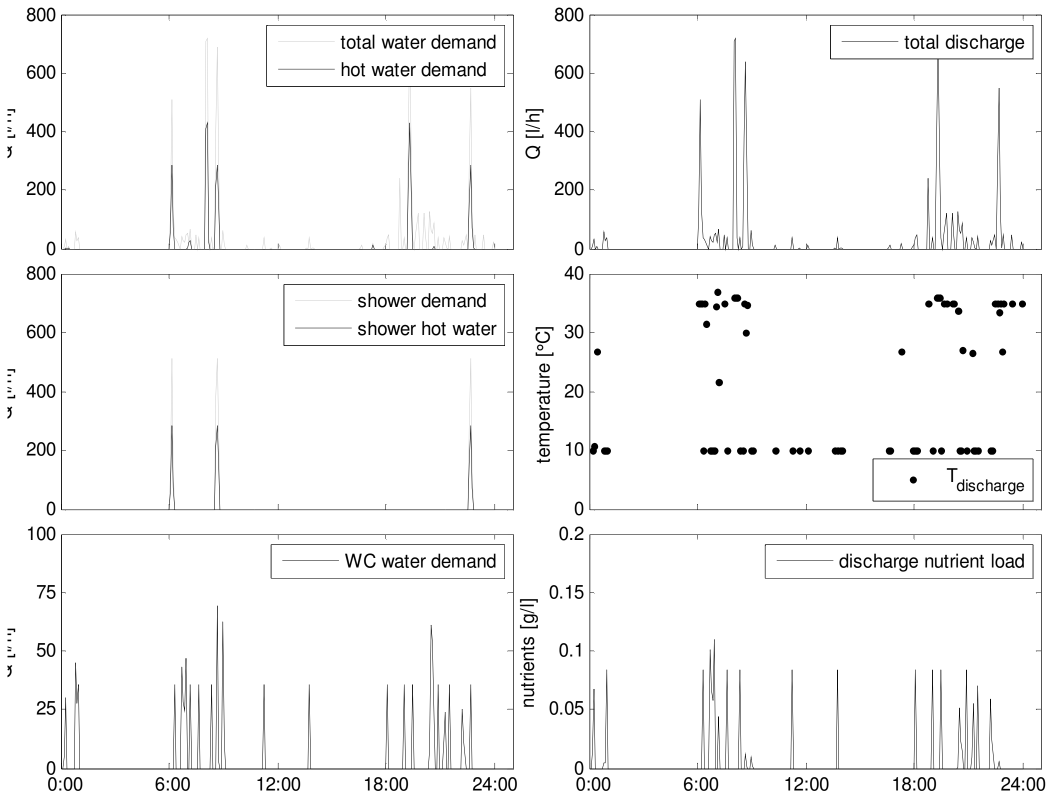

Figure 5 Demand and discharge characteristics of a residential building on 5 minute time base.

5 Conclusion

SIMDEUM® can simulate residential and non-residential cold and hot water demand patterns as well as characteristics of a building's discharge, like discharge flow, temperature and concentration of nutrients. In this paper three successful applications of SIMDEUM for sustainability in water supply and drainage are illustrated. First, SIMDEUM based design rules reduce the design of a heater capacity with a factor 2 to 4 compared to suppliers proposals, while still meeting the desired need and comfort. Second, SIMDEUM assists in a proper choice of storage capacities in grey water recycling and rainwater harvesting systems. It prevents the storage tanks to be overdimensioned and can be used in continuous simulations of recycle systems. Third, SIMDEUM's information on discharge characteristics can be used to study possibilities to recover energy and nutrients from wastewater. They will also serve to have a more accurate design of the grey water and rain harvesting systems.

Due to its physical basis, SIMDEUM can be used for other countries, buildings and purposes, when specific information on users and appliances is available. Influences of future developments, like behavioural changes (more conscious, or more luxurious), demographic changes (aging), technical progress (other appliances), legislative control, climate changes, can be easily investigated with scenario studies based on SIMDEUM.

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7 Presentation of Author(s)

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E.3 Urban Sustainable Refurbishment: Guidelines

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Abstract

In the sequence of the intensive building construction activity of the last century, presently the urban planning objectives must take into account the existent. These were developed without complying with any sustainable principles. Therefore, it is essential that new and old urban areas achieve sustainable standards including the nearly zero-energy buildings requirements, according to the EPBD recast of May 2010, as well as nearly zero-energy urban areas.

The old urban city centers were abandoned and new housing areas in the outskirts have grown without any concern on complying with sustainable principles. The need of urban revitalization and rehabilitation must consider actions that implement the most advanced sustainable measures. Concerned with the accelerated degradation in small and medium scale town centers, several municipalities are committed to develop projects aiming for sustainable refurbishment of urban centers.

This paper presents a case study developed on a relatively small city center that was analyzed according to sustainability indicators that support different sustainable evaluation tools. These consider six main areas of intervention: i) value of local dynamics and promotion of an adequate local integration; ii) promotion of resource consumption efficiency; iii) promotion of the sustainable socio-economic context; iv) insurance of the quality environmental focused on environmental comfort; v) reduction of the environmental loads; vi) sustainable guarantee of the built environment through environment management and innovation. From this evaluation main directives were identified to ensure its sustainable evolution. Particular attention was given to water efficient use in the aim of natural resources preservation. Results show that the rehabilitation strategies that were pointed out for this urban center can be applied to any other with slight adjustments and can constitute a guideline to them.

Keywords
Sustainability; indicators; urban center; water efficiency; refurbishment.

1 Introduction

Sustainability is deeply related to the existence and the continuity of man in this planet in harmony with nature and its preservation [1]. Climatic change led to the awareness of man on what is urgent for a sustainable attitude towards the world [2], but has also established of objectives to overcome the negative issues. Regarding construction and urban planning several ideas have been set although its application has been quite slow. Cities and its development are key elements as guides for sustainability and many urban based problems have appeared in the last decades from disordered and unplanned city growth.

Concerned with the degradation of urban centers a lot of municipalities have attempted to develop projects which aim sustainable refurbishment. In this project a small city center (Águeda) was analyzed according with sustainability indicators present in a lot of tools used today to evaluate built environment sustainability.

The aim of this paper is to show the solutions achieved in this urban center and its future positive evolution using a set of adopted indicators.

2 The demand for Urban Sustainability

2.1 Background

According to United Nations Organization [3], it is expected that between 2010 and 2050 the world population will grow from 6.9 billion to more than 9 billion, with 98% of its growth happening in developing countries. This explosive growth, associated with the huge consumption of natural resources, including water, is the main causes for the current environmental degradation and loss of biodiversity [4].

Environmental dysfunctions that threat the planet stability also result from the way cities are built and lived [5]. Most part of human lifetime is spent in built environments revealing the importance of the construction sector [6] and, according to [5], cities are places where human activities are concentrated, large energy flows exists and gas emissions, water and solid effluents are produced.

From early ages that cities ended up to represent a set of specialization of human functions. It is in cities all over that mankind resumes its culture and identity aspects and the buildings, the geometry of spaces, surrounding vegetation and landscaping define the history of a certain place and people living on it.

Construction is one of the sectors with considerable environmental impacts but also in the creation of a human heritage. It also represents a great potential in social and economical terms [6]. All construction activities effect the growth of the economic, social and environmental issues. The latter with the soil use and occupancy, by the consumption of finite resources, production of large scale effluents and waste, as well as the natural ecosystems alterations, directly interfering negatively on the environment [6].

Wrong decisions in terms of urban planning and land development are the origin of many environmental problems like unregulated urban growth or severe greenhouse gas emissions (GHG) [7, 8].

Sustainable towns' refurbishment is the correct and only valid option to solve the environmental problems related to urban planning and to make cities more livable and attractive. Accordingly the new construction would not be the better solution to solve these problems, because the number of existing buildings is excessive according the national necessities. Therefore, it is essential to promote the refurbishment of existing buildings and urban infrastructures with the implementation of measures to increase the number of buildings and infrastructures which not only fulfill current minimum energy performance requirements, but also present more energy and hydric efficiency. These measures will contribute to reduce both energy consumption and carbon dioxide emissions, with the goal to achieve zero-energy buildings and cities [9]. Accordingly, the urban refurbishments have to consider "zero" measures to achieve to the constructed environment [9]: net zero site energy use - amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the constructed environment; net zero source energy use – generates the same amount of energy as is used, including the energy used to transport the energy to the constructed environment; net zero energy emissions – is generally defined as one with zero net energy emissions, also known as a zero carbon or zero emissions constructed environment; net zero cost constructed environment – the cost of purchasing energy is balanced by income from sales of electricity to the electricity network grid generated on-site; net off-site zero energy use constructed environment – may be considered a Zero Emissions if 100% of the energy purchased comes from renewable energy sources, even if the energy is generated off- site.

These measures also have to include the recycling and reuse of grey waters and water saving measures like flow regulators or rainwater harvesting [10, 11] as well as measures to achieve the zero-waste goal [12].

In Portugal the National Strategy for Sustainable Development (ENDS - 2005-2015) [13] has as principal guidelines "the creation of an urban dynamic that is less destructive" which implementation relies on: (a) the existence at the national level of special urban and regional planning; (b) by the adoption of a national strategy for the cities that will implement the Local Agenda 21 giving priority to the urban refurbishment at least in 80% of the town councils"; (c) the "substantial improvement of the urban air quality to safeguard public health".

So, it should pay attention not only to the buildings but also to the other structures and systems that are part of the town: energy production and consumption, water treatment, recycling and distribution, among other factors.

Global concern about the environment, social and economical impacts expressed in many Local 21 Agendas should be part of any decision process.

2.2 Sustainability and Urban Refurbishment

Since the United Nations Rio Conference, back in 1992, several countries have adopted sustainable development as a concern in their policies [6]. Together with this concept it was necessary to develop a set of indicators and tools to allow the sustainability assessment of urban centers and buildings. The main objective of these indicators is to aggregate and quantify information in order to make it more useful and understandable [7] contributing to useful pedagogic and planning instruments (Table 1).

Table 1- Utility of the sustainability indicators (adapted from [6])

Educational and pedagogic instrument	Assist the decision makers to understand the operational meaning of the sustainable development concept.
Planning instrument	Assist in the chosen of alternative policies showing the sustainable goals to achieve. Give a direction to decision makers. When contribute to select one from several alternatives, have planning role.
Goal assessment	Assess the success level in the achievement of the established goals related with the sustainable development, having an assessment role.

Sustainability indicators can involve environmental, social and economical areas. To perform the assessment of the sustainable development of an urban centre it is useful to define sustainability indicators. There has been a lot of proposals for these indicators [6] at European level usually including the following parameters: equity and social inclusion; participation of all local community sectors in local planning and decision-making processes; satisfaction of needs at the local level on a sustainable way; local economy passing through adaptation to local needs and capacities; protection of the environment by adopting an ecosystem approach; minimizing the use of natural resources and soils, the waste production and the emission of pollutants; increase the biodiversity; protect the cultural heritage and quality of the built environment, protecting, preserving and rehabilitating cultural and historical values, strengthening and safeguarding the attractiveness and functionality of spaces and buildings.

For the city sustainability assessment it is important the evaluation of buildings sustainability construction, so, several countries have developed different methods based on life cycle analysis or in performance analysis.

3 Sustainability Assessment

The term "sustainable construction" was firstly proposed by Kibert [7] to describe the responsibilities of the construction concerning the concept and objectives of sustainability. According to Kibert [7], the existing knowledge and the diagnosis of the construction industry, in terms of environmental impacts, show that there is a need for changes to achieve sustainability objectives. The United States Green Building Council (www.usgbc.org), recognize that a good environmental performance is characterized by achieving reduced negative environmental impacts. Hence, building sustainability assessment can be carried out according to sustainable management of built area, water and energy efficiency, renewable energy use, conservation of materials and resources and indoor environmental quality [8]. The ability to identify the essential aspects of sustainability is a key factor to the sustainability assessment of construction, its development, implementation and results [14]. The sustainability assessment purpose is to gather data and report information to serve as a basis for decision-making, during the different phases of a building lifecycle. Nowadays, there are several tools that can be applied in the construction sustainability assessment during the design, execution and operation phase of buildings [8,15-17]: SimaPro, BEES, ATHENA, LISA, NABERS, LEED, BREEAM, CEEQUAL, LiderA, SBTool , and some of them have an urban assessment version: LEED Neighbourhood Development, BREEAM Communities, CASBEE for Urban Development. In Portugal was developed a tool named LiderA, the acronym for Leadership for the Environment in Sustainable Building, which is an assessment and voluntary acknowledgement system for sustainable building.

LiderA - Sustainability Assessment System is a Portuguese registered brand and is composed of construction environmental performance levels from the point of view of sustainability, that can be compared with different performance levels, A to E, which should be better than existing practices – the E level [18]. The LiderA system uses a set of 43 criteria in 6 different areas to measure the sustainability level. The method evaluates 6 main areas that include specific areas of intervention based on 43 criteria which assess sustainable measures [18]. These areas include different weight and are local integration (14%), the consumption of resources (32%), socio-economic values (19%), environmental impacts and comfort (15%), environment and innovation management (8%). The most significant in the assessment is the consumption of resources due to its higher relative importance (see Figure 1).

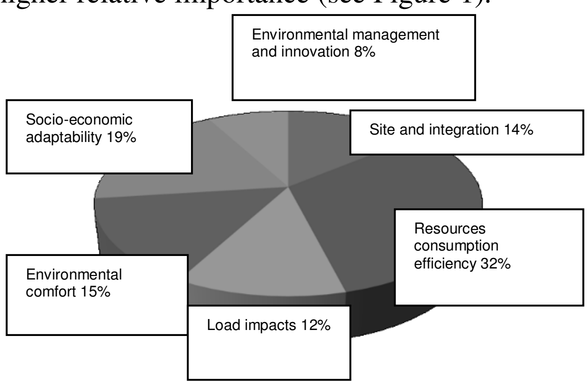

Figure 1: Areas weight LiderA 2.0 [18]

4 Case study: Urban area

4.1 Introduction

This work aims to evaluate the sustainability state of a small urban centre (Águeda in the centre of Portugal) and propose measures that could contribute to a better performance and lead to a more attractive urban centre. Like many other towns, Águeda urban centre is suffering a desertion phenomena and it is a strong intention of the town city hall authorities to launch measures that could contribute to make the urban centre more attractive to residents and visitors.

Public spaces at city centers, especially when no care is taken, tend to degrade and contribute to social exclusion phenomena which increase even more to the degradation and desertion to the outskirt. These are the phenomena that sustainable measures applied for instance to urban refurbishment and development try to oppose [19].

4.2 Local characterization

Águeda is a town at the centre of Portugal, crossed by a river with the same name. It presents a total area of 335 km^2 and it has an average population around 50000 people, which corresponds to a density of 149 inhabitant/km^2. Considering only the area regarded as Águeda urban centre, the last census in 2001 reported 11357 inhabitants [20].

The climate is classified as mild with ocean influence, presenting dry and warm summers and moderate winters. In terms of precipitation, it is considered as moderate wet, with an average annual precipitation value between 1200 to 2000 mm.

The Águeda River tends to cause floods in the city centre which is one of the questions that has to be dealt with.

In the last three decades Águeda suffered a high urbanization pressure. From 1990 to 2000 the number of houses increased 27%, and an excess of 1800 of accommodations was verified in the end of this period. This rapid growth with a significant dispersion around the town also led to urbanization and environmental problems, leading in some cases to a loss of quality in the urban spaces. The urban centre is getting quite degraded with a lot of buildings owners living away from Águeda. On the other hand, Águeda is an important industrial area of the centre of the country with important industries, for instance, in the ceramic and metallic sectors.

4.3 Sustainability measures proposed for the urban centre refurbishment

From the sustainability analysis and taking into account the LiderA assessment system indicators for its different areas, it is herein proposed a set of measures that could contribute for a more attractive centre. They are presented according to relevant areas established by LiderA and also according to the local sustainability agenda, the Águeda 21 Report [20].

Under this area one of the indicators is related to territorial valorization. The knowledge on the type of soils, its fertility, infrastructures and vulnerabilities is very important. It is proposed to set up a map that gathers this information and to adequate building activity to the type of soil. It is fundamental to avoid building that increases impervious fertile soils and to recuperate degraded or contaminated ones (Table 2). The expected impact should be to reduce the negative use of soils and to value its use. In terms of environment optimization should be favor refurbishment actions of town centre buildings. The expected impact is clearly to minimize new constructions and impervious new soils. There is an important activity from a cultural and social point of view.

Table 2: Soil use: territorial valorisation

Soil use	
Improvement measure	**Environmental impact**
Territorial valorisation	
Map the soils information: type of soil, fertility, infrastructures and vulnerabilities Adequate building activity to the type of soi Recuperate degraded and contaminated soils Do not build in fertile soil.	• Reduce the negative use of soils • Valorize the soil use • Do not increase the area of impermeable soils.

According to soil use and to the environment optimization indicator, improvement actions for the urban centre refurbishment were identified (Table 3).

Table 3: Soil use: environment valorisation

Soil use	
Improvement measure	**Environmental impact**
Environment optimization	
Improve refurbishment actions of urban centre building stock.	Minimize new constructions Avoid making impervious new soil use.

Another indicator is related to natural ecosystems which consider ecological valorization actions and interconnectivity of habitats. Vegetation should favor biodiversity choosing local species. Green areas should be protected and habitats pathways should be preserved or built. Ecological fragmentation should be avoided and heterogeneity should be promoted (Table 4).

Table 4 – Natural ecosystems

Natural Ecosystems	
Improvement measure	**Environmental impact**
Ecological valorisation and interconnectivity of habitats	
Vegetation should favor biodiversity, choosi local species Pathways should be preserved or built Ecological fragmentation should be avoided and heterogeneity should be promoted.	Promote urban green areas and the well being o the species Promote the interconnectivity of habitats.

Regarding the landscape and heritage area, the measures depicted in Table 5 were proposed. Local landscaping integration is one of the indicators where buildings rehabilitation, facades preservation and the respect on these issues that new buildings must present are major factors. Projects should be adapted to the local and soil movements should be avoided. The expected impact is the preservation of the urban landscape, natural or built one.

Table 5 – Landscape and heritage area

Landscape and Heritage Area	
Improvement measure	**Environmental impact**
Local landscaping, integration and built heritage protection	
Buildings rehabilitation Facades preservation Construction projects adapted to the local Avoid great movements of soil Identification of buildings and infrastructures that characterize the town.	Preservation of the urban landscape, natural or built Preservation of local heritage and its valorisatioı

Another indicator in this domain is the built heritage protection and preservation. The identification of buildings and other infrastructures that characterizes the town and its traditions is capital and should be valued namely by legal measures. The expected impact is the preservation of Águeda local heritage and its valorization. In the natural resources area, there are interventions planned for the energy, water, materials and food indicators.

Regarding Energy, Águeda authorities have already implemented measures [20] like tax reductions for projects with A or A+ class in terms of energy certification. They have also launched this kind of certification in municipal buildings, setting up the example. Quantification of CO_2 emissions in municipal transports and the establishment of photovoltaic energy generation stations was also some of the measures already launched. Projects like 1000 solar roofs and studies on LED technology for public lighting have been set. Besides these measures it is also suggested in this particular area that the municipality could award projects leading to passive solutions in refurbishment actions that could lead to energy efficiency (Table 6). Other measures could contribute to this efficiency like the use of renewable sources for certain consuming activities (lighting, signaling, etc.) should be considered. Management systems that could control public lighting needs and promotion of electric transport of small dimension could be another type of measures. At this level it is expected that these measures will lead to the reduction of energy consumption and CO_2 emissions, also contributing to a more efficient lighting system and to promote a better mobility and access for all, making Águeda a more inclusive town.

Related to the water efficiency indicator the town authorities have already implemented the creation of a secondary watering systems for gardens using rainwater harvesting, the use of flow regulators, the adjustment of the watering periods, the plantation of local species with lesser needs of water, among other measures [20].

Table 6 – Natural resources: energy

Natural Resources	
Improvement measure	**Environmental impact**
Energy (proposed measures)	
Promote the implementation of passive energy measures in rehabilitation and ne projects to get energy efficiency Management systems to control public lighting Promote the use of electric vehicles.	Reduction of energy consumption Reduction of CO_2 emissions.

Besides this, it is also suggested with this work the recycling and reuse of grey waters for public gardens and cleaning of public areas (Table 7). Population should also be led to install water saving measures like flow regulators or rainwater harvesting [10]. Other measures involve the use of pavements that are not impervious and mechanisms that allow the harvesting of water from different sources in public areas. Water retention areas should also be created since it also contributes to flood control. It is expected with these measures to reduce water consumption and to increase water efficiency, decrease water loss and mitigate floods probability. Since water sources could be reloaded it would also decrease the pollution of underground and surface waters.

Table 7 – Natural resources: water

Natural Resources	
Improvement measure	**Environmental impact**
Water (proposed measures)	
Recycling and reuse of grey waters for public gardens and cleaning of public places Led the population to install water saving measures like flow regulators (water efficiency products) or rainwater harvesting Use of pavements that are not impervious and mechanisms that allow the harvesting of water from different sources in public areas.	Reduction of water consumption Increase water efficiency Decrease water loss Mitigate floods probability.

Besides the public water supply system always have losses of water that can reach a large proportion of total consumption, because its length and complexity of existing organs and joints. The water distribution systems are not completely waterproof, so the occurrence of water losses is inevitable, but high losses have negative environmental and economic consequences. The increase of environmental sustainability is one of the consequences of the water losses reduction, thereby contributing to the efficient use of water and energy. The reduction of GHG emissions to the atmosphere that arise from the energy consumption associated with water is one of the main factors that contribute for sustainable development. The identification of water losses in a public supply system can also be reflected in financial economy not only for the managing body as well as for the consumer [21].

Planning applications for all towns should be accompanied by a water cycle strategy that provides a plan for the necessary water services infrastructure improvements (water and sewerage companies). The strategy should: assess the impact that the proposed development will have on water demand within the framework of the water companies' water resource management plans and set out the proposed measures which will limit additional water demand. So, to achieve a nearly zero urban area on water management, should aspire to water neutrality, i.e. achieving development without increasing overall water use across a wider area. In particular, the water cycle strategy should set out how: the development would be designed and delivered to limit the impact of the new development on water use; new homes and non-domestic buildings will be equipped to meet high standards of water efficiency. So, water neutrality is the concept where the total water used after a new development is no more than the total water used before the development. This requires meeting the new demand through improving the efficiency of use of the existing water resources, utilising the most water efficient products in retrofitting of existing buildings and in new constructions and where appropriate looking at water reuse options.

Regarding the materials indicator, the use of more sustainable materials should be encouraged. A list of the district materials producers should be made in order to promote local production specially the ones that could be regarded as sustainable. Producing companies that take actions towards sustainability should be encouraged to set up their installations in the district. The expected impact should be the production and extensive use of sustainable materials, promotion of local industry and commerce and minimization of environmental impacts (Table 8).

Table 8 – Materials

Materials	
Improvement measure	**Environmental impact**
Sustainable Materials	
Encouraged the use of more sustainable materials Made a list of the district materials producers in order to promote local production specially the ones that could be regarded as sustainable.	Promotion of the production and extensive use of sustainable materials Promotion of local industry and commerce Minimization of environmental impacts.

Regarding the last indicator, local food production, biological agriculture and social farming in urban houses should be promoted. Local products could be sold in local market and, on the other hand, use of abandoned land is important to prevent soil erosion. Social occupation and jobs promotion could be another interesting result.

Another area of sustainability is concerned with effluents emission and the following measures are proposed. Regarding the residual water treatment indicator it is suggested that local treatment units, low cost and easy to build, are made in a way that biological treatments can apply. In what concerns the reuse of grey water as an indicator, studies to assess the viability of its recycling and use in watering and non-potable end use should be promoted. The indicators concerned with waste production, recycling and management can be improved by implementing strategies of waste recycling and valorization. The use of recycled materials or products with high recycled content is a positive measure towards sustainability. Companies that produce this kind of products or promote their use should be encouraged to set in. A plan of waste management should be installed and industrial symbioses should be carried out to eliminate all kind of residues. Door to door waste recovery can be a solution for certain type of wastes as it energy valorization. The expected results involve as well apart from waste reduction, the decrease in the use of natural raw materials and lower contamination probability from hazardous materials. Another area is related to the air quality, where monitoring strategies are proposed. Many of the measures indicated in other areas also contribute to this one. In the lighting and acoustic comfort area it is proposed to balance public spaces in order to function as acoustic protective areas, study the sound levels in order to structure acoustic barriers where needed. The lighting area was already a target for proposals before.

Access and mobility area is a critical one where several measures can be suggested in order to improve the city centre attractiveness. Easy access to public transports that could prevent the use of cars in the city centre is capital and for that the type of transportation, its frequency and location of passengers' stations is fundamental to its success. Another issue is related to low impact mobility that can be achieved through cycling pathways, electrical buses or electrical bicycles for rental. To improve safe pedestrian paths is also an important measure (Table 9).

Table 9 – Access and mobility

Access and Mobility	
Improvement measure	**Environmental impact**
Low Impact Mobility	
Cycling pathways Electrical buses Safe pedestrian paths Electrical bicycles for rental Innovative mobility options like the shweeb or the personal rapid transit (PRT).	Reduction of energy consumption Reduction of CO_2 emissions Achieve a more inclusive town.

The elimination of barriers for impaired people outside and inside of buildings is an important measure to be taken not only for people with particular mobility needs. It is expected with these measures to diminish pollution, to improve mobility and accesses issues in the city of Águeda, especially because of its rough topography, and overall to make Águeda a more inclusive town with an attractive urban centre [22].

5 Conclusions

With this study it was possible to realize the importance of urban areas and its development for all society, for biodiversity, natural resources and particularly for the environment. The case study confirms that it is fundamental to preserve the built heritage. The process for social and economic growth together with the concern about environmental issues allows making populations more aware on the need to incorporate sustainability principles in urban planning and development. This urban fabric contemplates the built ensemble, the industrial, commercial and other type of activities altogether. These activities that gather population also have environmental impacts, hence, interventions that balance them with the quality of living must be a concern for all, particularly, for those who manage cities and its activities. That is the way that equilibrium is maintained between human life and the consumption of natural resources in the planet. To develop urban refurbishment or conservation projects it is necessary to fulfill the urban rehabilitation principles and at the same time incorporate the sustainability principles. Any proposed measure for urban refurbishment should be evaluated by sustainability assessment tools that are currently available in many countries, including Portugal. That is why this work attempted to suggest a series of measures correlated with indicators or guidelines present in a specific assessment tool developed and adapted to Portugal (LiderA). The adjustment was made in order to contemplate the applications concerned with urban spaces rather than only the buildings.

Besides the proposed measures have a direct effect on target urban spaces, it can also be conclude that these sustainability based interventions affect other important issues of the urban fabric. The energy efficiency of public systems, air quality improvement, water harvesting and recycling, mitigation of pollution through correct policies of public transportation and other measures are some of the examples that present an effect on human health and quality of life.

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Water Scarcity and Building Sustainability: An OPENHOUSE Approach

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Abstract:
Availability of water is a concern in most European countries, and with increasing population and potential impact of the climate change the concern is growing. Governmental and non-governmental agencies are leading the effort to evaluate the level of stress within the water environment and to regulate or promote measures to transition to a more sustainable use of the scarce freshwater resources. Sustainable building rating schemes, such as LEED[7] and BREEAM[1], are measures by non-governmental agencies that promote sustainable development and provide benchmarks for comparison of building sustainability. The developments are awarded ratings based on a number of criteria that include water efficiency. Credits can be awarded for use of water efficient fixtures and appliances, and for the use of water reuse systems (such as rainwater harvesting greywater reuse) to reduce the overall water demand of new buildings. The variability in local water stress and availability of water is not currently considered in the weighted scoring of the leading sustainability rating schemes. OPENHOUSE[5] is a European FP7 project with the primary objective of "benchmarking and mainstreaming building sustainability in the EU based on transparency and openness (open source and availability) from model to implementation". The overall objective of OPEN HOUSE is to develop and to implement a common European transparent building assessment methodology, complementing the existing ones, for planning and constructing sustainable buildings by means of an open approach and technical platform. It is considering the adoption of a novel approach of awarding credits for water efficiency based on local water availability. This paper outlines a methodology that considers water scarcity when awarding water efficiency credits.

Keywords
Water Scarcity, Water Exploitation Index, WEI, sustainability, OPEN HOUSE, EU, FP7, Rainwater Harvesting, Greywater reuse, Carbon intensity of water. Benchmark, BREEAM, LEED, European Environment Agency.

1 Introduction

The water resources in many European countries are stressed to a varying degree, and the level of stress is expected to increase due to population increase, changing behaviours in water consumption and reduction in availability of water due to climate change. The water stress levels at regional level have been mapped out by the European Environment Agency[3] and are shown in Figure 1 below, where the water exploitation index identifies the available water resources in a country or region compared to the amount of water used. An index of over 20% usually indicates water scarcity.

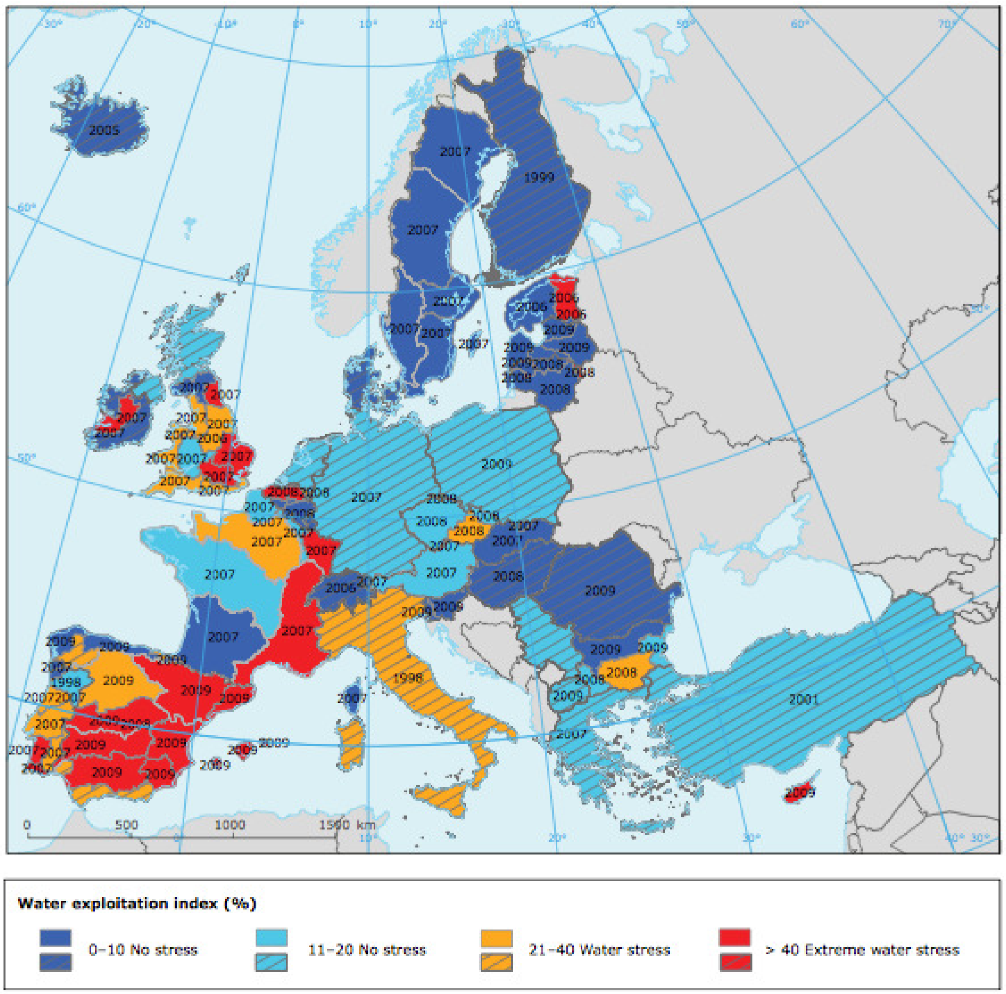

Figure 1 Water Exploitation Index at Regional Scale (Source: EEA[3])

Figure 1 shows the severity of stress in not just the Southern Mediterranean regions, but also in some of the Northern European regions, such as South East England and parts of Northern France and Belgium. These water stress levels in these catchments will increase significantly due to combination of reduced precipitation and increased in population.

The EU's Water Framework Directive's (WFD) objective of achieving 'good status' for all the water bodies by 2015 will result in further restrictions on the quantity of freshwater that can be abstracted from the environment. In a recent report by the European Environment Agency[3], resource efficiency technologies in the buildings were identified as a principle means of achieving sustainability in water use. By using water efficient technologies, significant savings can be made in water consumption without sacrificing the standard of service offered to end-users.

This approach is based on the goals set out in 'Resource Efficiency Europe' initiative by the European Union. The vision is outlined as:

> 'By 2050 the EU's economy has grown in a way that respects resource constraints and planetary boundaries, thus contributing to global economic transformation. Our economy is competitive, inclusive and provides a high standard of living with much lower environmental impacts. All resources are sustainably managed, from raw materials to energy, water, air, land and soil. Climate change milestones have been reached, while biodiversity and the ecosystem services it underpins have been protected, valued and substantially restored.'

As part of this initiative, 'Blueprint to safeguard Europe's Water Resources' report (expected in 2012) will be identify policy measures on water resource efficiency, water scarcity, drought, climate change vulnerability and adaptation. Improving the sustainability of buildings is likely to form part of the means of achieving resource efficiency in the water resources.

Green building codes and sustainability rating schemes are one of the likely mechanisms to meet the goals set by this initiative.

2 Sustainability Rating Schemes

There are a number of sustainability rating schemes currently in use around Europe, with some focussed on residential buildings and others focussing on commercial buildings. The weighting of water efficiency varies between the scheme and Table 1 compares some of the schemes in use internationally.

Table 1 Water Efficiency Weighting in Sustainability Rating Schemes

Rating Scheme	Type of Building	Weighting for water efficiency
LEED – US [8]	All	5%
BREEAM – UK [1]	Industrial, Commercial, Multi-residential	2.5%
PassiveHaus – International[6]	Residential	Not considered
Code for Sustainable Homes – UK[2]	Residential	9%
Pearl Rating Scheme - Abu Dhabi [7]	All	25%

The variability in the weighting for water efficiency in these international is related to the general availability of water in the geographic regions, with Pearl Rating Scheme (by Estidama of Abu Dhabi) providing a significantly higher weight for water efficiency measures than the others benchmarks.

The water efficiency credits can be achieved by use of

a) Water efficient fixtures (taps, showers, WC cisterns)
b) Water efficiency appliances (washing machines, dish washers)
c) Rainwater harvesting
d) Greywater reuse

Parts of Europe suffer from water scarcity in similar scale to Abu Dhabi. Regionally, the water efficiency could be a greater concern than other credits in the rating schemes. However, the rating schemes such as LEED and BREEAM are more focussed on energy, and their current use in such locations may not appropriate.

It is also worth noting that in some European regions, water is plentiful and can be supplied at lower cost and with less energy (and carbon) consumption from public water supply in comparison to rainwater harvesting and greywater reuse. In such locations, awarding credits for use of rainwater harvesting or greywater use may not be sustainable solution.

3. OPENHOUSE project

The overall objective of OPEN HOUSE is to develop and to implement a common European transparent building assessment methodology, complementing the existing ones, for planning and constructing sustainable buildings by means of an open approach and technical platform.

OPEN HOUSE will provide a transparent approach able to emerge collectively in an open way across the EU. The approach will accommodate views of key stakeholders.

The baseline will be existing standards (both CEN/TC 350 'Sustainability of Construction Works' and ISO TC59/SC17 'Sustainability in building and civil engineering works'), the EPBD Directive and its national transpositions and methodologies for assessing building sustainability at international, European and national level.

The scientific and technical objectives are:

- To define the OPEN HOUSE baseline: an open and transparent European platform for building sustainability
- To widely communicate the baseline concept and outline the mechanism for interaction among the project and stakeholders
- To build up the OPEN HOUSE Platform: facilitating a 'pan EU' effort towards a common view on building sustainability

- To pave the way for implementing and evaluating the methodology: selection of case studies and mechanisms for decision making
- To evaluate and refine the methodology by the feedback resulting from case studies and real sustainable public procurement cases and other stakeholders inputs
- Towards dissemination and exploitation of the OPEN HOUSE methodology

4. An OPENHOUSE Approach to Water Efficiency Credits

The above issue has been considered and a novel approach to consideration of water availability in awarding credits has been developed. At the core of the OPENHOUSE water credits award is the Arup 'Water Hierarchy' (Figure 2), where the efficiency measures are considered alongside the water scarcity and the energy required delivering the water.

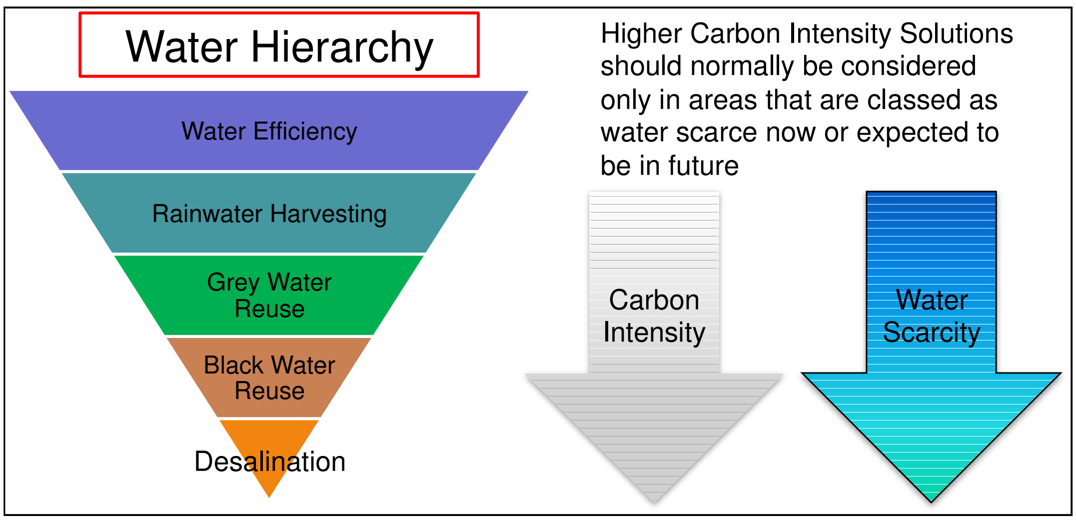

Figure 2 Arup Water Hierarchy as used by OPENHOUSE

Water is a local issue with local solutions, and applying the water hierarchy to awarding credits ensures that solutions are based on local needs and constraints, such as water scarcity or stormwater control.

Where OPENHOUSE rating is used

- Credits can only be claimed for carbon intensive water reuse technology if the site is in area of high water scarcity, e.g. where Water Exploitation Index (WEI) is greater than 20%
- Additional credits are available for sizing system capacity based on local needs (water scarcity, stormwater control)

Using this approach will help reduce the embodied and operational carbon of the development in areas where water scarcity is not a major issue. It would reduce the contrary incentive of obtaining credits for water efficiency by using energy intense water reuse systems. It would also ensure that solutions implemented in new developments are prioritized based on local water management needs rather than an arbitrary weighting of a rating scheme.

5. Summary

Water efficiency in buildings have been identified as a means of delivering long term sustainable water management in Europe, and sustainability rating schemes are means of promoting sustainable water use in new buildings.

However, the current rating schemes are more focussed on comparative benchmarking of buildings and they do not provide any tools to allow for additional credits for achieving higher water efficiency in water stressed regions. As a consequence, they have significant limitation in providing benchmarks that address local conditions and local environmental constraints.

The OPENHOUSE approach uses an evidence based method using local water usage metrics, and allows for

- Weights and credits based on local needs;
- Minimum thresholds for awarding credits;
- Additional credits for increased benefits if there is local need (e.g. Larger RWH tanks for storm water attenuation).

OPENHOUSE is due to be published in 2013.

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A field study to investigate green roofs: retention capacity and water quality

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Abstract

Green roofs are an important strategy for mitigating the impacts of the soil imperviousness and water scarcity in the cities.They retain part of the runoff quantity andcan improve or worsen the water quality. This paper presents the results of the evaluation of green roofs concerning the retention and the quality of water drained by four green roofs installed in cell tests with atotal area of 6.05 m^2. We investigated extensive and semi-intensive systems, with the same substratecomposition and different thickness(10 and 25 cm)All cell tests were constructed in the experimental area located at the University of Campinas campus, in the city of Campinas, State of São Paulo. We analysed the soil composition (grain size and nutrients) and retention capacity. Storm water and runoff volume were measured by pluviographs. Water samples were collected in different rain events and analysed in laboratory (physical, chemical and biological parameters). Results show differences in the performance of the green roofs studied, which must be observed in the specification of this type of strategy for more effectiveness in its use. The quality of water harvested from green roofs was, in general, worse than both water harvested from conventional roof and directly from de atmosphere.

Key-words:green roof; rain water; water quality; runoff

1. Introduction

Green roofs are being recommended for comfort performance improvement and also as a non-structural issue for stormwater control. They retain part of the runoff and promote a delay, so they can contribute for stormwater management[1, 2, 3, 4, 5].

The performance of green roofs concerning water retention depends on many factors, like composition and thickness of the substrate; moisture substrate content before the rain event; type of the vegetation; slope of the roof; roof age; and others [1, 3, 5, 6, 7, 8].

Size and position of the pores of the substrate may change, both due to the natural soil settlement and due to changes in the content of organic matter[6]. This behavior may determine a different performance of green roofs over time.

Using water harvested inside buildings, another important contribution of green roofs can be explored, which is the decrease of the use of potable water for some activities using non-potable water. For this purpose, it is important to investigate the quality of the water harvested to specify treatment system needs.

Green roofs can improve the water quality acting as a "sink of pollutants" or, on the other hand, it can be a source of contaminants [9, 10, 11]. The behaviour of green roofs concerning quality of the water harvested depends on the sources of pollutants. Rainwater can contain pollutants, which can be leached or not; substrate composition and maintenance routines can introduce pollutants as well. Interactions between these characteristics will determine the quality of water harvested.

There is little information concerning the performance of green roofs in Brazil, and Brazilian Standard for rainwater harvesting systems does not contemplate parameters that are important for the evaluation of water harvested from green roofs. Inserted in this context, this article aims to evaluate the performance of four roofs, one conventional with ceramic tiles, and three green roofs.

2 Material and Methods

Roofs investigated were installed in test cells constructed in the experimental area of the School of Civil Engineering and Architecture and Urban Design, University of Campinas, city of Campinas, state of Sao Paulo, Brazil.

The rainfall pattern is characterized by a rainy season between October and March, where mean monthly rainfall varies from 102 to 267 mm [12].

This study used the same test installation of other research, which aimed to evaluate the contribution of green roofs in the thermal performance and stormwater retention. That study contemplatedninetest cells: eight are green roofs and one is conventional [13].

This article contemplates four roofs, one (R) has ceramic tiles and was used as reference; three are green roofs (G1, G2, G3).

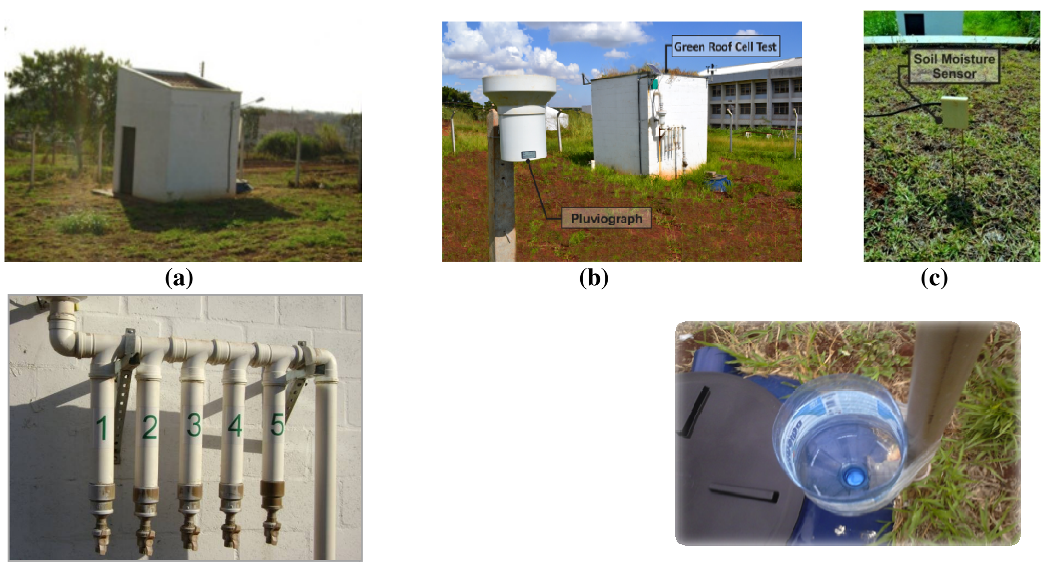
All green roofs investigated are continuous, have the same type of substrate and have two geotextile layers. However, G1 and G2 are classified as extensive, with a substrate thickness of 10 cm, and G3 is semi-extensive, with a substrate thickness of 25 cm.The other difference among G1, G2 and G3 is concerning vegetation: G1 received *Zozya*

Japonica; G2 contains *Aptenia Cordifolia, Portulaca Granifolia, Echeveria Elegans e Lampranthus Productus*; and G3 received *Arachis Repens; Evolvulus Glomeratus and Lantana Undulata*.

All test cells have a total area of 7.61m² (2,76m x 2,76m), are 3.15m high, and were installed above concrete slabs (slope of 2%), with a bituminous paint. The effective area of green roofs is 6.05m².

Figure 1 shows the experimental apparatus. Test cells were instrumented with moisture sensors (model CS616 WCR, Campbell Scientific®) positioned within the soil; in addition, the rain intensity of each event and the runoff were monitored by pluviograph (model TE525WS, Campbell Scientific®). All roofs have also sampling devices for the water harvested, which contain one vertical drain and 5 PVC pipes (2.6 L) controlled by valves. This study contemplates only data from pipe 1. Samples of the rainwater directly from the atmosphere were collected only one time and the device used is also shown in Figure 1.

Irrigation was used only for the initial period of implantation, until October 2010. After this period, there was no irrigation or maintenance.



(a) (b) (c) (d) (e)

Figure 1 – Experimental apparatus: (a) test cell R (ceramic tiles); (b) pluviograph and green roof cell test; (c) soil moisture sensor; (d) rainwater sampling devices; (e) atmosphere rainwater sampling device

Rainfall data were collect in two periods: (I) January to March 2011 and (II) January to March 2012. These periods have more rainfall events than other periods of the year. Rainfall events were defined considering isolated events when separated by less then 6 hours as used by VanWoert*et al.* (2005). Thus, there were a total of 46 events in the period I and 47 in the period II.

The evaluation of the moisture substrate content took in account the lowest value recorded before the start of the rain event and the highest value reached during the rain event. Thus, the retention volume was calculated using Equation 1:

$$\theta = \frac{Vw}{Vs} \quad \therefore \quad Vw = \theta \cdot Vs \tag{1}$$

Where: ϴ: volumetric moisture content; Vw: water volume retained in the soil; Vs: cell test soil volume.

Besides field monitoring, green roofs substrates were analyzed in the laboratory to determine grain-size characteristics, physical parameters and organic matter content. Samples for rainwater quality analysis were collected in two periods: C1 and C2 in 2011, April and the others (C3, C4, C5, C6 and C7) in 2012, January and February. Sample of the water directly from the atmosphere was collected only at C2.

The following water quality parameters were analyzed in the laboratory: color; total fixed solids; total volatile solids; turbidity; pH; organic N; Cd, Cr, Cu, Fe, Mn, Zn, total coliform and E. Coli. All procedures followed [14].

Due to the small number of rain events and the inability to show that the water quality data follow a normal distribution, the nonparametric Mann-Witney test, with a significance level of 0.05, was used to make comparative analysis of the water quality data, as recommended by [10].For the statistical analysis, all data indicated by means of detectable minimum level were changed by the respective limit value.

3 Results and Discussion

3.1 Physical and chemical parameters of the green roofs substrates

Table 1 shows physical and chemical parameters of the substrate of green roofs. Grain sizecharacteristics are shown in Figure 2.

Table 1 – Physical and Chemical parameters of the substrates

Celltest	Density (g/cm^3)	Bulk Density (g/cm^3)	Porosity (%)	Voidratio (%)	Organicmatterindex (%)
G1	2.506	1.027	59.001	1.444	4.60
G2	2.621	0.921	64.849	1.848	3.40
G3	2.553	1.022	59.977	1.502	3.30

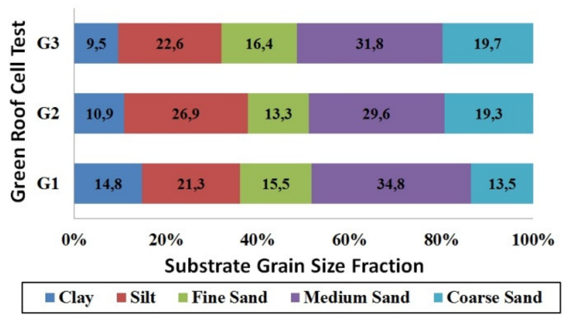


Figure2 – Grain size characteristicsof the substrates of the green roofs.

3.2 Water retention

Figure 3 shows volumesretained in green roofs G1, G2 and G3in both monitoring periods, which were calculated by the Equation 1.This figure shows also maximum and minimum values of the soil moisture and the precipitation.

Roofs G1 and G2 are similar (extensive with a substrate thickness of 10cm, continuous, two geotextile layers and same type of substrate), however, it is noticed that the largest fraction of clay (4.7% higher) and organic matter content (1.2% higher) in roof G1 provided it a better performance in terms of rainwater retention during the two monitoring periods. Nevertheless, these higher fractions of clay and organic matter were not sufficient to compensate the best rainwater performance of roof G3, which has a thicker substrate.

Also, higher density of vegetation in roof G2, visually detected, was not sufficient to provide greater water retaining when comparing with roof G1.

Moisture contents recorded at the end of each rain event that occurred between January and March 2011 (period I – 46 rain events), and between January and March 2012 (period II – 47 rain events) were converted in water volume retained in the substrate by equation 1, as shown in the Method item. Figure 3 shows the water volume retained in green roofs during each rain event in both periods of monitoring.

The higher substrate thickness and soil moisture content of G3 provided it a better performance in terms of water retention when comparing all green roofs for the same rain events.

This best performance of a ticker substrate agrees with the results obtained by[1], where extensive roofs retained about 30% of the total rainfall, whereas intensive roofs retained about 50%. However, this authors highligths that a low discharge ratio can also be realised with an adequate substrate composition. In our study, the composition of the green roofs was almost the same,with exception of the vegetation layer, however, it was not possible to detect performance differences because of it.

Finally, it can be detached that the maximum values of moisture content of both cells test occurs in those events with big intensities. This behavior indicates that they may accumulate water above substrate, assuming that the rain intensity is greater than the capacity of percolation of the water in the soil.

Roof G3 had higher maximum values of the moisture content than roofs G1 and G2. This indicates it can retain higher values of rainwater.

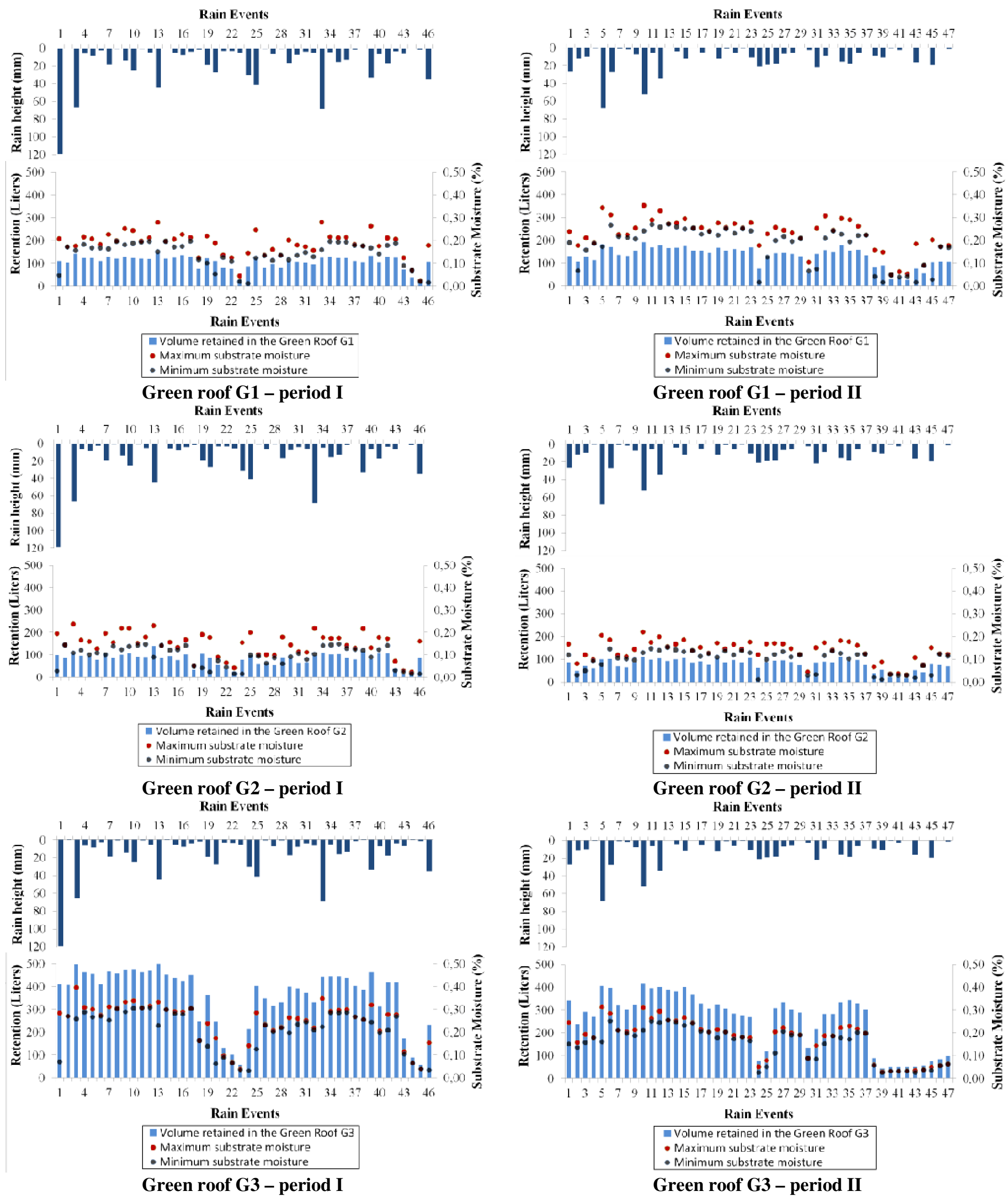


Figure 3 – Precipitation, volume retained, maximum and minimum moisture contents (at the beginning and at the end of the rain event) for cell test G1 – Monitoring periods I and II.

Thus, intense rains in green roofs with a substrate with low percolation capacity can accumulate water above the substrate, beyond their retention capacity. This characteristic has advantages and disadvantages: green roof may work as a detention unit, decreasing the flow velocity of the water through the urban drainage system; on the other hand, its structure must support the load of the added weight of accumulated water layer above the substrate.

Furthermore, the system design should avoid water overflow to other areas, and also, to prevent the puddling for long periods, in order to prevent the proliferation of insects and other organisms.

In intensive rain events preceded by days without rain, the green roofs had an increase of the retention capacity proportional to the reduction of moisture content. On the other hand, during rainy period, when the moisture content was already high, the retention capacity was reduced.

3.3 Water quality

Table 2 shows the quality of water collected directly from the atmosphere (rain event 2). Figure 4 shows results of the Mann-Whitney test ($\alpha = 0.05$) pairing comparison of the parameters of the water harvested from all roofs; values are shown in Figures 5 and 6.

Table 2 – Physical and chemical parameters of the rainwater collected directly from the atmosphere – rainfall event: C2

Parameter	Value
Apparent color (uC)	4.0
Turbidity (NTu)	1.4
Total solids (mg/L)	3.8
Total fixed solids (mg/L)	6.4
pH	5.6
Condutivity (µS/cm)	5.0
BOD	2.0
COD (mg/L)	2.9
Total coliforms (NMP/100mL)	< DL
E.Coli(NMP/100mL)	< DL

DL – detectable limit

In [1] it is said that "the claim that the rainwater is purified by passing through a green roof is clearly not true" as shown.This affirmation is also true in our study, where the majority of the results indicates an enrichment of the parameters when comparing with the water collected directly from the atmosphere. In our study, for example, organic loads, characterised by BOD and COD parameters, were higher, indicating pollution by organic matter.

On the other hand, water samples harvested from green and conventional roofs had higher values of pH than water collected directly from the atmosphere, a result that corroborates with other studies found in the literature[1, 10, 15, 16].

The majority of the parameters was not significantly different when comparing green roofs G1, G2 and G3 in pairs in the Mann-Whitney test for α=0,05. Conductivity and total volatile solids were significantly different in any of thesecomparisons.

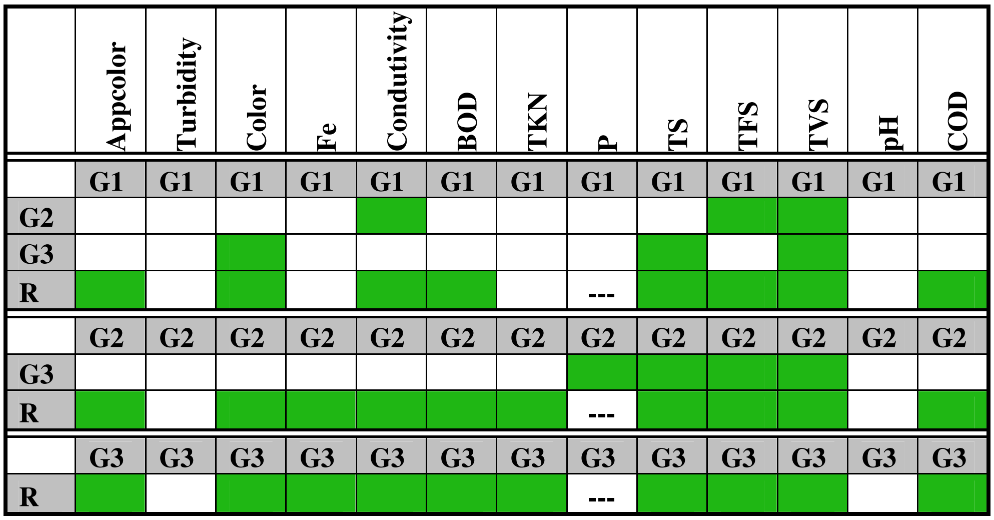


Figure 4: Mann-Whitney test results. Green squares indicate that the parameter that is in the first line is significant different (α = 0,05) for pairing comparison.

Solids detected in all water samples from green roofs are essentially organic, represented by high values of the total volatile solids. Furthermore, BOD and TKN results indicate the organic matter is derived from organic molecules, without N.

Samples of water of G3 had high values of total fixed solids and this fact explains higher values of the conductivity, as these parameters have a high correlation (R^2 = 0.93 in our study).

Values of Fe were not significantly different when comparing results obtained with the water harvested from the green roofs, although color was significantly different when analyzing G1 versus G3. Results of soil nutrients characterization indicates that substrate of roof G1 has higher value of Fe than G2 e G3, which may indicate the presence of humic and fulvic compounds resulting from the partial decomposition of organic matter in green roofs.

Turbidity values were low for all green roofs, which indicate clay and silt retention in all roofs.

Main differences occurred when comparing each green roof with the conventional roof R, where just pH and turbidity were not significantly different for all of these comparisons.

Total phosphorus values were higher only in the two first rain events, for all green roofs. From rain event 3, which was almost one year later, the concentration of P was decreasing with the time.

High levels of total coliforms may explain high values of COD in the water harvested from green roofs. Total coliforms levels were between 1.3 x 10^2 and more than 2.4 x 10^3 NMP/100mL. E.Coli levels were between less than 1 and 3 NMP/100mL, and changed among rain events, however, these changes can be considered low, less than 1 Logarithm.

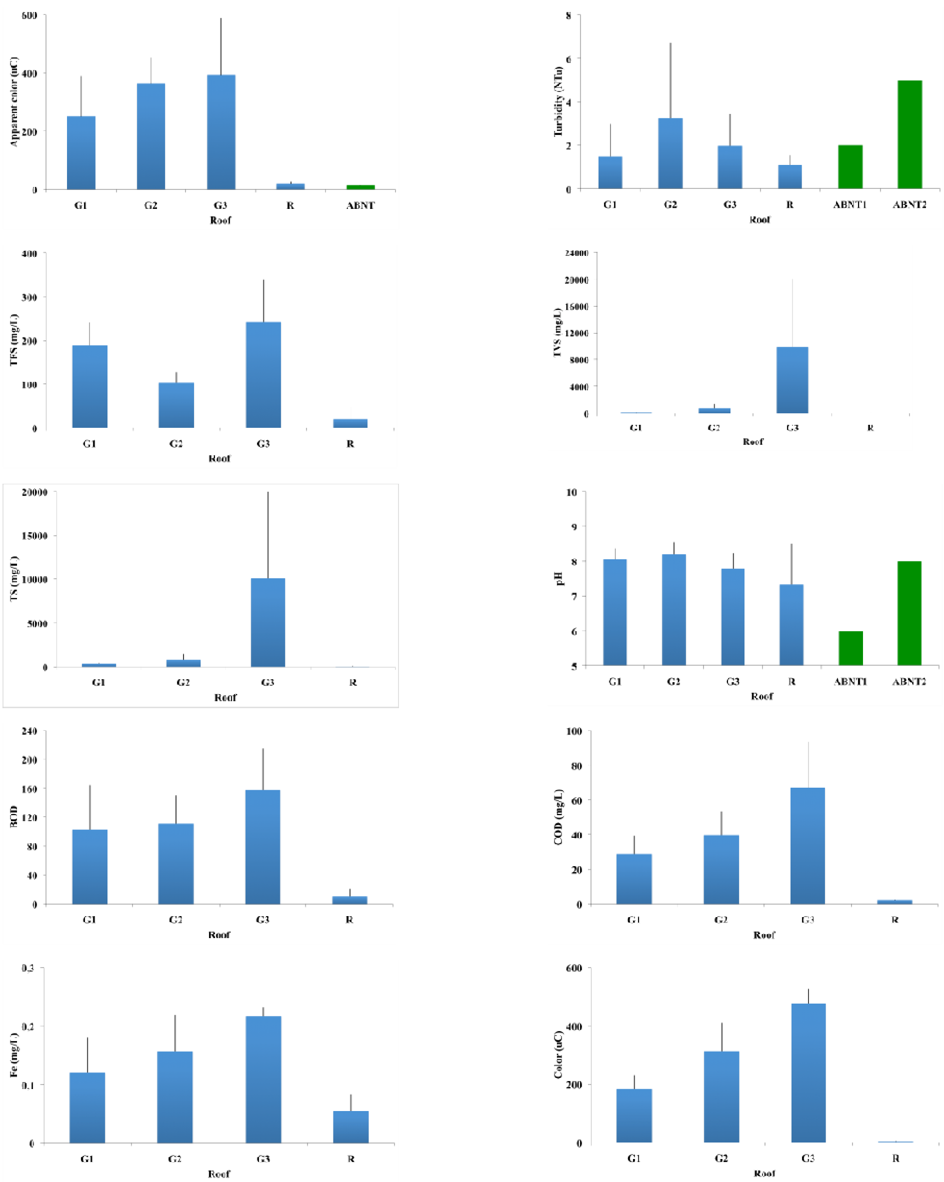


Figure 5: Mean values of quality of water harvested: green roofs G1, G2 and G3, and conventional roof R – seven rain events. Black lines show one positive standard deviation. Green bars show Brazilian Standard limits.

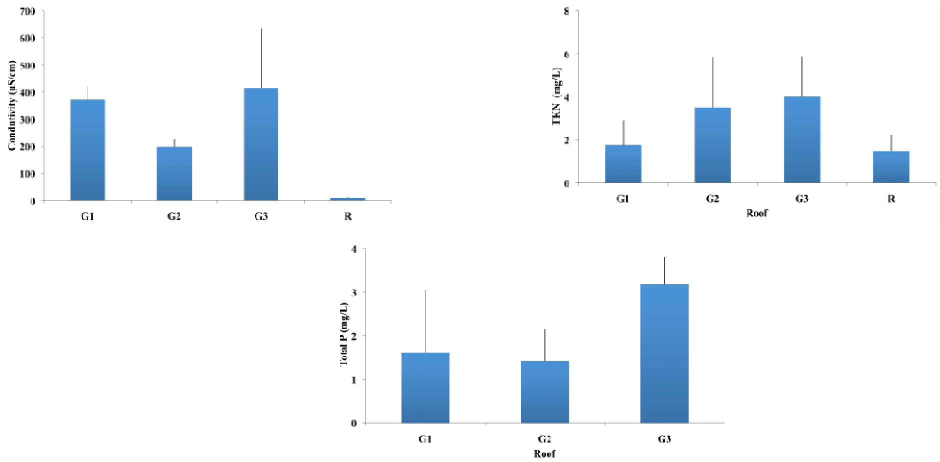


Figure 6: Mean values of quality of water harvested: green roofs G1, G2 and G3, and conventional roof R – seven rain events. Black lines show one positive standard deviation.

The levels of metals(Cu, Cd,Cr, Ni andPB, Zn) in all green roofs were always below the minimum detectable limits. The same was observed for the conventional roof. In the case of Zn, the level was higher than the minimum detectable limit only for roof R, which can be explained by the existence of a gutter of this material.

Brazilian standard do not contemplate parameters for the quality of water harvested in green roofs. Thus, results obtained in our study were compared with the water quality parameters of the Brazilian Standard for rainwater harvesting systems [17].

Apparent color value was exceededin all samples of water harvested from green roofs; for roof R, this value was not exceed only in two rain events. Turbidity values were not exceeded only by rain event 4; roof G2 samples had turbidity much higher thanthese limits. Values of pH were within the limits, except for the conventional roof in rain events1 and 5, where the pH values were just below that range. Total coliforms limit was exceeded in all samples of water.

4 Conclusions

This article presented a performance evaluation of three green roofs in terms of water retention, aiming to act as a non-structural tool for stormwater control, and in terms of the quality of water harvested, comparing with samples collect from a conventional roof and directly form the atmosphere.

Constructive characteristics of green buildings are important for its performance, in terms of rainwater retention and quality of water harvested. Small differences between composition and grain size fraction of the substrates were not enough to compensate the influence of their thickness.

The substrate thickness, for the green roofs investigated in this study, was the most important constructive characteristic for water retention. However, it is important to take into account the limitations on the number of events evaluated, and also, the amount of interrelated parameters, so that conclusions should not be extrapolated to other regions without further research and consolidated. Some parameters should be considered, such as grain size and composition of the substrate, fertilizers added to the substrate and external conditions (temperature, humidity, vegetation, compaction).

Furthermore, the different load introduced to the structure should be also considered when adopting intensive or semi-intensive green roofs. In our study, the saturated density is about 160kg/m^2 for roofs G1 and G2, and 408 kg/m^2 for G3.

The quality of water decreased when comparing sample collected directly from the atmosphere and also of water harvested from all green roofs investigated in our study. The majority of the parameters were not significantly different when comparing the green roofs in pairs. However, almost all parameters were significantly different when comparing each green roof with the conventional one.

Finally, results of apparent color, turbidity and total coliforms exceeded limits of water quality parameters for non-potable use, contemplated in the Brazilian Standard for rainwater harvesting. Even for non-potable use, high values of COD, as found in our study, may be a source of contaminants when associated with chlorine, which consists of the most frequent disinfection system used in Brazil.

In general, there was improvement of some water quality parameters when comparing samples of the two first rain events and the others, which occurred aboutnine monthslater. This fact indicates a stabilization of all parameters from the phase of roofs installation, as shown by other authors.

Acknowledgments

Authors would like to thank FAPESP and CNPq for funding, Architect Marcia Ibiapina for the assembly of the experimental apparatus, the technicians of the Laboratory of Sanitation of FEC-UNICAMP for their assistance inconducting the tests, and prof. Dr. Edson Nour and prof. Dr. Miriam Miguel for their help in data analysis.

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History and Subjects of Rainwater Harvesting and Wastewater Recycling in Japan

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Abstract

Based on the documentation and research results of authors etc., the history, present condition and future subject of the rainwater harvesting and wastewater recycling in Japan are described.

As history, the measure against a flood of a river in the 16th century, the object for water supplies in the rice agriculture performed in the agricultural area even now, and the water service technology from the 17th century to the 19th century are described. Moreover, the changes for water supplies in buildings from the 20th century are described.

And decision of the circumstances where the rainwater harvesting and wastewater recycling in Japan came to be performed from around 1980, the water quality and technical standard accompanying this are described.

A future subject is drawn from these results of an investigation. It is a measure to dealing with global generating of a flood and a drought according to a climate change, and the water reservation at the time of a disaster, and it is the establishment of a technical standard, technical sharing and the consideration of regionality about the subject of rainwater harvesting and wastewater recycling.

Keywords

Rainwater Harvesting; Water Recycling; Japanese History

1. Introduction

The problem of the climate changes and water preservation including the paper of Brazil and Portugal in the CIB W062 2011 poses a large problem in the world. Although Japan goes into much rainfall as compared with other countries, the amount of water that can be used per person is small. So, by present day, the measure against rain water and drainage reuse are performed.

While explaining the history of the measure against rainwater and drainage reuse in Japan, the trend of each country and a future subject are described.

2. History and climate about river improvement and irrigation of Japan

About the name of a place described below, the map of Figure-1 shows a place.

General Shingen Takeda (1521-1573) of the Age of Civil Wars and a Kai country (present Yamanashi Prefecture) has advanced the river improvement enterprise. The measure technology to the flood by the heavy rain called “Shingen Zutsumi” : river bank is famous. Moreover, a reservoir and a bank called "Waju" nationally and the “Ushirui” which are one of the spur dikes were made (Figure-2).

Japan is clear in change of the four seasons from the first, and a rainy season, a typhoon, and melted snow supply a lot of water to the area.

The precipitation of Tokyo is shown in Figure-3. The typhoon has an important duty which brings Japan a lot of water, though what occurs in about 26 pieces per year, and passes through Japan (Figure-4) causes many flood damage, and Figure-5 shows total snowfall of the Yamakoshi observation poin. Total snowfall amounts also to 1200 cm in the 2011 fiscal year. The rainy season in June is the important time in irrigation of a paddy field. For example, in the terrace paddy field in the Yamakoshi area, water is led in a horizontal well, water is dropped to a level difference, and the paddy field is irrigated.

From the first, many water service had secured groundwater as a head makes a dam in the upper stream with the increase in population, or aggravation of water quality, sends in water in a river, makes tap water in a water purification plant, and supplies water to a wide area increasingly on a pipeline. The dam that supplies water to the metropolitan area is shown in figure-6. The dam is useful not only reservation of water resources but for river improvement, such as flood defense and prevention of a mudflow. Moreover, electric power is also supplied by waterpower generation. However, the rate of the waterpower generation in electric power of Japan is not so large (Figure-7). Although the water wheel (Figure-8) was put on the stream and it was once used as power, most present age is not used. Instead, small scale hydropower attracts attention.

The technology of water service is also old. The Tatsumi city water in Kanazawa City pulled the pipe of the stone 15 km in 1632, and had sent water to the Kanazawa castle by back siphonage. Tamagawa waterway in Tokyo was bearing the water service of the population of the Edo 1 million people said to be 43 km of waterway in 1653. However, in the detached island in Nagasaki Prefecture or Okinawa Prefecture, rainwater may be used even now including drinking water.[7),8)] Water is sent to the part on the pipeline from the mainland.

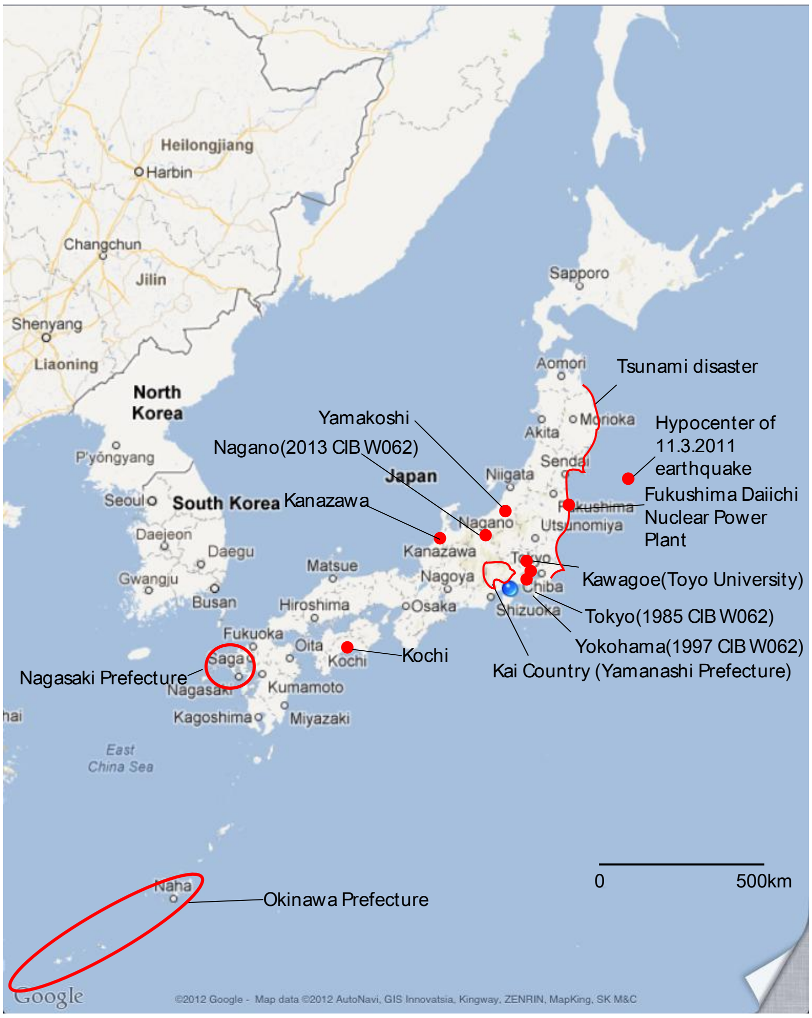


Figure-1 The name of a place to introduce

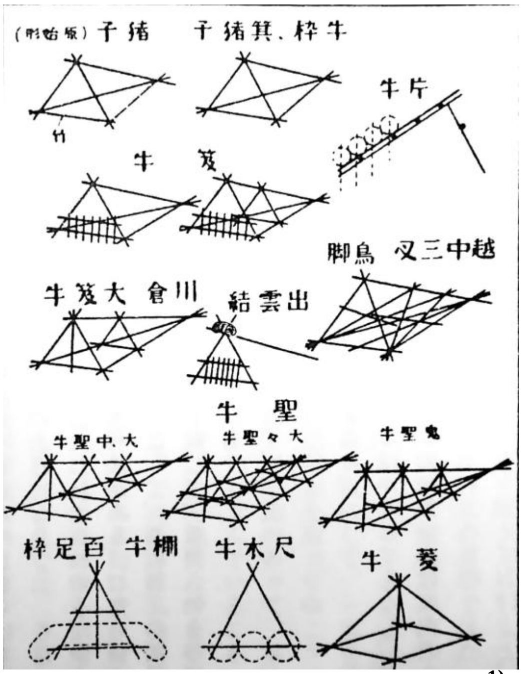


Figure-2 The spur dikes "Ushirui"[1)]

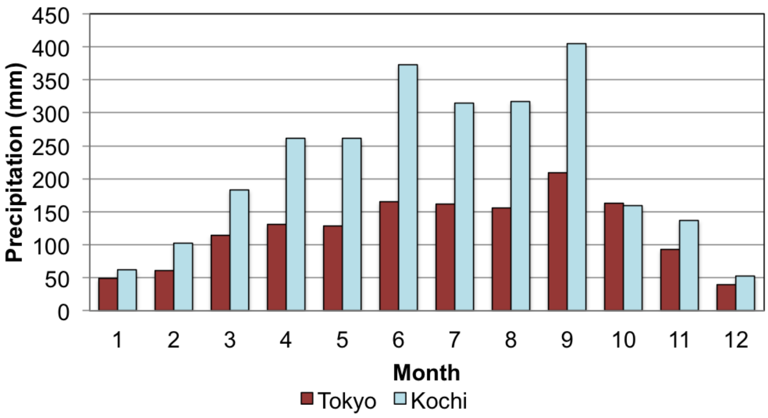


Figure-3 Precipitation of Tokyo and Kochi [from data 2)]

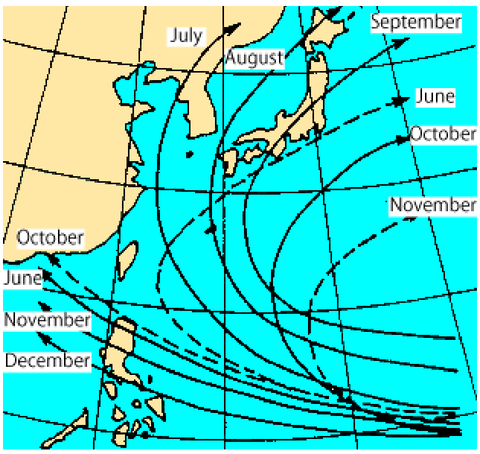


Figure-4 The course of a monthly typhoon [3)]

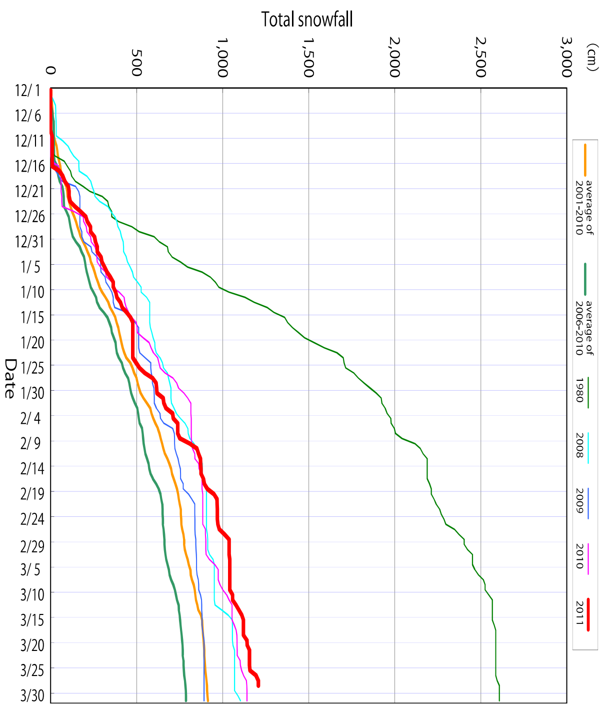


Figure-5 Total snowfall of the Yamakoshi observation point [5)]

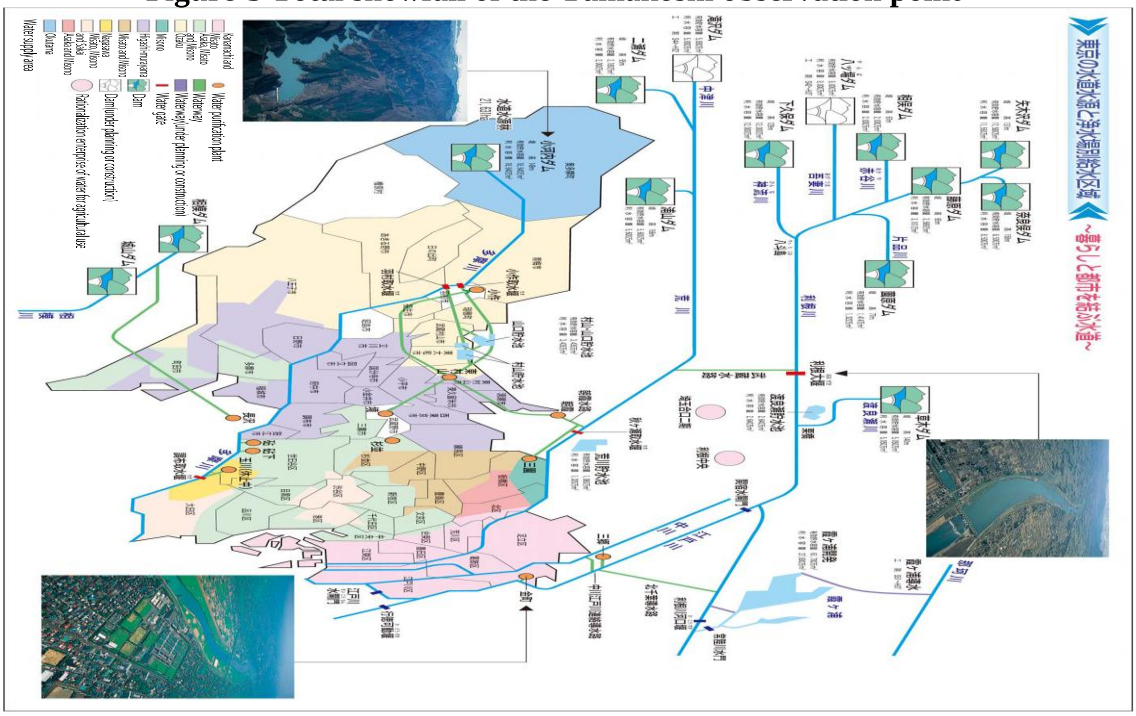


Figure-6 The source of tap water in Tokyo, and the water supply zone classified by water purification plant [6)]

3. The time of reuse and recycle water

Political change called the Meiji Restoration to 1968 in Japan happened, and, also in water service, modernization was advanced. Yokohama City in 1887, Hakodate City, Hokkaido in 1889, and Hadano City, Kanagawa in 1890 of modern water service are early introduction.

On the other hand, reservation of the head according rural areas to a well had continued for a long time. A water service diffusion rate is shown in figure-7. Opening of traffic of water service continued expanding a city and population.

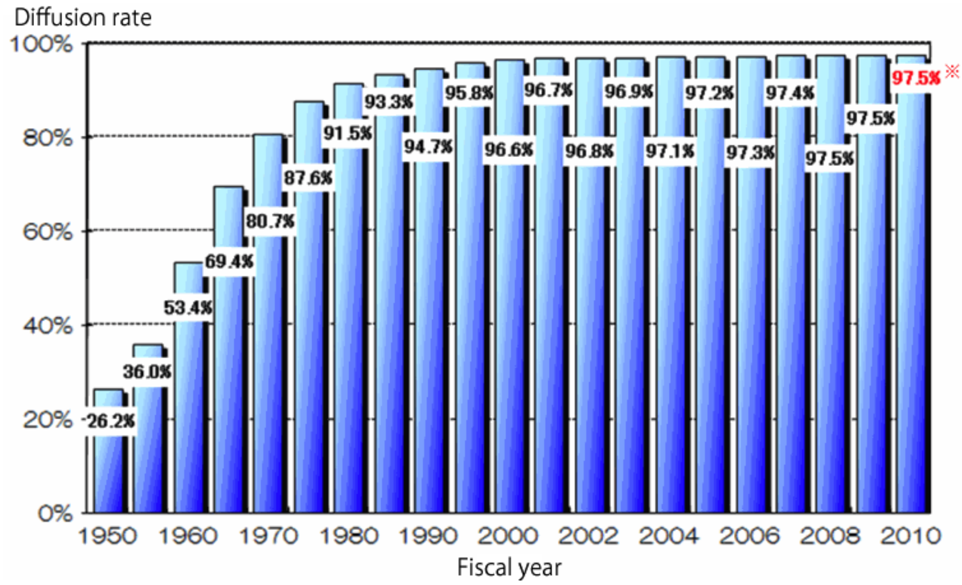
Applying from around 1900 in 1963, Japanese drinking water was supplied from water service, and, on the other hand, the rinse water of the toilet was supplied from groundwater. However, land subsidence occurred in pumping of groundwater and pumping of groundwater was forbidden from 1962 in Tokyo. Furthermore, the population of the city in Japan grew rapidly and a water shortage produced it. Moreover, urbanization progressed and the flood by a flood also occurred frequently.

Under such circumstances, rainwater use and drainage reuse came to be performed around from 1980. In addition, as for rainwater use, rainwater underground osmosis as the rainwater storage and the groundwater occurrence as a measure against a flood will be performed simultaneously.

As an example, rainwater use was performed at the IBM Japan Iikura building in 1978. Moreover, rainwater use of the Sumo stadium (Kokugikan) was performed in 1984, and rain water use of TOKYO DOME (the first indoor baseball field in Japan) was performed in 1988. In TOKYO DOME, the rain which fell to 15,700 square meters which is equivalent to the abbreviation half of a roof is stored to the water tank under a stand seat, or the cook room drainage in a dome is stored. These were processed and it uses as water for toilets in TOKYO DOME.[10)]

Thus, the system that takes in rainwater use in a building taking advantage of the rainwater use by roof construction will spread. Change of the subsequent number of examples is shown in figure-8. Although 3,550 is attained to at the end of the 2009 fiscal year, if the adoption example in a single house is also included, the rainwater use system is introduced into much more institutions.

Then, the Ministry of Construction (that time) created the technical standard in 1981, and the Ministry of Health and Welfare (that time) created the waterworks-for-miscellaneous-use water quality standard in the same year. The Minister of Construction secretariat building and repairing department published drainage reuse, rainwater use system design criteria, and the description in 1991. Many books about rainwater use have been published from the 1980s.



Water service diffusion rate = the total water supplied population/overall population, However, total water supplied population = waterworks population + simple waterworks population + private waterworks population

Figure-7 Transition of a water service diffusion rate [9)]

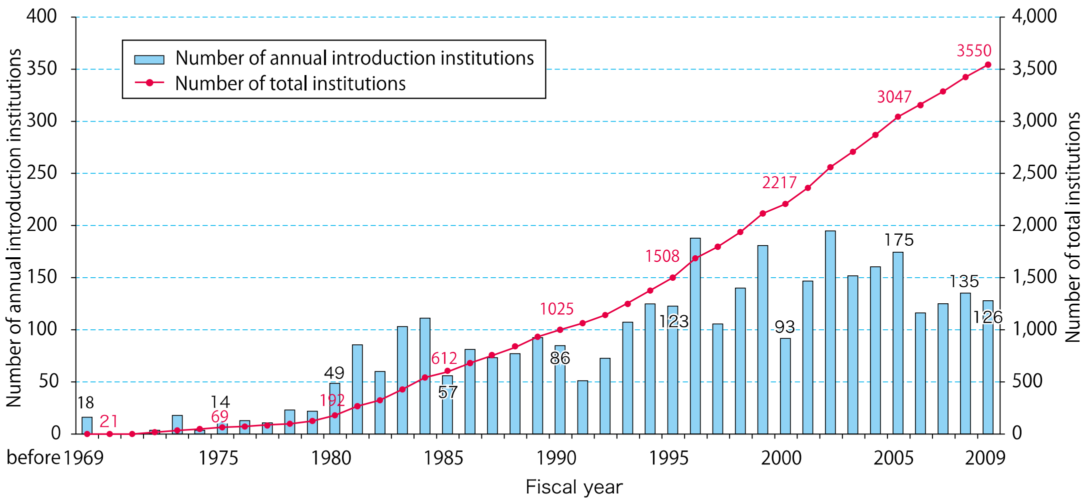


Figure-8 Transition of the number of rainwater or wastewater recycling institutions [11)]

4. Present measure and subject

Although the shower called "shower" from before in a summer had occurred in Japan, the phenomena in which a lot of rain falls for a short time called "guerrilla downpours" have occurred frequently recently. Hourly rainfall may amount to 100 mm or more.This is said to be what is depended on the situation where rain cloud progresses rapidly by the heat island effect. Moreover, it may also be in a cause that temperature is rising under the influence of a climate change. From the rainfall exceeding the design criteria of the present rainwater drainage being seen, the necessity for a new standard is imminent.

In CIB W062, Kiya and Uchida have announced as research on drainage recycle and rainwater use in 1994 (Brighton). Research and activity about rain water use were advanced at the time even in the Architectural Institute of Japan, and “Learning of rain architecture“ was published in 2000 and “Technic of rain architecture“ was published in 2005, and "Way of rain architecture " was published in 2011. Moreover, the "Guideline for rainwater harvesting architecture" was published simultaneously.

The "Rainwater Network Meeting" used as the place for performing information exchange / activity cooperation was founded in 2008 so that a citizen, a company, administration, a society, etc. of national every place might form a loose network and might spread mutual activity more effectively systematically. On the other hand, manualization of the rain water use system was considered in the field of building equipment from the Society of Heating, Air-conditioning & Sanitary Engineers of Japan , and "Rdain water use system design and business" were published in 1997. "The knowledge design, the construction, and the maintenance management manual of the business of rainwater use" which will be a revised edition of the writing 2011 more were published.

As research etc. with which a writer is concerned, the "rain water use program" was created by 2007 in development of the total energy simulation tool "BEST" of an outer cover and building frame, and equipment and apparatus [12)]. Moreover, it inquired as a rooftop gardening system which utilized rainwater about the measurement and evaluation of the rooftop gardening system which used the hydrophyte (Figure-9) in the 2009 to 2011 fiscal year [13)].

Furthermore, the infiltration of rainwater potential map in Hadano city is created now using GIS. While the possibility of prospective infiltration of rainwater or rainwater use is shown through this process of a series of, cooperation with the GIS data of a groundwater system is aimed at, and it is inquiring for the purpose of the construction and the city future model which realizes the healthy water cycle in the area being shown[14)].

Figure-9 Rooftop gardening system used the hydrophyte [13)]

5. Conclusions and future subjects

This report explained the historical circumstances which result in the river improvement, irrigation, and rainwater use or water recycle in Japan for which research in recent years and measure are introduced, and clarified the measure and subject to the water cycle centering on a building.

Now, flood and drought damage have occurred in various places globally. The measure in Japan also has the necessity of taking into consideration having happened in every corner of the earth. The importance of performing information sharing at international conferences, such as CIB W062, is recognized.

In Japan, it follows on the Great East Japan Earthquake that occurred in 11 March 2011, and the water reservation at the time of a disaster attracts attention anew. In the building of the skyscraper depending on especially water service and a sewer, etc., it is necessary to examine anew reservation of the water at the time of a disaster, rain water storage in it, and the necessity for practical use.

On the other hand, under the influence of the accident of a nuclear power plant, the radioactive material dispersed in various places and the problem on which a radioactive material is accumulated by the rainwater use system has arisen. It is necessary to gaze at a future trend about this.

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Study for reuse of effluents of sewage treatment stations in the garden irrigation

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Abstract

The water reuse finds in Brazil a significant range of potential applications. The use of instrument to restore the balance between supply and demand of water in several Brazilian regions. Thus, it becomes necessary institutionalize, regulate and promote the water reuse in the country, causing the practice development in accordance to appropriate engineering principles, being economically viable, socially acceptable and safe in terms of environmental preservation.. (HESPANHOL, 2003). Due to the need of water resources conservation, it becomes of extremely importance the development of studies, which aimed to the planned reuse of effluents resultants from the domestic sewage treatment, in order to reduce the consumption of drinking water in activities that do not need this type of water, generating a reduction in the demand of the stocks of good quality. The reuse of effluents from treatment stations can represent a huge potential of water with quality and quantity to be used for different purposes, including irrigation of gardens and parks. The present research aimed to study the effluents generated in a domestic sewage treatment station, in order to reuse this effluents for gardens irrigation. To observe the behavior of the pathogenic load, were made tests in order to obtain data related to the survival of the bacteria in the effluent storage conditions and for use in the garden. To this end, were studied the reuse potential of the effluents from a sewage treatment station with aerobic reactor, with the intention of determine if there is a risk of microbiological contamination due to contact of people with grass gardens. Alongside, were stored effluents from two sewage treatment stations with two different types of systems, with anaerobic reactor and stabilization ponds, and were performed analyzes to determine the survival of coliforms group bacteria in storage tanks for several days. In the results of the effluent application in the irrigation of gardens, it was observed a varied behavior with reductions and increases at the bacteria population from the coliform group and thermotolerant group, both under conditions of isolated application or in several successive applications. In the analyzes of effluent storage the behavior was very distinct, whereas in the anaerobic reactor system there was a reduction of the population during the storage period, in the effluent of the pond stabilization system, initially, there was an increase in bacterial population, to decrease only after 21 days after the storage, but still keeping very high population levels. With the development of this research is expected to have contributed to a safer reuse of effluents of sewage treatment stations and to a reuse with less risk to the user's health.

Keywords: sewage treatment, reuse, gardens, effluent quality.

1. INTRODUCTION

In arid and semi-arid regions the water became a limiting factor for the urban, industrial and agricultural development. Even areas with abundant hydric resources experience use conflicts and suffer restrictions that affect the economic development, and the quality of life. Under these conditions, the water preservation became an imperative in terms of management, mainly in regions with low availability, or insufficient water resources.

The water reuse finds in Brazil a significant range of potential applications. The use of treated effluents in agriculture and in the urban areas, for non- potable uses, attending to the industrial demand and to the artificial recharge of aquifers, constitutes a powerful instrument to restore the balance between supply and demand of water in several Brazilian regions. Thus it becomes necessary, institutionalize, regulate and promote the water reuse in the country, causing the practice development in accordance to appropriate engineering principles, being economically viable, socially acceptable and safe in terms of environmental preservation. (HESPANHOL, 2003).

Due to the need of water resources conservation it becomes of extremely importance the development of studies which aimed to the planned reuse of effluents resultants from the domestic sewage treatment, in order to reduce the consumption of drinking water in activities that do not need this type of water, generating a reduction in the demand of the stocks of good quality.

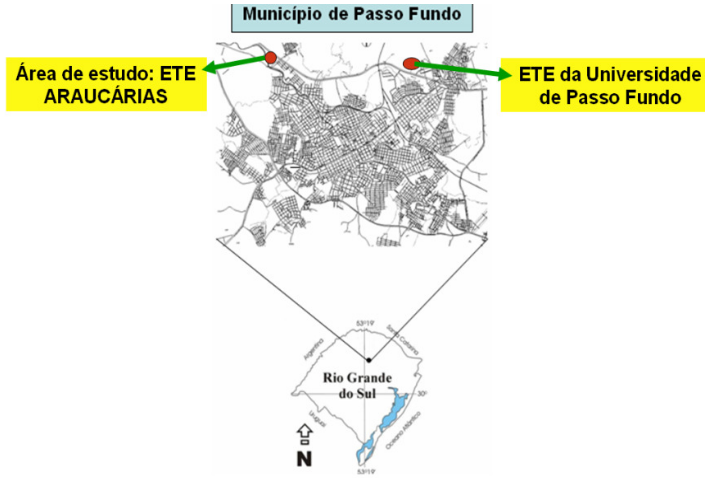
The present research had as general objective study the effluents generated in two domestic sewage treatment systems, in order to reuse this effluents for gardens irrigation.

2. MATERIALS AND METHODS

2.1 Local of study

The study was conducted in two locations, the first was the Sewage Treatment Station (STS) in the city of Passo Fundo (Araucaria Sewage Treatment Station) as shown in Figure 1.

Figure 1 – Location map of the studied sewage treatment stations



The STS-Araucaria currently collects the sewage of the central region of the city, covering approximately 20% of the network. Located on the left bank of the BR 285, towards Passo Fundo – Carazinho, nearby of the Alexandre Zachia neighborhood as shown in Figure 2. It occupies an area of 26 hectares, with an input flow of 100 L/s, and are treated 3000 m³ / day of sewage. The collected sewage is first directed to the pumping station, where it receives a pre-treatment, this station is also located in the BR-285, approximately 2 km far from the STS. After this, the sewage is pumped to the STS, where is treated in a set of four ponds. The first pond is anaerobic, the second is optional, and the last two are of maturation.

The second location studied was the Sewage Treatment Station (STS) of the Foundation of the University of Passo Fundo – UPF, located on the BR 285 km 171, Campus I - Sao Jose neighborhood, Passo Fundo-RS, as can be seen in Figure 1. The system used in the STS is the technological process of anaerobic digestion reactor in upflow sludge blanket type UASB, aerobic biological reactor and secondary settling tank, with a capacity to serve about 18,000 people.

2.2 Methodological development

To observe the behavior of the pathogenic load were made tests in order to obtain data related to the survival of the bacteria in the effluent storage conditions, and for its use in the garden.

1 – Conservation experiment: were obtained effluents samples from the two treatment stations and were stored, in plastic canisters of 50 liters, at the waste storage central deposit of the University of Passo Fundo. The collection was made on 03/05/2010 and were collected two samples by canister, in duplicate, for the thermotolerant and total coliform analysis at the Microbiology Laboratory of the Faculty of Food Engineering of the University of Passo Fundo. Evaluations were made at 1, 2, 7, 10, 14, 17, 21, 14 and 30 days after the initial collection.

2 – Experiment of application in garden: it drew attention to a garden plot of 10 m x 30 m. After marking the area it made up the application of the effluent on the local of

study, as shown in Figure 5. For this it was used a collector tractor effluents, with a total capacity of 200 liters. It should be remember that before the application, two samples of 100 mL were collected to count bacteria. After the application, grass samples were cut in five points of the plot, two samples / collection, and then they were put in plastic bags. The samples were made at 1, 2, 3, 4, 7 and 10 days after application.

The isolation of bacteria was done by washing the material collected in the sample bag itself with 1 liter of distilled and sterilized water. The content of the wash was filtered to remove dirt and sheet remains and were placed in vials of 100 ml for analysis of fecal coliform, two vials for each sample. The determinations were made at the Microbiology Laboratory of the Faculty of Food Engineering of the University of Passo Fundo.

3 – Microbiological analysis: After being isolated for 48 hours in a bacteriological incubator at a temperature of ± 1ºC it was made a presumptive test of the samples. In the sequel it was made the repetition of the presumptive test, to confirm the presence or absence of fecal coliforms.

To confirm the presumptive test the samples were maintained for 48 hours in a water bath with stirring, at an average temperature of 0.2 ° C. In this sequence it was possible to visually determine the presence or absence of the coliform group. With the data analysis were obtained the behavior curves of the bacterial population in storage conditions, and also in the experiments application to observe the survival of the fecal and total coliform groups.

3. RESULTS AND DISCUSSION

3.1 Experiments of survival in storage conditions

The experiments of survival in storage conditions of the fecal coliform group bacteria were conducted to determine if for the condition of having to store the effluent for reuse later, there may be alterations in the bacterial population, which can influence in the probable risk of human exposure to these pathogenic agents. The data for the two treatment systems, as well as the bacteria behavior, are presented in Figures 2 and 3.

As can be seen for the case of the reactor UASB effluent, the initial bacteria population of the total coliforms, just as for the fecal group, was initially big, with an MPN average of 35.000/100mL. For two days after de effluent collection and its storage, the population of the fecal group fell to 9,4% of the initial population, while the total coliform group remained unchanged. At the seventh day of storage the population of the total coliform group represented 27% of the initial population, whereas the fecal coliform group showed a population that corresponds to 8% of the verified in the effluent collection before the storage. At 10 days these populations corresponded, respectively, 18.2% and 5.1%, for the total and fecal coliforms groups. At 17 days the population continued declining, considering that the fecal and total coliforms population represented only 0.54% of the initial population observed in the effluent before the storage. The population remained low until 24 days, despite the total coliform group have suffered a small increase in the MPN value at 21 days.

Figure 2 – Survival of coliform group bacteria in storage conditions of the effluent of STS - UPF

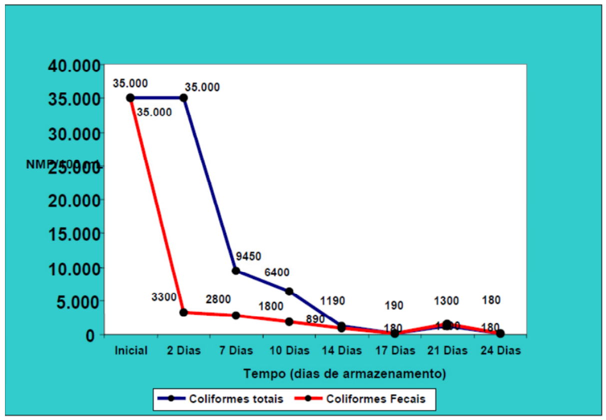
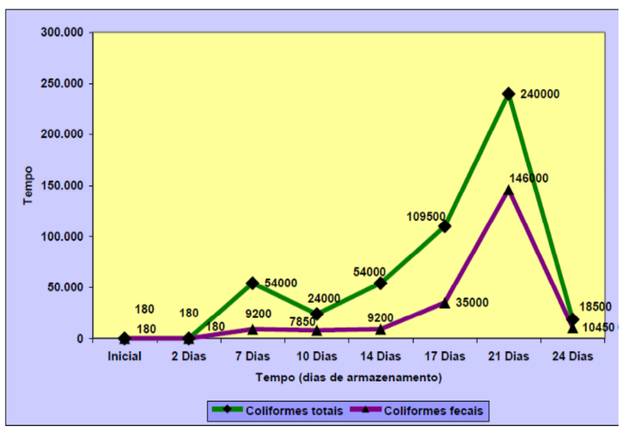


Figure 3 – Survival of coliform group bacteria in storage conditions of the effluent of STS - Araucaria.



In the case of the STS-Araucaria effluent the initial bacterial population was smaller, in function that it is a stabilization pond system in series, with a bigger reduction of pathogenic microorganisms efficiency than the anaerobic reactors, as pointed out by Von Sperling (1996). The population remained low until two days of storage, however, on the seventh day of storage it was observed a significative increase for both groups, the bigger increase occurred in the fecal coliform group, which had an highly significative population increase, of a MPN of 180/100 ml to 54.000/100mL. After a short population decrease on the tenth day, it significative was verified again a population increase in the both analyzed group, the total coliform group always presented a bigger increase than the fecal coliform group in the whole study period. This increase reached its summit at 21 days, and then showed a high decrease at 24 days, when the populations of the total and fecal coliforms groups represented only, respectively, 7.7% and 7.1% of the population observed at the previous date of collection and evaluation. However, it should be noticed that the remaining population in both groups is highly elevated, far superior to any quality standard of water of reuse.

As for the differential behavior of the two systems, the fact that perhaps best explains is the characteristic of the growth process of the bacterial population, in a controlled and limited environment. In the case of the STS-UPF, which has a system of upflow anaerobic reactor, the initial bacterial population was very high, due to the low efficiency of the process for this parameter. During the whole storage period its decrease can be explained by the reduction in the availability of nutrients and/or probable depletion of other essentials factors to this growth. In the case of the effluent of the STS-Araucaria, which despite having low initial population, had essentials factors to its growth, and on that storage conditions suffered an accelerated growth, typical of bacteria. At 21 days reached its maximum value, and then, probably, by the same factor alleged for the previous case, suffered a significant decrease on its population.

However, for the STS – Araucaria effluent the observed condition indicates to a possibility of maintenance and/or elevation of the bacterial population of these two groups, with a significant high associated risk, since the results of the comparison between the two systems indicate completely opposite directions.

The results of the effluent physicochemical analysis shows variations for the BOD of the STS – UPF of 7-165 mg O2/ L, and the nitrogen variation is of 9.5 to 56 mg / L. While for the STS-Araucaria the BOD values varied from 8 to 64 mg O2/L, and the total phosphorus varied from 0.6 to 8.2 mg / L. It is known that the bacteria are the microorganisms group of biggest presence in effluents, and its population growth is mainly limited by the availability or not of nutrients as organic substance, which constitutes the main source of carbon, energy, nitrogen and phosphorus. As it is equally true that their nutritional requirements vary with the specie. A preliminary analysis of the cited data, shows that in the effluent stored of the two systems, these sources were available in relatively high values. In STS-UPF, however, this availability may not be compatible with the needs of the highest population, leading to its quick decrease. In the case of the STS-Araucaria, of lower initial population, due to the bigger efficiency of the process, may have found an organic load of carbon, nitrogen and phosphorus, which can sustain at least, temporarily, a population growth peak, after the collapse that came, which came also by the probable exhaustion of these nutrients.

a. Experiments of survival after reuse for garden irrigation

In these experiments, the main objective was to determine the bacteria survival of the coliform group, after the reuse of the effluent of STS-UPF in garden irrigation, in order to assess the potential risks associated to the people contact to the treated vegetation. Thus, it was conducted an experiment where it made only one application, and it was made another experiment with various applications, intermittently, simulating a common condition that is the irrigation of gardens in the summer season, and with rainfall deficiency. The results are shown in Figures 4 and 5.

Figure 4 – Bacteria survival of the coliform group in garden grass after irrigation with the STS-UPF effluent.

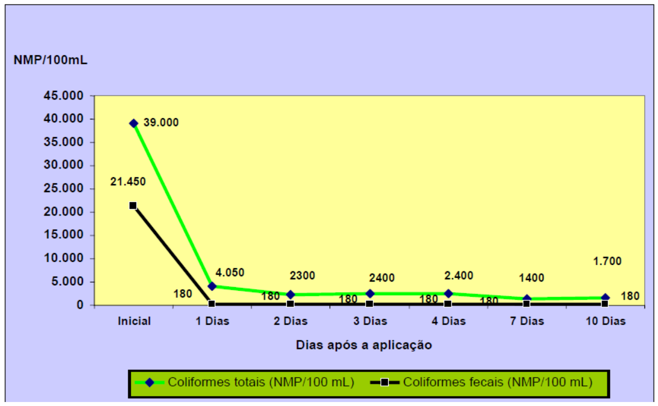
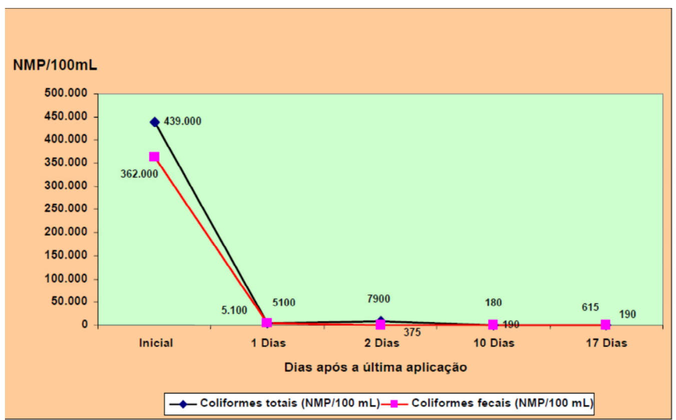


Figure 5 - Bacteria survival of the coliform group in garden grass after three successive irrigations with the STS-UPF effluent.



The initial population, in terms of total and fecal coliform groups, presented relatively high values. One day after the application, the analysis of the water washing of the collected material presented a very accentuated decrease on the MPN values. The data of the total coliform group points to a population which represented 10, 38% of the observed values in the effluent, before the irrigation. For the fecal coliform group this population represented only 0.83%, and remained unchanged until 10 days after garden irrigation. At two days, the total coliform group represented 5.89% of the initial population, it remained virtually unchanged until 7 days, when presented a decrease of 3,58% from the initial population. However, contrary to the fecal coliform group, this group had his MPN values always higher than the recommended literature standards, which range 200-1000/100 mL, having as normal zone for reuse 1000/100 mL, which can represent risk of people contamination (FAO, 1985; AYERS, WESTCOT, 1994).

In relation to the experiment with three successive irrigations, the results of the Figure 5 shows that despite the microbial population for the two groups be extremely high (population average observed in the three applications), there was a very large decrease in this population at the first day after the application, being, respectively, 1.16% and

1.4%, for the total and fecal coliform group, but the values are far superior to the quality standard recommended for this type of reuse. At 7 days, whereas it was observed an increase in bacteria of total coliform group, the population of the fecal coliform group represented 0.10% of the initial population, decreasing to 0.052% at 10 days, and remaining like this until the end of the experiment period. The behavior of the total coliform group was similar, although it was verified a population increase at 17 days, but the MPN value was within the recommended limits.

According to the WHO (1989) recommended microbiological guidelines, the reuse conditions for parks irrigation, sports fields and irrigation of crops to be eaten raw have to be of 1000/100 mL, and is not applicable for grain crops. The data of both experiments shows that despite having a high decrease in the bacteria survival, the remaining population may present microbiological risk, as observed for the total coliform group in the experiment with only one application, which remained over the recommended limit until the tenth day. Requiring, wherefore, bigger efficiency and control in treatment systems, just as monitoring after the irrigation.

The anaerobic reactor system, used at the STS-UPF, presented low efficiency to reduce the population of these bacteria, which determined the presence of high populations in the effluent of reuse, demonstrating that besides the system used, should be considered the influence of project and operating factors on the final quality of the effluent reuse, requiring greater quality control.

The physicochemical parameters of the analysis of the two treatment stations were compared with the recommended limits according to FAO (1985) and AYERS and Westcot (1994) that were raised in the literature review. It was made a survey of all samples that presented values above of these limits. The data are presented in Table 1. The physicochemical parameters considered in function of laboratory analysis performed were pH, total phosphorus, BOD, oil and greases, suspended solids, ammoniacal nitrogen and fecal coliform.

Table 1 - Comparative of the analyzed parameters for the two treatment systems with the limits recommended for reuse.

Parameter	**Recommended limits (FAO,1985;Ayers e Westcot,1994)**	**% of samples above the limits**	
		STS –UPF	**STS -Araucaria**
pH	6,5-8,4	0	0
Total phosphorus (mg/L)	2,0	NA	81,5
BOD (mg/L O_2)	30	92,5	58,8
Oil and greases (mg/L)	8,0	25,9	NA
Suspended solids (mg/L)	50,0	74,0	54,5
N-ammoniacal (mg/L)	5,0	100,0	70,0
Fecal coliforms (NMP/100mL)	200-1000	NA	46,7

NA = Not analyzed

The results of Table 1 shows that is high the non-conformity rate in relation to the limits used for the two systems and for the considered parameters. In the case of STS-UPF the percentage of samples with value above of the recommended limit for the reuse of water, or treated sewage, was 92.5% for BOD, 74% for suspended solids and 100% for ammoniacal nitrogen, while that to greases and oils was 25.9%. The same happened to the standards of STS-Araucaria, which had high percentages of values above the recommended limits, as is the case of total phosphorus with 81.5% of samples with values above the recommended limit, and ammoniacal nitrogen with 70% of values higher than recommended. It should also highlight that the fecal coliform group, because of the associated microbiological risks.

These results demonstrate that the reuse of water from treated domestic sewage, depending on the system used and its operating efficiency, may depend on the practical use of pre-treatment aiming to the adjustment of the recommended quality limits, to environmental safety and / or to public health. The use of treated effluent with low technical capacity to remove pathogens, such as UASB reactors, can set limitations to the reuse in irrigation practices, where there may be high exposure of people, such as in the irrigation of gardens and parks. The reuse of water in irrigation systems must involve the consideration of the sewage treatment techniques, and the final quality of the effluent for reuse, it should be consider aspects of environmental quality, public health and agronomic, such as the compatibility of these requirements with the irrigation techniques, the soil and climatological characteristics.

4. CONCLUSIONS

According to the objectives proposed in this paper, the results demonstrate that the reuse of effluent of domestic sewage treatment systems for irrigation of gardens and public parks, when occurs direct contact, as is the case of reuse on lawns of parks and gardens, it is demanded the use of a pre-treatment system aiming to its adequacy to control criteria to health risk and environmental risk. The comparison of these values with the indices of quality of reuse water, found in the literature, showed a high rate of discordance with the parameters, such as total phosphorus, BOD, fecal coliform, oil and greases, suspended solids and ammoniacal nitrogen, in the two studied systems.

The bacteria survival, of total and fecal coliform group, presented a distinct behavior in conservation experiments, and this behavior is related to the initial population. In the anaerobic reactor system of STS-UPF, which had a higher initial population, there was an abrupt decrease in bacterial growth, whereas in the effluent of the stabilization pond system of STS-Araucaria, with a very low initial population, there was a population increase to very high levels until 21 days of storage, after declined, but maintained high bacteria counts for both groups.

In the experiments of garden application, with a single irrigation, or with three irrigations, the bacteria survival of both groups was significantly reduced and reached values below of the recommended limits to the human health protection.

On the other hand, the results of this study suggest that the reuse of domestic effluents, for irrigation purposes and for non-potable urban uses, must have a monitoring of their physicochemical and biological standards, since they may not correspond to specific criteria for reuse, which are distinct from those for discharge into water bodies.

Finally, the results of microbiological tests, demonstrate the need of conducting further studies, in order to study the behavior of fecal coliform bacteria in sewage for irrigation, where occurs the human exposure and human contact, as well as the adoption of analysis methods of risk to human health due to this potential exposure.

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Water Efficiency: A community study

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Abstract

Water efficiency is the optimised use of water commensurate to need. Achieving water efficiency requires a holistic and integrated approach, starting with the right policy that promotes user and community engagement, better delivery of buildings and the effective use of technologies.

With the latest political emphasis on policy strategies that encourage bottom-up solutions (Big Society, Localism and Community Engagement and Empowerment etc.); this study presents findings from a survey conducted in a community in Sussex.

The objective of the study was to investigate the community's collective views on water (and energy) efficiency. The survey started with a general assessment of basic household demographics and building characteristics before investigating water and energy use. Questions include factors that encourage or discourage water efficiency behaviours, views on water efficiency interventions including information, engagement and technological strategies.

Headline findings show that the cost of water/technological interventions is not considered a delimiting factor for embracing water efficiency. However, the security and reliability of water supply is a primary concern for most respondents. They also considered it important that water efficiency information is provided by a trustworthy source; independent organisations and NGOs were highly favoured. Lastly, the findings confirmed that improving knowledge capacity, directly engaging with water users to find water efficient solutions relevant to them and also empowering communities is essential to promoting a bottom-up solution to water efficiency.

This study was commissioned by the Water Efficiency in Buildings Network, currently funded by the Department of Environment, Food and Rural Affairs (DEFRA), UK.

Keywords

Households and community engagement, water (and energy) efficiency, water efficiency strategies

1. Introduction

Water efficiency, compared to water conservation, is the optimised use of water commensurate to need which is not based on objective indicators but subjective needs (Adeyeye & Piroozfar 2012). It requires people to reduce the amount of water they use by modifying daily activities, e.g. have a shorter shower, change behaviour or adopt water saving technologies. The Water Efficiency in Buildings Network resolved that increasing community resilience impacts on behaviour and social nuances, and thus provides a logical basis for introducing water efficiency to the fore of social and community life (Watef, 2011a). In the current climate, individuals, neighbourhoods and communities are looking for ways to future-proof against future costs, risks that may arise as a result of water, and other resource shortages. Engaging with these concerns and providing support in achieving this goal serves as a useful 'foot in the door' approach for promoting water efficiency to the benefit of all concerned.

Ignoring public sentiment can prevent water-related initiatives from being implemented (Dolnicar & Hurlimann, 2010). With respect to communities, efforts should be made to understand context and make solutions and recommendations relevant to their local resources and local issues to achieve local solutions. Efficiency goals can only be met through high public participation levels (Mckenzie-Mohr, 2000). However, high-level participation is not easy to achieve. It is imperative that the right message is given by the right person or authority to encourage long-term water efficient behaviour by engaging the user (Watef, 2011a).

Two-way communication, in all its forms, is a critical feature of efforts to build community resilience (Article 13, 2012). Communication is essential for creating a positive outcome for water efficiency strategies and policy. Therefore, the main community stakeholders should be engaged with (Watef, 2011b) and areas where a mutual benefit is possible should be collaboratively identified. The purpose of the study reported in this paper is tacitly to facilitate some degree of communication. In addition, studies show that a community's water-use behaviour and attitudes is required to determine the drivers and barriers of water saving behaviours (Graymore & Wallis, 2010). Questions need to be asked to find out what water efficiency means to each individual, building up to the community level, and what are the motivational drivers. By understanding water customers and need, efficient use can be achieved through behaviour, technology and infrastructure efficiency (Adeyeye, 2011). By considering opportunities and constraints to community-scale water efficiency solutions and strategies e.g. implementing community-wide technological solutions, it will be possible to identify the benefits and barriers of water efficiency interventions.

This paper explores the collective views of residents of a rural community in Sussex with regards to water efficiency. The qualitative research methodology was utilised. The survey started with a general assessment of basic household demographics and building characteristics before investigating water and energy use. Questions include factors that encourage or discourage water efficiency behaviours, views on water efficiency interventions including information, engagement and technological strategies. From survey results, it was possible to discuss strategies for empowering communities and its constituting households to engage with water efficiency issues for the benefit of the community as a whole.

2. Water efficiency in the community

It is the responsibility of all to ensure that the supply and use of water has the least possible effect on the environment. Water plays a fundamental social role so policy-related decisions regarding water should take into account public concerns and interests to ensure support. As without consumer support any public resistance may lead to failure (Dolnicar and Hurlimann, 2010). Public buy-in is necessary for effective water policy and uptake of water saving initiatives. The factors influencing peoples' attitudes regarding water-related matters need to be understood and this should influence public information and engagement strategies (Dolnicar and Saunders, 2006). Consumers will want to ensure that the government, policy makers as well as water companies have considered their needs. Trust and satisfaction is necessary to build a relationship to achieve results and continuity, so trust in the information source will encourage willingness to cooperate (Selnes, 1998). Graymore & Wallis (2010) found that a key factor that influences water-use behaviour was trust in the water authority and government; the perception of the abundance of water, trust in the water authority and attitude to government's past performance on water management influence attitudes. An Australian survey asked who would influence their attitude towards water related matters. Findings showed that in general, an individual/organisation qualified in water management as well as scientists, scored highly, then the water authority, with the government the least influential (Dolnicar and Hurlimann, 2010a). These studies show in addition to information and communication strategies, 'trust in the messenger' is equally important for the public to support water policy; this is further explored in the study presented in this paper.

Public community education and awareness are likely to have long-run positive effects in sustaining reduced water usage, with awareness and responsibility best viewed as community assets that should be properly nourished and enhanced through education and awareness programmes (Hurd 2006). Studies (e.g. Allon and Sofoulis, 2006) already show that while people are prepared to take some DIY measures to save water, they are 'stuck' within current socio-technical systems. However, many can imagine alternatives, and would be prepared to do more with improved knowledge, better leadership, fewer obstacles, and more incentives to bring about a shift to a different kind of water culture.

Many individuals have positive attitudes to water savings however these attitudes are not consistently translated into actual behaviour with some of the main barriers being the perception of inconvenience and impracticality, and the costs associated with purchasing water saving appliances (Dolnicar and Hurlimann, 2010b). A social research project investigating the factors that influence community receptivity to using alternative water sources and technologies at the household scale (Clarke & Brown, 2006) found key barriers included cost, the difficultly of implementation and if the property was rented. A recent UK study (Adeyeye & Piroozfar 2012) found similar results. A survey conducted of around 10 000 OECD worldwide households gave results indicating that environmental attitudes and ownership status are strong predictors of adoption of water efficient equipment (Millock and Nauges, 2010).

Donicar and Hurlimann suggested that one of the ways to reduce the perceived inconvenience of adopting water saving alternatives is through social marketing campaigns by providing information on the quality of water saving appliances and how they can be integrated into everyday life with the least inconvenience. However, community-based social marketing requires an understanding of the community's water-use behaviour and attitudes to determine the drivers and barriers of water-saving behaviours (Graymore & Wallis, 2010).

To achieve lasting behaviour change that is not only seen when there are drought restrictions or when publicity makes an impact, understanding what causes behaviour change is necessary. After identifying barriers, one needs to identify whether the resources exist to overcome these barriers (McKenzie-Mohr, 2000). Study results (Campbell *et al*, 2004) supported earlier work warning that offsetting behaviour can negate technological solutions to policy problems. Retrofitting can show mixed results with offsetting behaviour reducing the effectiveness of the water saving device. However, by adding communication to technological solutions, cooperation can be created that overcomes offsetting behaviour.

The poor link between energy and water is also an issue, especially in urban areas where environmental problems due to water shortages is not visibly apparent. Water has a carbon footprint, so by saving water, one is saving energy. This is most noticeable with the use of hot water at household level, but energy generation requires a lot of water for cooling and likewise heating, treating and distributing water requires a lot of energy (Waterwise, 2012). Metering is also increasingly an important issue particularly in the UK context. For a while, studies have shown that metered users are more conservative particularly during severe water shortages (van Vugt & Samuelson, 1999). However not all properties are able to be metered. Water is ultimately consumed by people and this should be factored into the costs; although it is difficult to standard and generalise water consumption, and savings, at this scale. The fact that investing in water efficiency technologies such as rainwater or grey water systems do not directly yield incentives e.g. reduction in water bills, also affects water perception. Retrofitting can show mixed results with offsetting behaviour reducing the effectiveness of the water saving devices used (Campbell *et al*. 2004).

Collaboration between all the stakeholders is essential to make the most of the opportunities available (Watef, 2011b). Essential stakeholders in small communities could include: Parish councils, Local authorities, Environment Agency (EA), local environmental trusts and conservation societies, local businesses, water companies. There is the need to foster better relationship and communications between stakeholders, not only within the community, but with outside organisations as well. Messages and water efficiency information provided by different sources can influence attitudes to water related matters (Dolnicar & Hurlimann, 2010)

3 Research Methodology

The research utilised a quantitative approach to obtaining primary data. The questionnaire method was used because it was easy and efficient to deploy in terms of time, cost and human resource. It was also considered less intrusive for respondents as they could provide honest response to questions they may otherwise not feel comfortable to discuss with strangers.

As strict sampling protocols were not applied, it was important to include general questions in order to understand the profile and characteristics of respondents and their dwellings. It is worth mentioning that this water survey was conducted as part of a wider study carried out by the community's local energy group which included; household energy surveys and assessments, renewable energy assessments, community building energy assessments and household retrofits. The purpose of these studies was to evaluate opportunities for cost savings, resource (water, energy) efficient homes, and a reduced carbon footprint for the village. Energy and water is interlinked, and the additional water survey was designed to help understand peoples' perceptions and attitudes to water.

3.1 Summary of findings

The survey participants were residents in a village in rural Sussex. The village is located close to a river in an area of natural beauty and important wildlife. Water for recreation is essential in this community e.g. for anglers, nature walkers etc. The river is highlt valued by the community because increases the affordability of things that add value to the community and influences their quality of life, such as leisure activities. In times of low rainfall or water-shortages, the effect on the local environment due to lower water levels and lower rates of flow as well as the visible levels of the local reservoir are noticeable. The river is also an important abstraction source of water to this community and neighbouring areas. This village is close knit and quite forward thinking, with many residents embracing sustainable practises individually and collectively.

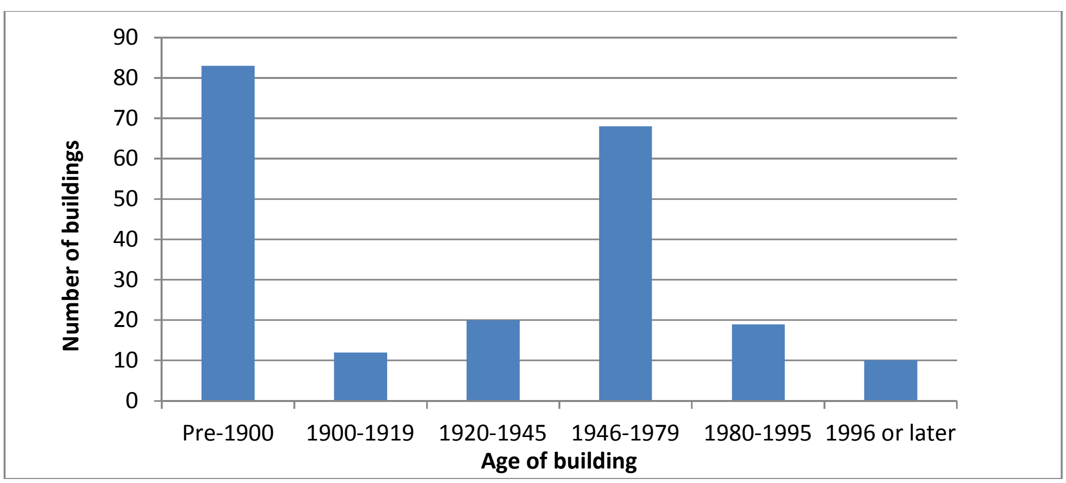

Figure 1 Age of respondent's properties

218 households took part in the survey; the total population according to the 2001 census is 1411. Data from the survey were inputted into a spreadsheet and further analysed in SOFA, an open source statistical package. User comments are presented in quotes and italics. With regards to the dwellings, questions focussed on ownership, the age of the building, type and size of property, and evaluated perception, attitudes, knowledge and trust. Further questions were asked about electricity, general heating and water heating systems, and if any renewable energy technologies are present. This information was further analysed to correlate with water questions. Of the 218 households that responded, 76% of the household residents owned their own properties, with 24% renting. 30% of households have children 16 years old and younger. The mean age of residents is 59 years old. 69% of household residents are 50 years old or older. It was found that 39% of the respondent's homes were built prior to 1900 and only 5% were built from 1996 onwards. In total, 86% were built prior to 1980. Of these, 53% of the homes are detached properties (Figure 1).

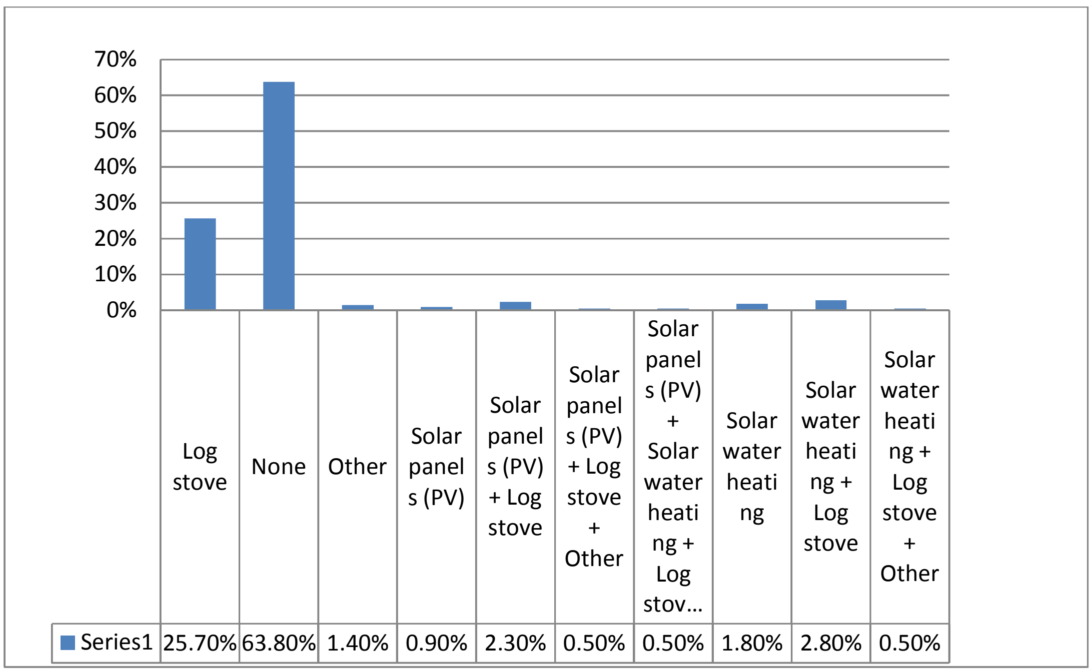

Figure 2 Renewable energy sources used by respondents

"Save water, save energy" is a phrase that is often used to encourage water users to be efficient. It was therefore important to assess the energy provisions in the dwelling and if there is any correlation between this and water consumption and behaviours. It was found that those with sustainable energy provisions had a higher propensity to save water or is willing to do so. 36% of homes use a renewable energy source for heating, of which 89% have a log stove. Of these; 36% having a renewable energy source, only 7% felt they were unable to save water. For 64% the main heating fuel is oil with a further 6% utilising oil in addition to other heating fuels. Economy 7 is the main heating fuel for 11% of households. 38% had wall insulation with a further 28% being unsure. Only 6% did not have any roof/loft insulation with 28% being unsure due to no access. 41%

insulated their boilers, with a further 57% being unsure due to access. Many rented householders were unsure of the insulation levels and other general building questions.

3.1.1 The water user

When asked about their water supply: 40% considered the reliability of water as the most important factor, 23% chose drinkable water for potable use only, 12% chose drinkable water for all uses, 8% considered the environmental impact as their most important factor (with a further 5% stating this as an additional factor), 5% felt the price of water was the most important single factor. For some householders more than one option was chosen. 5% considered the reliability of water and for potable as equally important. An elderly homeowner commented that she was undecided how to respond when considering the need for high water usage for non potable use:

> *"I have a fundamental problem with the philosophy of providing high quality water for general use. Probably 90% of the product is discarded as waste. Guess domestically less than 5% of water is used for drinking."*
>
> *"Modern living demands water for washing machines, dishwashers, bathing/showering, flushing, car washing, window cleaning, gardening, car washing plants, irrigation of sports venues etc....AND thousands of new houses called for by Government. Do we really need high quality water for these uses?"*

Householders' views on saving water were encouraging (Figure 3): 70% already save water but feel they could probably do more, 13% are already doing all they can to save water, 7% do not or choose not to save water, 1% is inhibited due to their lifestyle and culture, 3% felt that they can't do any more due to financial constraints, 6% wish to know more about how to save water. When asked the general question if they are able to save water when they want to, overall 86% of households feel they can.

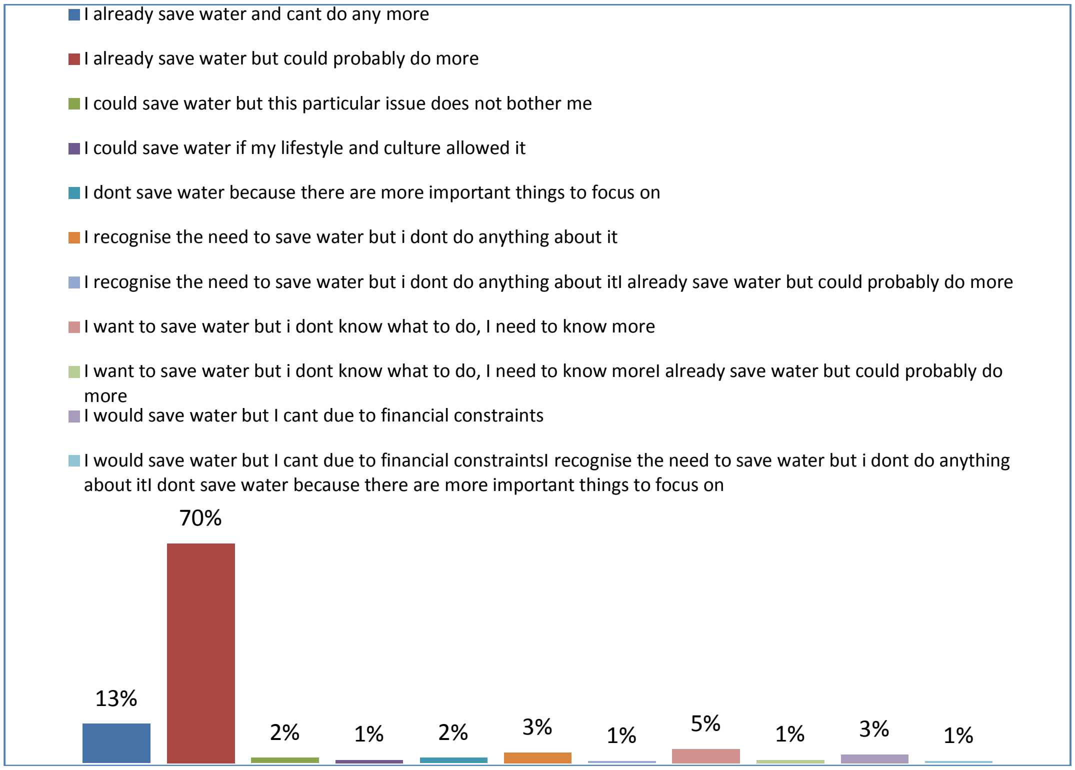

Figure 3 Respondent's attitudes to saving water

3.1.2 Cost

The response on cost factors varied depending on the perceived effect on household income. 84% of respondents said they would be very worried if the cost of water supply greatly increased and households are faced with water bills of at least 10% of household income. 12% would be a little worried, 2% would not be worried, and for 2% it is already at least 10% of their income. However, with regards to important factors regarding water efficiency, discussed later in this section, only 5% felt the price of water was the most important single factor.

3.1.3 Fixtures and fittings

The cost of retrofitting water-efficient fixtures and fittings, especially where current fixtures and fittings are usable, were also explored in the survey.

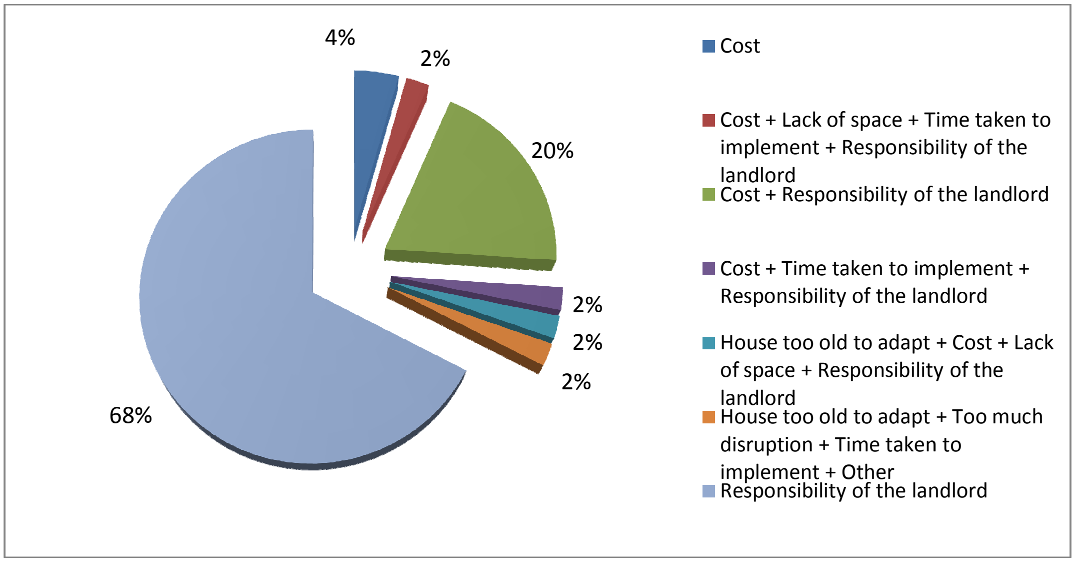

Figure 4 Response from renting respondents

Factors that may affect households changing the fixtures or fitting in the house are understandably influenced by whether the property is owned or rented. 68% of renting respondents felt changing fixtures and fittings are the landlord's responsibility as cost is a major factor (Figure 4). Others also felt the time taken and disruption involved were factors, and for a few the lack of space is a problem. 42% of homeowners gave cost as the main factor affecting changing the fixtures and fittings in their home. Up to 20% felt the disruption and the time taken to implement were additional factors affecting their decision to make changes. Some residents had recently renovated and others felt their houses are too old to adapt or there is a lack of space. Overall, 83.9% majority mentioned cost as at least one of the factors that affect their decision to retrofit fixtures and fittings in order to improve water efficiency in the home. However, a small number of respondents commented that more new products are not necessary to save water, stating that it is more beneficial if people change behaviours. People can have shorter showers and the simple use of flush bags in toilets without dual flushing systems is a big water saver.

"We don't need more products to save water; we just need to use less"

With 39% of the buildings built prior to 1900 and in total 86% built prior to 1980, it was found that many respondents considered this a major delimiting factor in achieving water efficiency through technological retrofits. The following summary shows the correlation between the age of buildings and the factors that affect the adoption of water saving technologies in homes in the village:

- Pre 1900 (39% of buildings): Cost as the greatest factor. A small percentage felt the houses are too old to adapt. Others recently renovated and are not willing to incur the further costs and disruption of renovating again.
- 1900-1919 (6% of buildings): Cost and the building too old to adapt were the major factors.
- 1920-1945 (9% of buildings): Cost was the major factor

- 1946-1979 (32% of buildings): Cost was the major factor. Time taken to implement and too much disruption also being important factors.
- 1980-1995 (9% of buildings): Cost and the disruption were the main factors.
- 1996 or later (5% of buildings): Most owners answered that the houses are still relatively new and also cited costs as a factor if changes to be made.

3.1.4 Knowledge and availability of information

On the knowledge and information questions, 18% respondents agree that the greatest motivator in encouraging water efficiency is knowledge, not information, and when chosen in combination with other motivating factors this increased to 31%. Only 17% of respondents stated that an increase in the cost of water would motivate them to be more water efficient. However, respondents also agree that having more consumption information on water bills (10%), having a water meter fitted (12%) and also drought conditions (7%) can also serve as *useful reminders*. It is also worth mentioning that there was a group of respondents, about 3%, who are simply not interested in being water efficient at home. Some positive comments from respondents when asked what it will take for them to embrace water efficiency in their home include:

> *"I do my best already", "We try to now", "I embrace it already"*
> *"I am efficient", "I have a meter and we are careful"*

Opinions differed when asked who to trust to provide advice on water efficiency products. Many respondents gave more than one answer. Where *only one* answer was chosen, responses were as follows: Independent organisations and NGOs (33%), the Water Company (11%), The Government (7%), Installers and fitters (4%). Where *more than one option* was selected: Trust in Government advice increased to 15% with support from mainly independent organisations and NGOs, and the water companies. Where other combined options and the Government was chosen, trust increased to 21%. Where independent organisations and NGO's were chosen in combination with other options, trust in them raised to 62%. Installers and fitters opinions were considered more trustworthy when chosen in combination with others, increasing to 20%. Trust in water companies increased with support from installers and fitters, as well as from independent organisation and NGOs to 32%. Manufacturers (2%), media (2%), publications (1%) and 'other' (4%) were chosen by a few as individual options but were mostly considered in combination with various other options.

The role of water companies in promoting water efficiency was not considered favourable by some respondents. One respondent commented that:

> *"...when water companies repair leaks instead of paying shareholders"*

Others comments are summarised below:

> *"Definitely not the water company!"*
> *"Re-nationalize the water companies and fix main leaks".*

Two respondents were specific in their response, stating that they had no trust in any of the options, as extent making a profit was more important, than saving water. However, another respondent felt he trusted all, but to varying degrees and in different respects. The *Which* Magazine was mentioned by two respondents as well as independent websites through one's own research. A local resident committed to conservation, water and energy efficiency was also mentioned as a trustworthy source.

4 Discussion

The study community is considered a forward thinking community with the majority of households are positive about being energy and water efficient. Research findings were to a large consistent with those reported in existing literature. For instance, there was the relatively low sensitivity of residential water demand to price changes (Hurd 2006). Where the water bill is not a large proportion of the household budget, small changes in pricing can often go unnoticed except by high users (Graymore & Wallis, 2010). This study confirms this finding as the data showed that the cost of water, and even up to 10% increase in tariffs, is not sufficient to influence a significant water efficiency response. However, the cost of replacing fixtures and fittings was considered more important. Responses also varied between respondents who owned their homes or were renting. This suggests that empowerment, the capacity or ability to effect a change, may influence water efficient behaviour and response. This confirms findings from previous studies (e.g. Clarke & Brown, 2006; Adeyeye & Piroozfar 2012). Compared to previous research by Carlsson-Kanyama *et al*, (2005), there was insufficient evidence to make correlations with detached houses and elderly residents with regards to clear attitudes towards water efficiency.

Respondents from this community, majority of who were aware of abstraction practises on their local river, were concerned about the reliability of their water. To this end, majority confirmed that potable water supply was not essential for all uses in the home. The results for whom to trust to provide advice on water efficiency differed greatly; for many a message from a source likely to benefit financially leads to mistrust. Also, respondents agree that the greatest motivator in water efficiency is to know more – confirming the importance of knowledge capacity in changing behaviour.

5. Conclusions

With the majority of respondents replying that the greatest motivator in water efficiency is knowledge, there is the need to focus water efficiency policy and strategies on increasing the knowledge capacity of water users and not just providing more information. For users to respond positively to water efficiency measures the message should be relayed by what they perceive to be a trustworthy source. Where communities are willing to engage in resource (water, energy) efficiency programmes, they should be encouraged and empowered, for example, by providing the right level of knowledge and investment support for the community to take ownership of their change process. One route to this is to integrate water efficiency plans and strategies in neighbourhood action plans.

Technological solutions are one step to improving the water footprint of a community but they do not necessarily impact on behaviour. Clear strategies to involve the entire community in water efficient practises during domestic and non-domestic activities need to be identified to encourage water efficiency from the grassroots.

6. Acknowledgements

The Water Efficiency in Buildings Network and its members and Defra for funding the project, Waterwise – particularly Joanne Zygmunt, Community 21, and community participants with special mention to the Barcombe Energy Club.

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A Study of Simulated Flood Control Using Urban Street Blocks and Raft Foundation Space

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Abstract
The overdevelopment of urban has decreased the city's ground permeability and increased its surface runoff. Moreover, global warming and climate changes have increased the frequency of typhoons in Taiwan every year, causing record-breaking rainfall, and rendering Taipei City's existing flood control systems unable to meet basic flood control safety requirements. To effectively and cost-efficiently increase flood control capability in Taipei City, this study proposed using idle raft foundation space in existing buildings as flood storage in urban flood control systems. This will reduce peak runoff in urban street block during typhoons, thus reaching the goal of urban flood control. This study selected a certain street block and building in Taipei City and 47 typhoons as research objectives, and constructed a Street Block-Raft Foundation flood control model (SB-RF model). First, the optimal solution for reducing peak runoff for the 47 typhoons was obtained using Linear Programming. Data from the optimal solution and Back Propagation Neural Network were then used to simulate the SB-RF model flood control. Results can be used as reference for urban flood control for Taipei City during typhoon season.

Keywords
Street block, building raft foundation, typhoon, urban flood control, Linear programming, Back Propagation Neural Network

1. Introduction

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 an average of 2-3 typhoons would assault Taiwan. Taipei City is located in the Taipei basin in northern Taiwan, with low-lying land and surrounded by tributaries of the Tamsui River Basin such as the Keelung River, the Dahan River and the Xindian River. During a typhoon assault, the tributaries in the mountain regions surrounding the basin frequently flood over due to heavy rain, and threaten the Taipei City area. To prevent the city from being disastrously submerged by floods, floodwalls and floodgates had to be erected on both banks of the rivers. Moreover, to prevent flooding in urban areas, the city has to depend on pumping stations of flood control facilities to drain the heavy rainfall from the city into rivers outside the floodwalls. However, factors such as global warming and weather changes have resulted in typhoon precipitation frequently exceeding the once a century standard expected by the Taipei City flood control engineering design. Hence the existing urban flood control facility in Taipei City, namely the drainage capacity of the pumping station, is dangerously inadequate. The research proposed using the space capacity of idle raft foundation in existing buildings as retention pool for urban flood control facilities to reduce peak runoff during typhoons and storms.

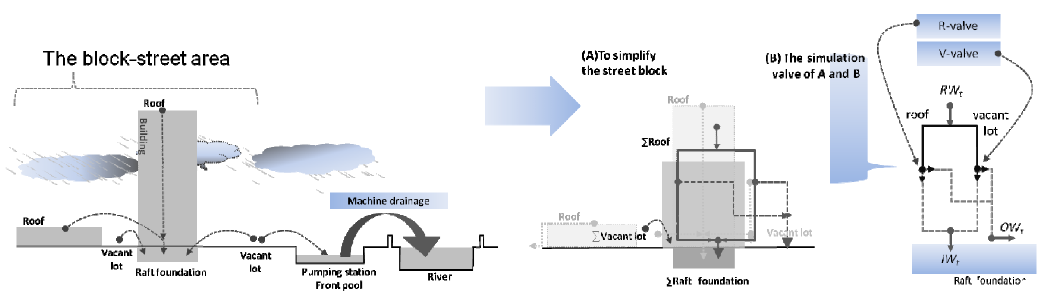


Fig.1 Conceptual diagram of SB-RF model of flood control

The raft foundation is a type of building foundation generally used in high-rise or large buildings. Other studies also showed that in Taipei City, raft foundation depths of buildings more than 12 stories tall range from 1.6-2.2 meters deep. To maximize the flood control advantage of raft foundation space capacity, this study proposed the Street Block Raft Foundation as a method of flood control. In other words, to increase rainwater retention, the rainwater collection area is expanded to include entire blocks of rooftops and vacant lots. In the Block Street-Raft Foundation (SB-RF) model of flood control, the following two assumptions are made: (1) Rainwater from block raft foundations are collected or released from either rooftop systems or vacant lot systems. As illustrated in Figure (1)~(A), the hypothetical rainwater drainage pipes collect water into the raft foundation or release water out into the block street; and (2) as shown in Figure (1)~(B), the hypothetical rainwater drainage pipes have hypothetical flow control valves, R-valve and V-valve, that respectively adjust the amount of rainwater collected and released. Hence the goal of this study was to predict the flood control operations of the hypothetical rainwater control valves during typhoons and storms.

2. Research Background

2.1 Literature Review

In 2008, the author presented a study named "Urban Drought Prevention Model by United Allocation with Reservoir and Building Raft Foundations for Storage", where building raft foundations were used as miniature reservoirs for collecting rainwater from rooftops (the collected rainwater were for non-bodily consumption such as flushing toilets). In coordination with Taipei's main Feitsui Reservoir, these miniature reservoirs use Linear Programming to optimize water distribution to resolve some of the urban water shortage problems. This research is a follow-up on the outcomes and recommendations of that study.

In terms of pumping station forecasting models, Cheng and Huang's (2008) paper on The Application of Fuzzy Control on Rain Water Pumping Station Monitoring System pointed out that in traditional pumping stations, switches on the pump systems were generally controlled by water level. However, during heavy rainfall in typhoon season, the forebay changes rapidly due to unpredictable intensity of weather and precipitation factors such as inflow volume and the amount of time for rainwater to reach the pumping station. Therefore using the Fuzzy Control Theory, this research used actual operation records and data to conduct a simulated analysis to improve the operations of pumping stations, and showed that the fuzzy control method is more practical than traditional fixed water level method.

In addition, in the study Counter-propagation Fuzzy-neural Network for City Flood Control System by Chang et al (2008), the counter-propagation fuzzy-neural network was used to forecast the number of pumping systems required by the Taipei City Yu-Cheng pumping station during typhoons and storms. The input layer of the neural network comprises 6 neurodes, namely the current and first five minutes of rainfall and forebay water level in the pumping station, current number of gate closures, and number of pump systems in operation. The output layer comprises one neurode, namely the number of pump systems in operation in the next five minutes. Such simulated results are relatively accurate.

2.2 Research objective

2.2.1 Researched area

As shown in Figure (2), the area studied in the Street Block Raft Foundation flood control model included a certain block containing both commercial and residential uses in the east side of Taipei City. The east and north sides of the block are next to 12 meters of road, the west side is connected to 40 meters of road, and the south side is next to 20 meters of road. Besides a 12-story office building on the east side of the block, there is a 5-story residential apartment building. The 12-story office building has a raft foundation. The block area is 6153.82m^2, the rooftop area is 4453.46m^2, the vacant lot area is 1700.36 m^2, and the raft foundation capacity is 1300.02m^3. Another street block studied is located at the far end of the urban water catchment area whose pumping station is right next to the Keelung River.

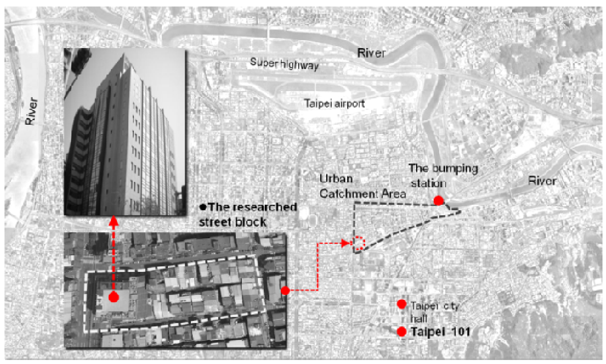


Fig .2 Schematics of the research area for the SB-RF flood control model.

2.2.2 Typhoon Forecast

Table 1. Typhoon precipitation data

Typhoon name	Time of attack	The max Accumulated precipitation of hour (mm/hr)	The total accumulated precipitation (mm)
●SHIRLEY	1960/7/31	212.2	25.8
●TRIX	1960/8/7	227.2	43.9
●AMY	1962/9/11	234.7	30.1
●GLORIA	1963/9/10	440.4	37
●TESS	1966/8/15	222.1	44.7
●ELAINE	1968/9/28	309.6	26.6
●ELSIE	1969/9/10	309.8	35.1
●FLOSSIE	1969/10/2	287.6	18.2
●WILDA	1970/8/11	237.3	26.1
●FRAN	1970/9/6	250	38.6
●SUSAN	1972/7/13	217.6	54
●WINNIE	1972/8/1	250.8	20.8
●BETTY	1972/8/16	225.4	16.2
●JEAN	1974/6/18	275.9	43
●BILLIE	1976/8/9	274.2	38.5
●VERA	1977/7/30	230.5	26
●AMY	1977/9/22	322	107
●ORA	1978/10/12	217	15.5
●IRVING	1979/8/14	219.5	21
●MAURY	1981/7/19	341.9	65
●CLARA	1981/9/20	212.1	46
●ANDY	1982/7/28	214.3	22.5
●CECIL	1982/8/9	205.8	37
●FREDA	1984/8/6	262.3	26
●HOLLY	1984/8/14	204.7	23
●WAYNE	1986/8/22	239.5	25
●ABBY	1986/9/19	213.5	27.5
●LOLA	1989/7/27	257.7	38
●SARAH	1989/9/10	229	26
●ROBYN	1990/7/9	284.8	58.5
●ABE	1990/8/29	338.5	47.5
●DOT	1990/9/3	282.4	23.5
●NAT	1991/9/22	231	53.4
●ZEB	1998/10/15	502.9	63.5
●BABS	1998/10/25	305.2	37
●XANGSANE	2000/10/31	333.4	32
●TORAJI	2001/9/1	197.7	42
●NALY	2001/9/17	852.5	76
●LEKIMA	2001/9/23	243.3	43
●AERE	2004/824	308.5	30.5
●HAIMA	2004/9/10	487	60.5
●NOCK-TEN	2004/10/24	219.5	28.5
●HAITANG	2005/717	228.5	35
●MATSA	2005/8/4	298.5	27.5
●SINLAKU	2008/9/13	470.5	44
●JANGMI	2008/9/27	204.2	19.5
●MORAKOT	2009/8/12	242.7	78.5

For data on typhoon precipitation, this research collected precipitation data of 407 typhoons occurring between 1960-2011 from Taipei rainfall stations. Based on the scale of the Street Block-Raft Foundation used in this study, if the accumulated precipitation from a single typhoon is less than 211.3mm, then it conforms to the raft foundation capacity and the entire typhoon precipitation can be collected. Accordingly, as shown in Table 1, each of the 47 typhoons had accumulated precipitation greater than 211.3mm, and calculating 36 hours of hourly precipitation data for each typhoon. Furthermore, on September 17, 2001, Typhoon Naly swept across Taiwan with an overwhelming amount of rainfall and causing heavy damages in Taipei City.

As shown in Figure (3), the accumulated precipitation data from the 407 typhoons were plotted on the x-axis and maximum hourly precipitations were plotted on the y-axis to obtain the distribution map of the 407 typhoons. Among the typhoons, the study further delineated and classified 47 typhoons with more than 211.3mm of accumulated precipitation. These were 4 Type I typhoons, represented by Typhoon Naly; 1 Type II typhoon, represented by Typhoon Sinlaku; 12 Type III typhoons, represented by Typhoons Nat and Tess; and 30 Type IV typhoons, represented by Typhoons Fran and Flaine.

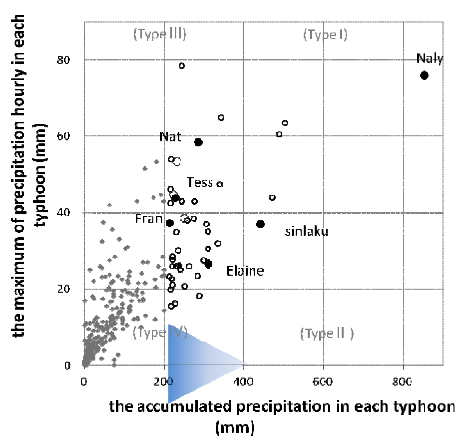


Fig .3 Descriptive diagram of typhoon data

3. Methodologies

3.1 Linear Programming (LP)

What is linear programming? Simply defined, it is the study of linear optimization. Standards for Linear Programming include three components, namely decision variable, objective function and constraints.

In this case, the decision objective (maximum or minimum value) was transformed into the objective function of the linear function; limitations of the various decision variables resources were transformed into the constraints of the linear function, which then constituted the region of convex set of feasible solutions. Last, in obtaining the linear programming solution, the set of optimal decision variable values was found in the endpoint of the feasible solutions region. Hence the constraints of the various conditions were satisfied while achieving the minimum or maximum value of the objective function.

3.2 Back Propagation Neural Network (BP)

As shown in Figure (4), the Back Propagation Neural Network (BP) structure constitutes the input layer, the hidden layer and the output later, with each layer comprising numerous neurodes. The input layer and output layer represent the input value (X_n) and output value (Y_k), respectively. Their respective number of neurodes (N, K) is determined by the type of problem. The number of neurodes in the hidden layer (L) is often determined by trial and error while the number of hidden layers is incremental according to the complexity of the problem. The network neurodes among the various layers are linked according to related weights ($W_{i,}$ W_j), and the input value (X_n) is input directly into the hidden layer via the input layer. Then as shown in Figure (4)-A, the subsequent weighted accumulation was transformed by the activation function to obtain the output value (Y_k) as shown in Figure (4)-B; and in the same way, transferred to the output layer. The frequently used activation function model, such as the Sigmoid function, is shown in Figure (4)-D.

As shown in Figure (4)-C, since the activation function of the S-function can be differentiated, the steepest descent method can be used to correct the weight and partial weight (W_i, W_j) during the training process. Hence error is successively reduced, thereby achieving the goal of training. Therefore the BP is a form of supervised training. By continuously adjusting the weight and partial weight of the network during the training process, the discrepancy between the network output value ($Y_{k,}$ Output) and the target value can be reduced until a tolerable error range is achieved. There are many standards for determining this error range, but generally the Root Mean Square Error (RMSE) is used, where the smaller the RMSE value, the greater the accuracy of the predictive value.

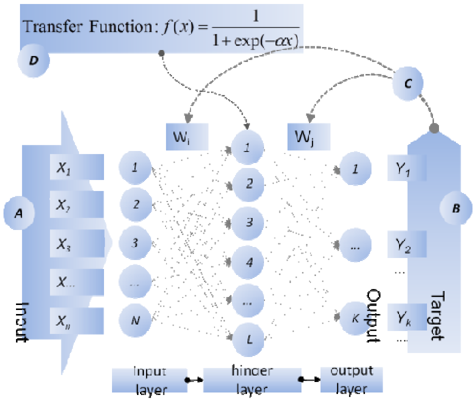
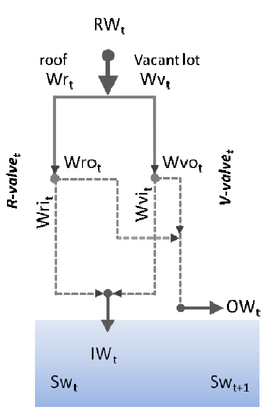


Fig. 4 Neural network schematic

4. Operation and Validation

4.1. Street Block-Raft Foundation Flood Control Model

Based on the Linear Programming flood control model, the research also proposed converting some other concepts into linear programming objective function and constraints. Conversion into objective function: the lesser the total runoff (Ow_t) from the flood control base, the better. The greater the flood storage (Iw_t) of building raft foundation and accumulated flood storage of raft foundation, that is, the greater the (Sw_t), the better. Conversion into constraints: As shown in Figure (5), when rainfall is heavy (≤5mm/hr) during typhoons, rainwater in rooftops and vacant lots should preferably not be stored, but instead be directly drained out of the street blocks; on the other hand, during extremely torrential rain (≥15mm/hr), flood storage is preferable over direct drainage out of street blocks, while between the two conditions during torrential rain (between 5mm/hr and 15mm/hr), management is not restricted but based on objective function.



R-valvet :	*Rooftop rainwater flow control valve*
V-valvet :	*Vacant lot rainwater flow control valve*
RWt :	*Total street block runoff (before flood storage)*
Wrt :	*Volume of rainwater collected from rooftop*
Wvt :	*Volume of rainwater collected from vacant lot*
Writ :	*Volume of flood storage from rooftop*
Wrot	*Volume of water drained from rooftop*
Wvit :	*Volume of flood storage from vacant lot*
Wvot	*Volume of water drained from vacant lot*
IWt :	*Volume of street block flood storage*
OWt :	*Total street block runoff (after flood storage)*
SWt :	*Accumulated flood storage of raft foundation rainwater*

Fig 5. Diagram of SB-RF flood control model.

According to the above concept, a Linear Programming model is established for the SB-RF flood control, as shown below.

Objective function :

$$\sum Max : Rw - Ow_t + Iw_{..t} + SW_t .....(1)$$

Constrains :

$$Sw_t + Wri_t + Wvi_t = Sw_{t+1} .....(2)$$

$$Wri_t + Wro_t + Wvi_t + Wvo_t = RW_t .....(3)....(If \quad precipitation \geq 15mm/hr)$$

$$Wri_t + Wro_t - Wvi_t - Wvo_t \geq 0 .....(4)....(If \quad precipitation \leq 5mm/hr)$$

$$Wro_t - Wvi_t \geq 0 .....(5)$$

$$Sw_t \leq 1300m^3 .....(6)$$

$$Sw_t Wri_t , Wvi_t , Wro_t , Wvo_t \geq 0 .....(7)$$

4.2 The Peak-Flow Reduction Rate

This study also used the maximum (continuous) 6-hour rainfall peak-flow reduction rate as an evaluation index for the SB-RF flood control model. in every typhoon, the maximum accumulated rainfall is calculated continuously for 6 hours ($\sum RW_{t=1,2,3,4,5,6}$), and the flood storage capacity for the same period ($\sum IW_{t=1,2,3,4,5,6,}$) is calculated, where the peak-flow reduction rate=$\sum IW_t$ /$\sum RW_t$. Since the maximum (continuous) accumulated precipitation for every typhoon is adequate enough to represent the maximum peak value, the peak-flow reduction rate sufficiently explains the advantages of the SB-RF flood control model in controlling floods during each typhoon.

4.3 SB-RF flood control model - Results and Discussions

In this study, hourly precipitation data from the 47 typhoons were individually input into the Linear Programming for the SB-RF flood control model to obtain the optimal solution for each typhoon. Results were explained in two parts: (1) After street block peak-flow reduction; and (2) water flow control valve value and rooftop water flow control valve value. Figure (6) indicates that in the Part (1) results.

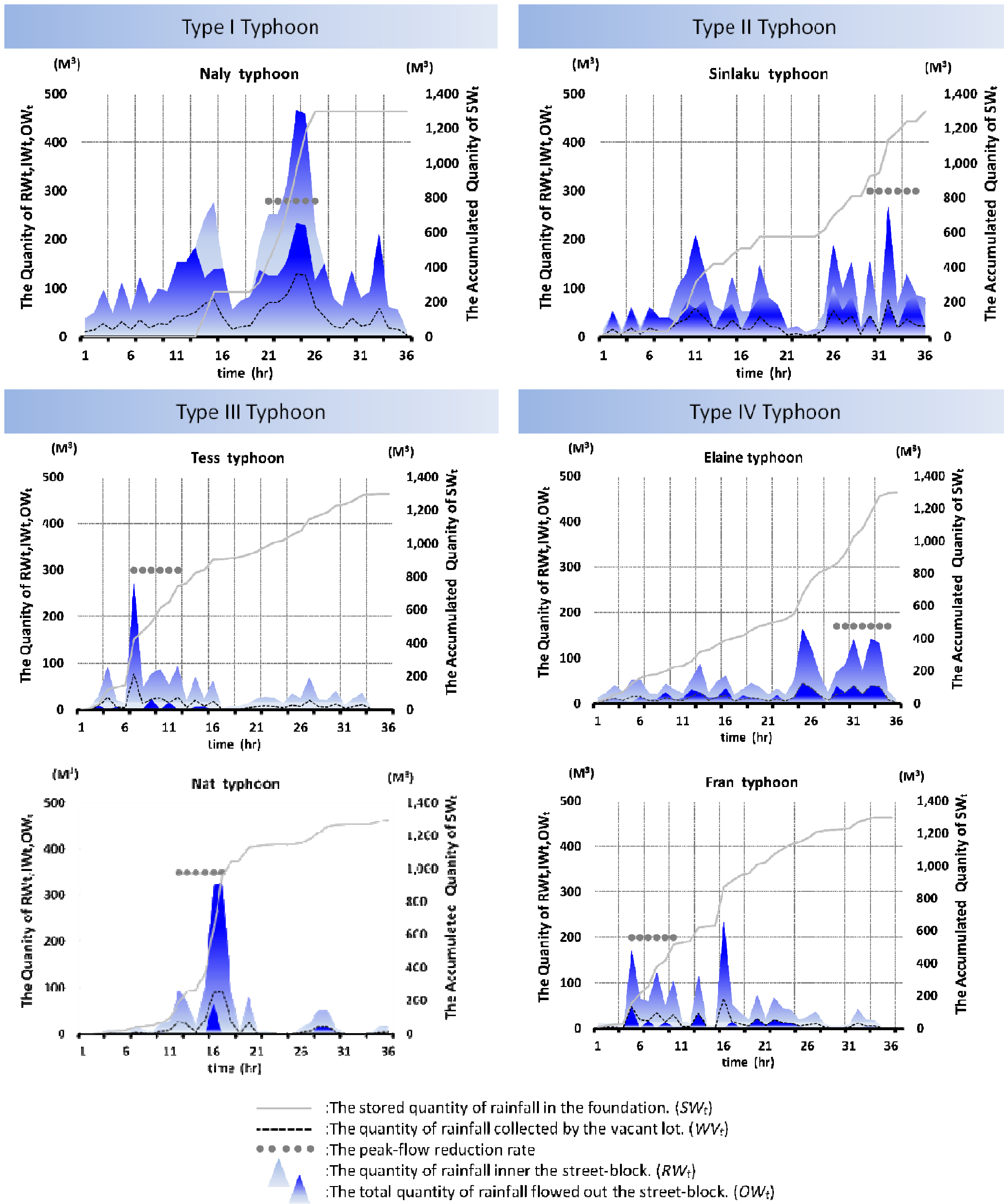


Fig.6 Diagram of calculation results for each representative typhoon in the SB-RF flood control model

As shown in Figure (7), the maximum (continuous) 6-hour rainfall peak-flow reduction rates for all 47 typhoons were also individually calculated. The peak-flow reduction rate distribution diagram clearly indicates that region (1) is the peak-flow reduction rate distribution for low precipitation Type III and Type IV typhoons, and has a reduction rate ranging from 100.0%~68.0%, and an average rate of 84.0%; and region (2) is the peak-flow reduction rate distribution for high precipitation Type I and Type II typhoons, where Typhoon Sinlaku showed a reduction rate of 58.9% while Typhoon Nari showed a rate of 50.0%.

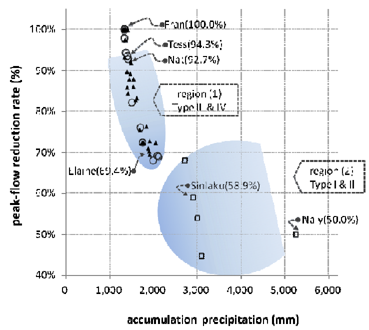


Fig. 7 Diagram of peak-flow reduction rate

Figure (8) shows the Part (2) results of rooftop(*R-valve$_t$*) and vacant lot (*V-valve$_t$*) rainwater control valve values for Types I, II, II, IV and all types of typhoons. Evidently, regardless of rooftop or vacant lot rainwater control valve, the values were discrete. The values of *R-valve* were concentrated around 1.0, 0.69, 0.62 and 0.0, the valve values of *V-valve* were concentrated around 1.0 and 0.00. Since values such as SW_t, RW_t, IW_t and OW_t were used as input value for forecasting, they were considered continuous values; the forecasted rooftop and vacant lot water flow control valve values (*R-valve$_t$*, *V-valve$_t$*) were the target value and considered discrete values. Hence, forecast accuracy were somewhat influenced, and categorical correction conversion was applied to the forecast output to increase the overall accuracy of the SB-RF flood control model.

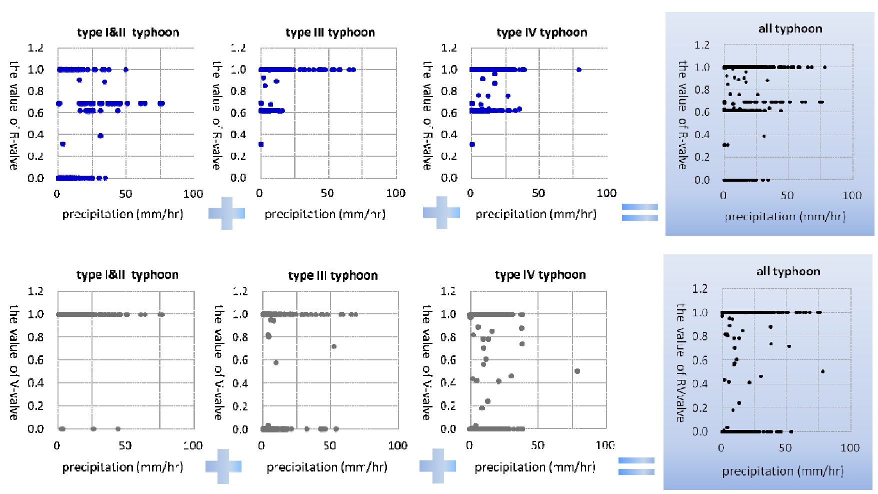


Fig.8 Diagram of *R-valve* and *V-valve* for different types of typhoons

4.4 Valve Operation Forecast

This research was structured on the Back Propagation Neural Network (BP). For the input layer, 11 neurodes were selected, namely SW_t ,RW_t, RW_{t-1}, IW_t, IW_{t-1}, OW_t, OW_{t-1},$R\text{-}valve_t$, $R\text{-}valve_{t-1}$ 、$V\text{-}valve_t$ and $V\text{-}valve_{t-1}$. For the output player, 2 output neurodes were selected, namely target values $R\text{-}valve_{t+1}$ and $V\text{-}valve_{t+1}$. The number of neurodes for the hidden layer was determined by numerous calculations, and according to minimum Root Mean Square Error (RMSE), 17 neurodes were selected for the hidden layer. After constructing the framework, a total of 1692 pieces of data such as rainfall for the 47 typhoons were divided into three parts, namely training, validation and testing. Data for training comprised 1440 pieces of data from 40 typhoons, such as rainfall; training validation data comprised 72 pieces of data from 2 typhoons, such as rainfall; and testing data comprised 108 pieces of data from 5 typhoons(e.g. Elaine, Fran, Tess, Nat and Sinlaku), such as rainfall.

4.5 Forecast Results and Discussions

Figure (9) shows the $R\text{-}valve_{t+1}$ and $V\text{-}valve_{t+1}$ of simulated forecast of the training, validation and testing stage. In terms of target value and Correlation coefficient (R) of the output value, the $R\text{-}valve_{t+1}$ of the training, validation and testing were R=0.86804, R=0.75227 and R=0.7514, respectively; and the $V\text{-}valve_{t+1}$ of the training, validation and testing stage were R=0.65985, R=0.62248 & R=0.61072, respectively, Figure 10.

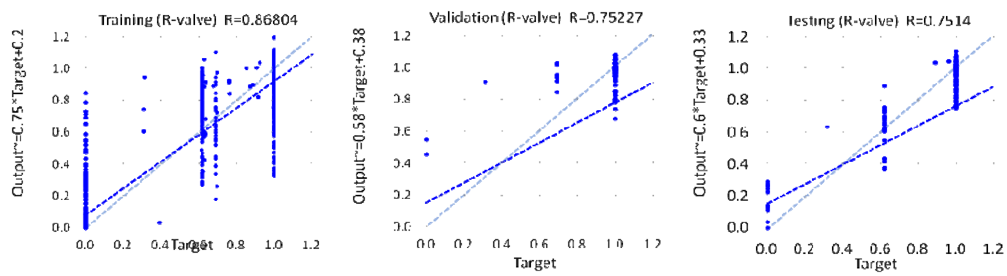


Fig.9 Results of $R\text{-}valve_{t+1}$ of the training, validation and testing stage.

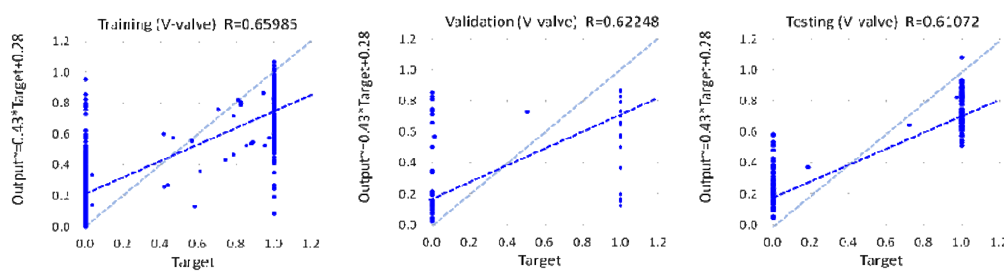


Fig.10 Results of $V\text{-}valve_{t+1}$ of the training, validation and testing stage.

Evidently, regardless of the *R-valve*$_{t+1}$ or *R-valve*$_{t+1}$ of the training, validation and testing stage, the results were not ideal. The reason might be the use of continuous input value to forecast discrete target value, as previously mentioned. To improve the overall forecast accuracy of the SB-RF flood control model, this study constructed a *R-valve*$_t$ and *V-valve*$_t$ forecast output conversion table (Table 2) based on the results shown in Fig (8).

Table 2. Forecast output conversion table for *R-valve*$_{t+1}$ and *V-valve*$_{t+1}$.

R-valve$_t$		*V-valve*$_t$	
output值	converted output值	output值	converted output值
1.2~0.75	1.0	1.2~0.6	1.0
0.75~0.65	0.69	0.6~0.4	0.5
0.65~0.35	0.62	0.4≤	0.0
0.35≤	0.0		

Last, Figures (11) and Figures (12) show the forecast output, converted output and target values of the *R-valve*$_{t+1}$ and *V-valve*$_{t+1}$ of representative Typhoons Elaine, Fran, Tess, Nat, and Sinlaku. The differences between the output and target values were compared with the differences between the converted output value and target value. The calculated RMSE between the output values and target values of *R-valve*$_{t+1}$ is 0.1251. The RMSE between converted output values and target values is 0.0506. The RMSE between the output values and target values of *V-valve*$_{t+1}$ is 0.2834. The RMSE between the converted output values and target values is 0.1511, showing that the converted output values clearly had forecast accuracy

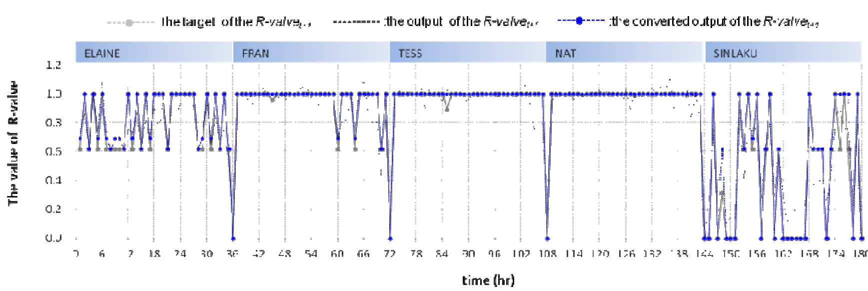


Fig.11 The forecast output value, converted output value and target value of the *R-valve*$_{t+1}$.

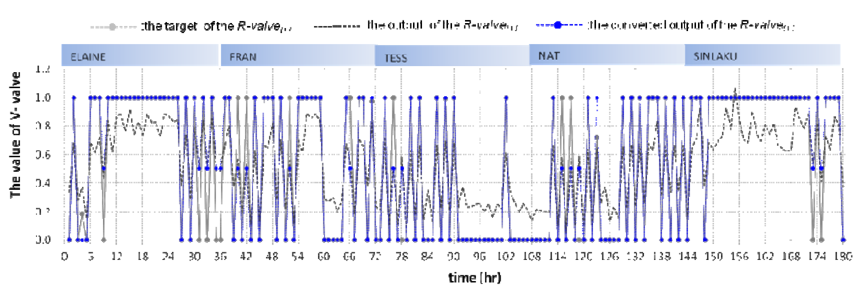


Fig.12 The forecast output value, converted output value and target value of *V-valve*$_{t+1}$.

5. Conclusions and Suggestion

This research collected data from 407 typhoons assaulting Taiwan between 1961 and 2011. In determining the flood control capability of the street block model, the study found that 360 typhoons with individual accumulated precipitation of less than 211.3mm did not result in any surface runoffs. The study also found that among the 47 typhoons, the average peak-reduction rate was 84.0%, thereby indicating that the flood storage ability of the Street Block-Raft Foundation flood control model was a relatively effective urban flood control for urban. This research used data forecasted from a neural network, that is Linear Programming calculations, rather than data observed from actual operations. These data were discrete values, which increased the difficulty of forecasting. Therefore categorical conversion was applied to increase the accuracy of the forecast.

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Investigation of outlet detritus accumulation at two different siphonic roof drainage sites

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Abstract

The number of siphonic rainwater drainage system installations has steadily risen since their development in Finland during the 1960s as an efficient and material-saving technique, especially for buildings with exceptionally large roof areas. The system offers numerous favourable features that traditional gravity-fed systems do not - through having the ability to become de-pressurised, resulting in the removal of greater quantities of water at the design rainfall intensity. With changes to the UK climate forecast i.e. expected prolonged dry weather periods and higher short-duration rainfall intensities, siphonic system performance and operation may also change, thereby placing greater importance on the design methodology adopted for future systems.

This paper presents the results of an ongoing investigation into the importance of outlet maintenance and the effect of detritus accumulation on the operational performance of siphonic rainwater systems. A summary of outlet accumulation profiles at two different sites is presented and compared with weather data. Findings that highlight how weather conditions affect siphonic operation are noted.

Keywords

Detritus, siphonic outlet, site monitoring.

1 Introduction

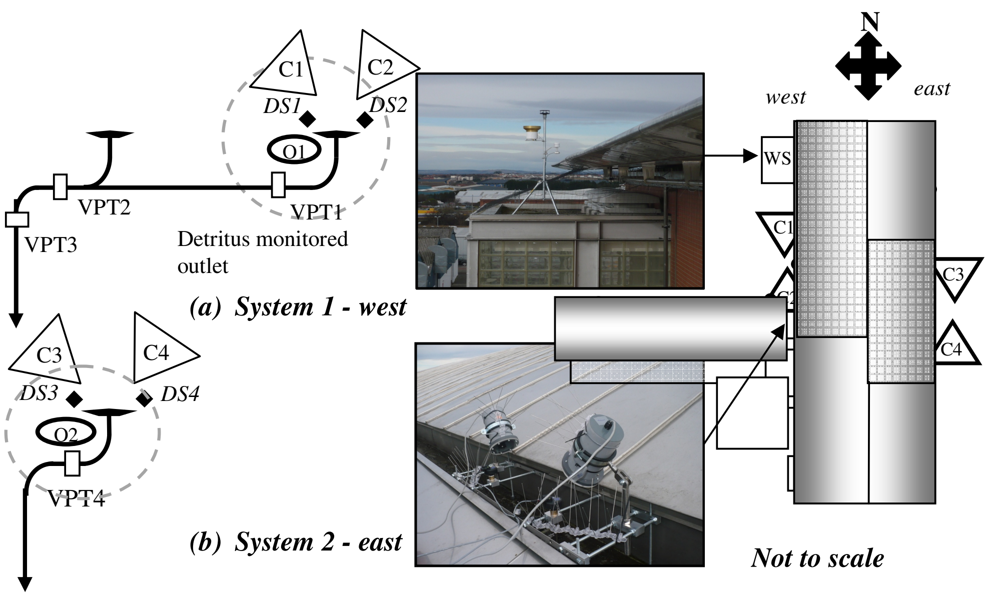
A rigorous maintenance and cleaning programme for all rainwater drainage systems is necessary in preventing outlet blockages(1). For siphonic systems, this is vitally important to ensure that leaf guards remain in position and are clear, otherwise the baffle or pipework may become blocked, possibly resulting in exceedance of gutter depths or, in extreme cases, pipe implosion. To understand detritus accumulation at siphonic system outlets, a novel monitoring programme has been undertaken, whereby environmental parameters have been recorded in conjunction with visual images of selected outlets. Gutter depths and pipework pressures were also noted. In this paper, detritus accumulation at outlets is categorised, graphed and mapped against measured environmental parameters, thus highlighting relationships between relevant variables.

2 Site monitoring

The onsite monitoring has two main aims; firstly, the identification of detritus material types/quantities, and how these are influenced by different weather parameters, and secondly, to investigate how outlet accumulation affects roof drainage performance.

2.1 Site 1: National Records building

The National Records building is owned and maintained by the Scottish Government and is located approximately three miles from Edinburgh city centre. There are a scattering of approximately 30 trees on this site, the closest being around 5 meters from the building. There are no structures directly adjacent to the building to shelter the site. The building comprises two roofs in a *'T'* shape layout. It has been observed that large flocks of birds (typically pigeons and gulls) roost on the roof(2).



Denotes:
A1 Area 1 (607m^2) **A2** Area 2 (311m^2) **C*** Recording camera **PC*** PC in roof void
VPT* Pressure transducer **O*** Detritus monitored outlet **DS*** Depth sensor
WS Weather station

Figure 1 - NRS, layout of monitored areas.

The (polished aluminium) roof selected for monitoring is the larger of the two and has an area of approximately 2094m^2 (see Figure 1). This area is drained, using box gutters, by five independent siphonic systems. Two of these have been instrumented and monitored. *'System 1'* is a two-outlet plate-baffle system on the west side of the building and serves a roof area of 607m^2. This system was selected as the index outlet (i.e. the outlet furthest from the downpipe) has a history of blocking, resulting in gutter pooling. *'System 2'* is a single-outlet plate-baffle system on the east side that serves a roof area of 311m^2. Each system comprises 50mm ID stainless steel pipework, and galvanised box gutters measuring 200 x 360mm.

2.2 Site 2: Ibrox stadium

Ibrox stadium has four main stands with two seated corner-stands. Three of the main stands use traditional gravity roof drainage systems. The fourth (front) stand, that employs siphonic rainwater drainage, has been monitored. The stadium is not sheltered by any trees or buildings.

The front stand has a roof area of approximately 5200m^2 which is served by two mirrored siphonic systems. Each drains half of the tin-clad roof (2600m^2) via valley gutters. Figure 2 shows, schematically, the monitored west half of the rainwater drainage system. There is no scheduled gutter cleaning programme for this site; rather outlets are cleaned upon inspection of the roof or when entrance to the roof void is required for other purposes. Gulls can occasionally be seen at the site.

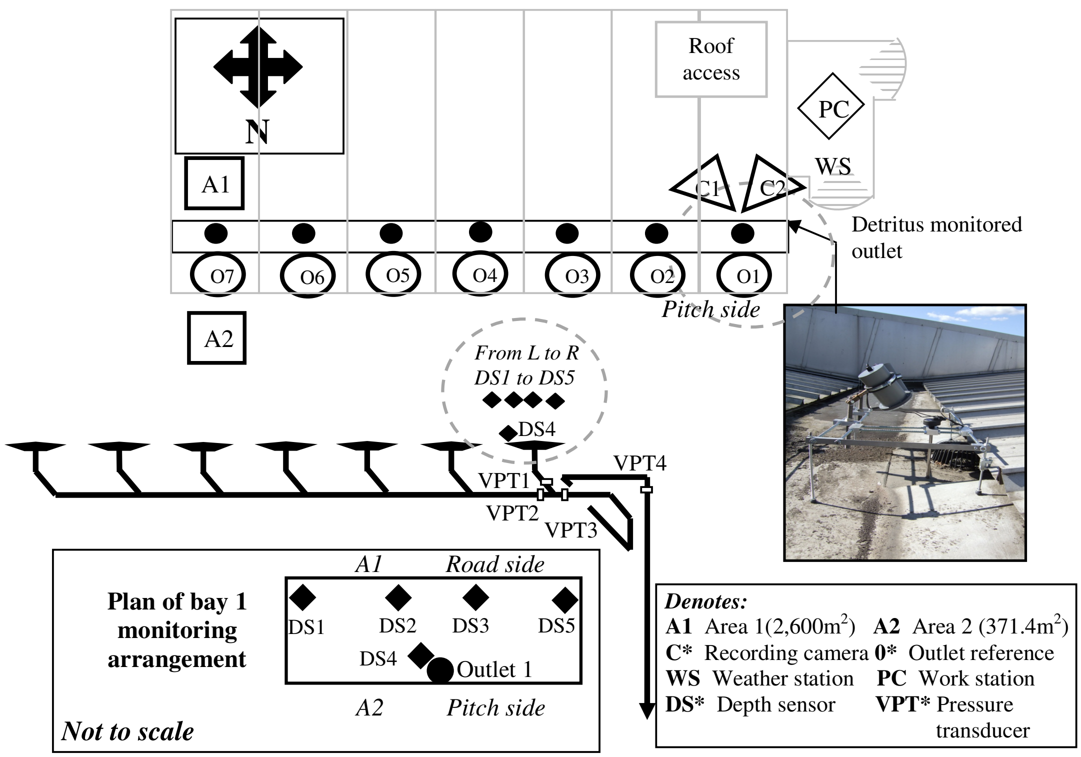


Figure 2 - Ibrox stadium, layout of monitored areas.

Seven cup-type baffles connect the valley gutter via HDPE pipework to a single 160mm (ID) downpipe that travels through the attached stairwell. Each of the seven outlets sits in an individual valley gutter, or *'bay'*, and drains an area of 371.4m^2. Bay 1 was selected as the outlet at which detritus accumulation would be monitored.

2.3 Monitoring apparatus and arrangement

Digital web cameras, built into weather-protected encasements, were installed at selected siphonic outlets to capture images of detritus accumulation at predefined time intervals. Camera images were recorded using a continuous 2-minute time lapse arrangement. File-names were given the format: Camera_YYYY_MM_DD_HH_MM_SS.jpg, thus providing an effective and efficient basis for finding specific images. This technique also allowed a mapping to corresponding weather station data and siphonic system measurements.

Three individual pieces of apparatus were included within the weather station and recorded five weather-related parameters:

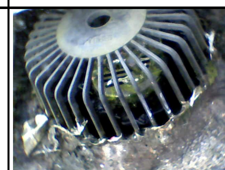
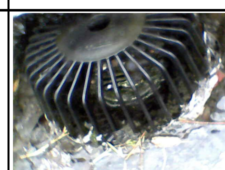
- precipitation;
- relative humidity and temperature;
- wind direction and velocity.

An aluminium tipping-bucket rain gauge with a resolution of 0.1mm was installed, along with a relative humidity and temperature sensor, and an ultrasonic wind sensor (measuring both direction and velocity). Pipework pressures were monitored using foil faced stainless-steel pressure transducers, and gutter depths recorded using capacitance-type depth sensors. The weather station apparatus was set up so as to record on a ten minute time-lapse sequence. The rain gauge worked independently from the rest of the weather station, in that once a rainfall event begins and the rainfall intensity exceeds 5mm/hr, the system acquisition programme prompts the initiation of data-capture from the pressure transducers and gutter depth sensors.

3 Site results: categorising the volume and type of detritus build-up

Figure 3 shows examples of images of detritus recorded at each site during the monitoring programme. The images indicate quite clearly, for the National Records building, 6 distinctive steps (in terms of outlet blockage), and 4 steps for Ibrox. These show the stages from a clean outlet to a worst-case blockage during the course of the year-long monitoring programme. Categorisation of blockage was determined by establishing a boundary between the blockage steps and then assigning each a dimensionless value from 0 to 6 (for NRS) or from 0 to 4 (Ibrox). This practice of assigning a number to identify the appearance of an object is referred to as the universal numbering technique(3). With applicability to the data reported herein, a *'0'* represents a *'clean'* outlet; progressively increasing to the worst case of *'very extreme'* accumulation with an assigned value of *'6'* for National Records and a '*4'* for Ibrox.

Figure 3 - Image categorisation of recorded detritus quantities.

Site 1 images	Approx coverage (%)	Plate reference	Scale value	Comment	Approx coverage (%)	Site 2 images
	0	a	0	Clean	0	
	≤8	b	1	Light scattering of detritus	≤2	
	≤20	c	2	Moderate side covering with detritus	≤6	
	≤32	d	3	Moderate/ Heavy, side covered with detritus	≤8	
	≤64	e	4	Heavy detritus levels, roof guard clear	≤10	
	≤90	f	5	Extreme detritus levels, little open area to outlet		
	≤100	g	6	V. Extreme detritus levels, no open area to outlet		

This categorisation of images allows pattern analysis of accumulation categories when mapped to measured environmental parameters; specifically daily rainfall depth (mm/depth).

4 Detritus build-up analysis

The following sections offer a discussion on detritus profiles for each system.

4.1 National Records building west-system (1)

Only three days after installation of the recording equipment, on the 8th March 2010, a scheduled gutter cleaning took place. This was fortuitous as it resulted in the identification of a benchmark *'ideal'* condition. The first incident of interest (see Figure 4) started on the 22nd May 2010 when an event of 5.92mm/hr increased the blockage categorisation to '*heavy'*. Detritus consisted of approximately four white feathers, birch leaves, and black solidified sediment. Gutter pooling did not occur on this occasion as the water was still able to pass through the detritus build-up. On the 20th July, an event of 6.65mm/hr occurred at 15:52:16 increasing the build-up to an '*extreme'* level; after which gutter depths remained at 71mm. Figures 5 and 6 illustrate data recorded from the siphonic system on the 20th July 2010. These show that pressures are quite steady around -0.22 mH20. A sudden depressurisation occurs at 32minutes from commencement of the event in response to an increase in rainfall intensity. It can also be seen, Figure 6, that gutter depths steadily rose to 73mm which caused a sharp siphonic system pressurisation at 32minutes.

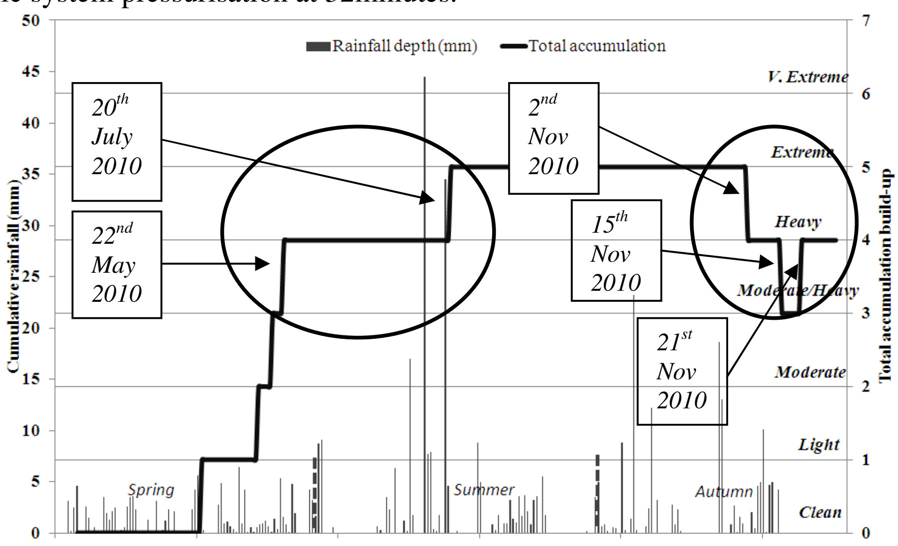


Figure 4 - NRS western system detritus accumulations, incidences 1 & 2.

On the 2nd November 2011, an event of 5.97mm/hr at 18:19:50 washed detritus through the system resulting in levels decreasing to '*heavy*'. An event which followed on the 15th November washed more detritus from the outlet, however water still remained within the gutter at a depth of 72mm depth. On the 21st November, an event of 5.76mm/hr washed detritus to the outlet increasing its categorisation to *'heavy'* and resulting in gutter water settling at a depth of 79mm. Images indicated that yellow/orange beech leaves and an exceptional quantity of solidified sediment had remained at the outlet. This is interesting as the start of November is the end of the fledgling period for the birds (4). In addition, it can be seen from Figure 7 that a sudden drop and subsequent increase in temperature correlates with the reduction and re-formation of detritus accumulation at the outlet.

On the 11th June 2011(see Figure 8), an event with a rainfall intensity of 5.19mm/hr occurred, subsequent to which gutter depths settled at 75mm. Another event which influenced accumulation occurred on the 19th June 2011 with an intensity of 5.51mm/hr and a maximum intensity of 7.02mm/hr, after which the accumulation increased to a *'very extreme'* level. Several gutter overtopping events occurred between 21st June 2011 and the end of the monitoring period.

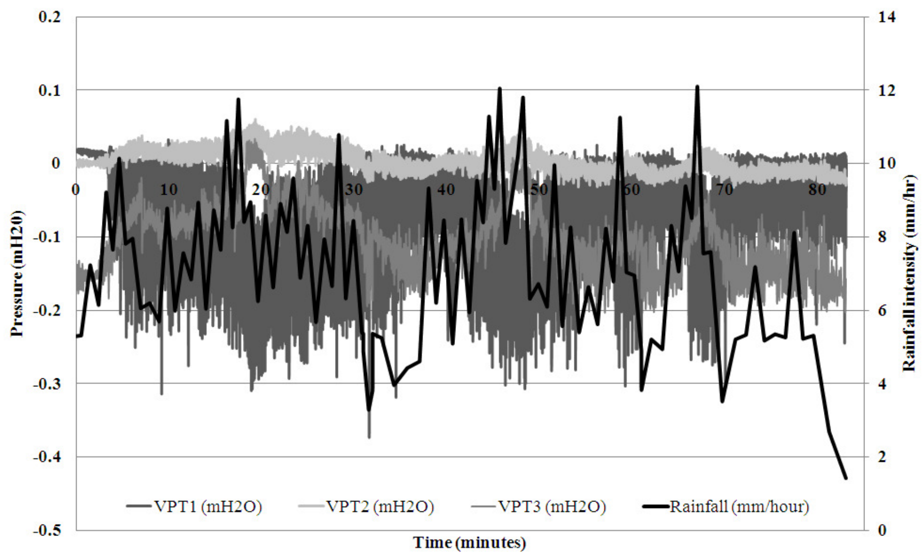


Figure 5 – NRS measured pressure data on 20th July 15:52:16 2010. (see fig. 1 for system layout)

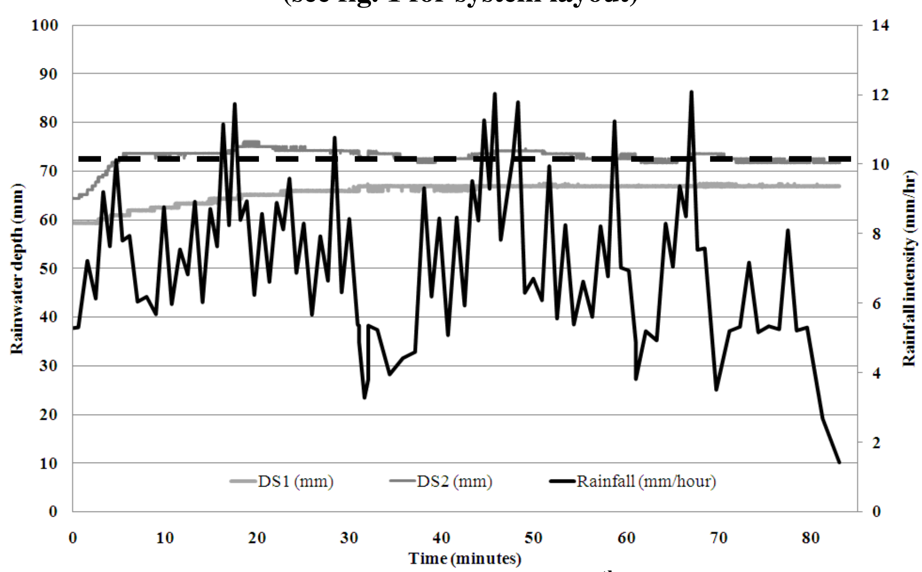


Figure 6 – NRS measured depth data on 20th July 15:52:16 2010. (see fig. 1 for system layout)

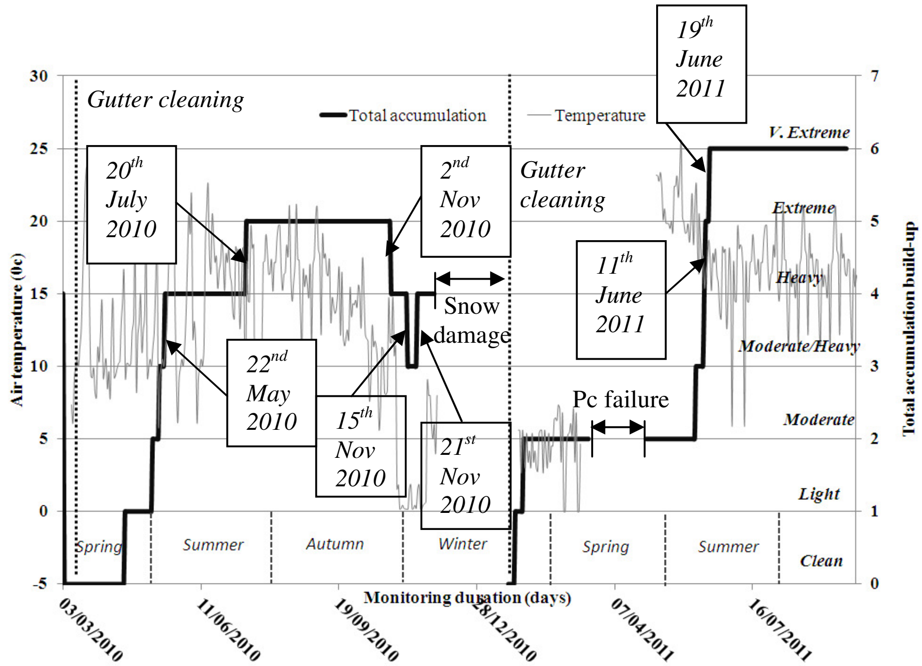


Figure 7 - NRS western system full detritus profile with temperature.

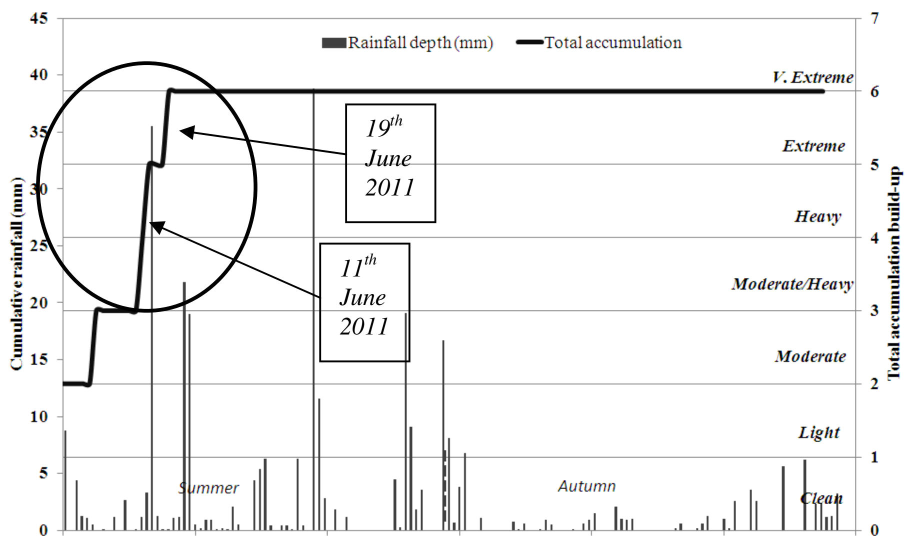


Figure 8 -NRS western system detritus accumulations

Figure 9 indicates the wind direction recorded for the *entire length* of the monitoring period with the detritus profile for system 1 overlaid. It can clearly be seen that the wind is generally southerly, and that no direct relationship or pattern appears in relation to detritus accumulation. System 2 when mapped against wind direction also indicated no direct relationship.

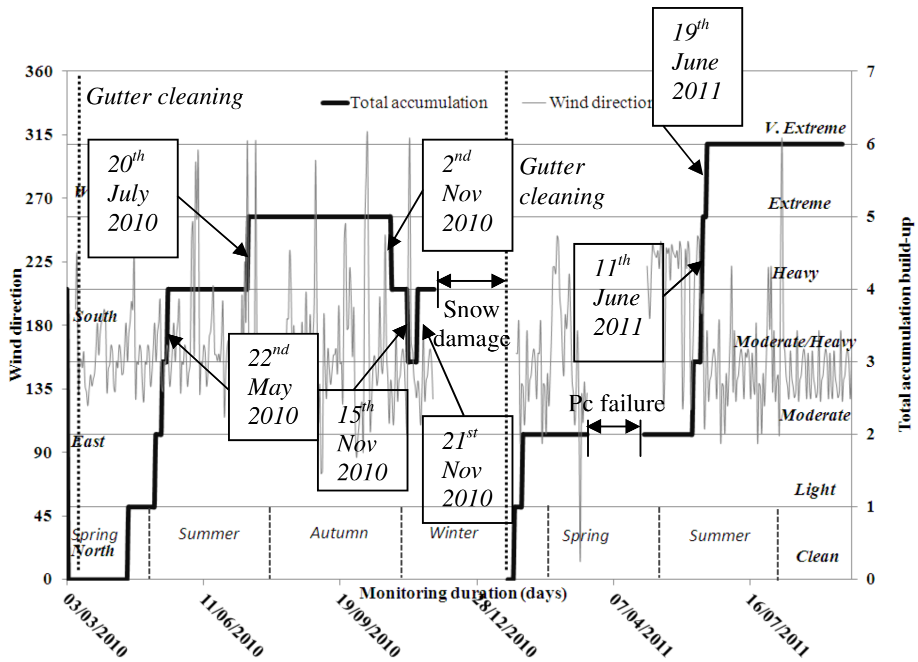


Figure 9 - NRS western system full detritus profile with wind direction.

4.2 National Records building east-system (2)

Taking rainfall intensity as the primary weather parameter, the following discusses two accumulation events shown in Figures 10 and 11 respectively.

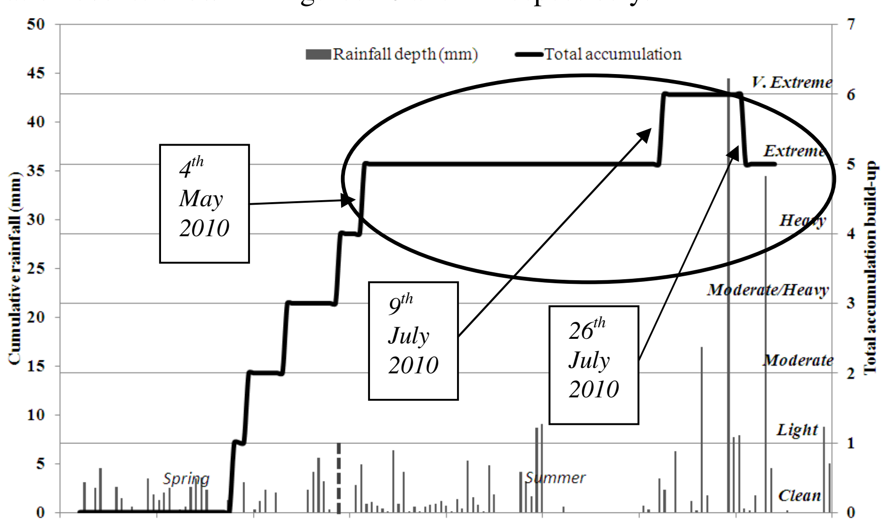


Figure 10 - NRS eastern system detritus accumulations, incident 1.

On the 4th May 2010, a 5.88mm/hr event left the gutter level at a 55.32mm depth and with a '*heavy'* detritus level. On the 9th July an 11.22mm/hr event left gutter water at a depth of 81.29mm. This resulted in detritus levels altering from *'extreme'* to '*very extreme'* (consisting of approximately three white feathers and an excessive amount of black solidified sediment) this was followed by an event on the 26th of July which saw the level of detritus at the outlet revert to *'extreme'*. Gutter overtopping occurred frequently after this.

As shown in Figure 11, the 7th June saw an event of 5.66mm/hr increase detritus levels from *'moderate heavy'* to *'heavy'*, where images indicated a copious amount of black sediment had accumulated, then on the 9th June from *'heavy'* to *'extreme'*. The event on the 9th June lasted for 5.44minutes with an intensity of 5.78mm/hr and washed detritus to the outlet to build upon the existing quantities, resulting in the gutters pooling at 66.72mm depth. After this the gutter overtopped frequently to the end of the monitoring period. As in previous cases, no apparent relationship has come from the other weather measured parameters.

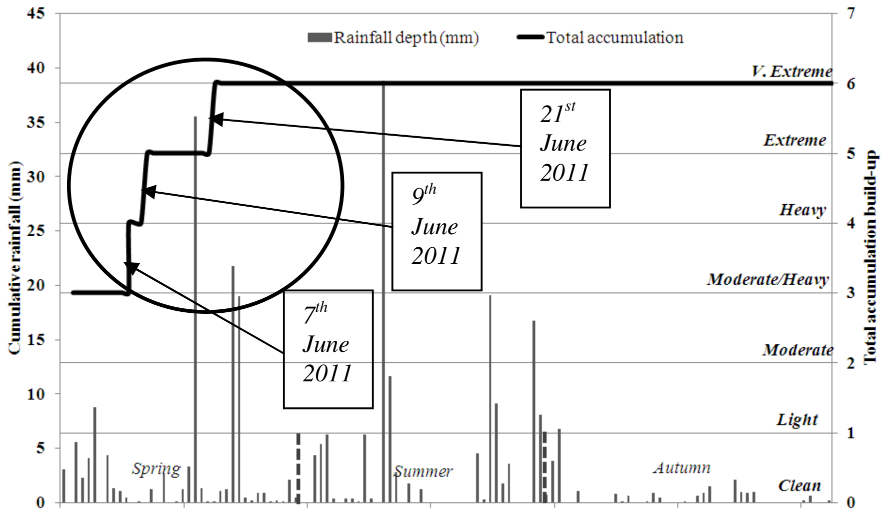


Figure 11 - NRS eastern system detritus accumulations

4.3 Ibrox stadium

Analysing precipitation as a primary weather parameter, it can be seen from Figure 12 that severe levels of accumulation developed around 3rd October 2010. At the time of 18:42:33 on this date, an event of 5.36mm/hr washed detritus to the outlet increasing the accumulation levels to *'heavy'* and a gutter pooling level of 35mm. A second event on the 18th October then removed detritus from the outlet with an intensity of 8.925mm/hr, and gutter depths after the event settled at 18mm. Following this, an event of 12.18mm/hr (with a maximum intensity, 39.17mm/hr) washed further detritus from the outlet, resulting in levels reducing to a *'moderate'* level.

Similarly, Figure 13, on 10th May 2011, detritus from the roof increased the build-up to a *'moderate heavy'* level, and consisted of small twigs and sediment. This event was quickly followed by a reduction in detritus to a *'moderate'* level on the 26th May with an event of 42.67mm/hr then light level on the 2nd June where the outlet had accumulated a marginal amount of twigs and a small quantity of black sediment. On the 26th June, a rainfall intensity of 38mm/hr increased the accumulation to a *'moderate'* category, with a gutter depth, settling at 29mm. It is interesting that the detritus accumulation stayed relatively steady during the remainder of the monitoring period.

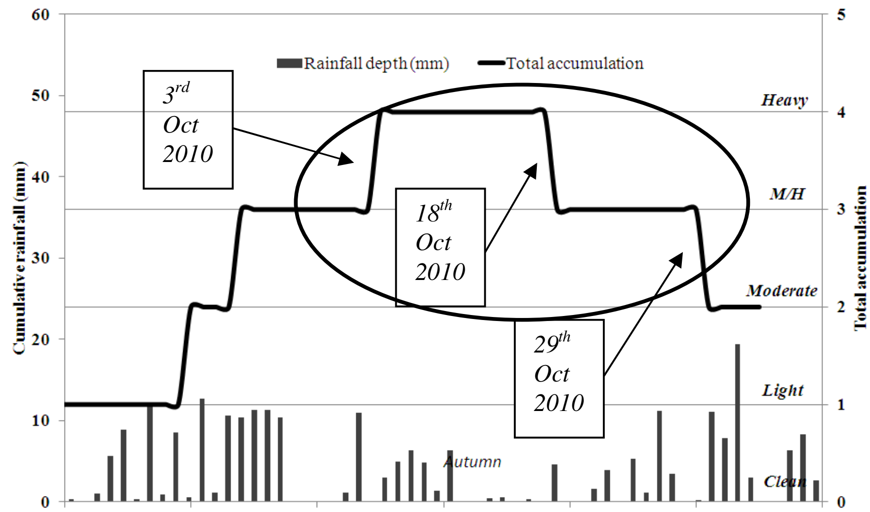


Figure 12 - Ibrox system detritus accumulations, incident 1.

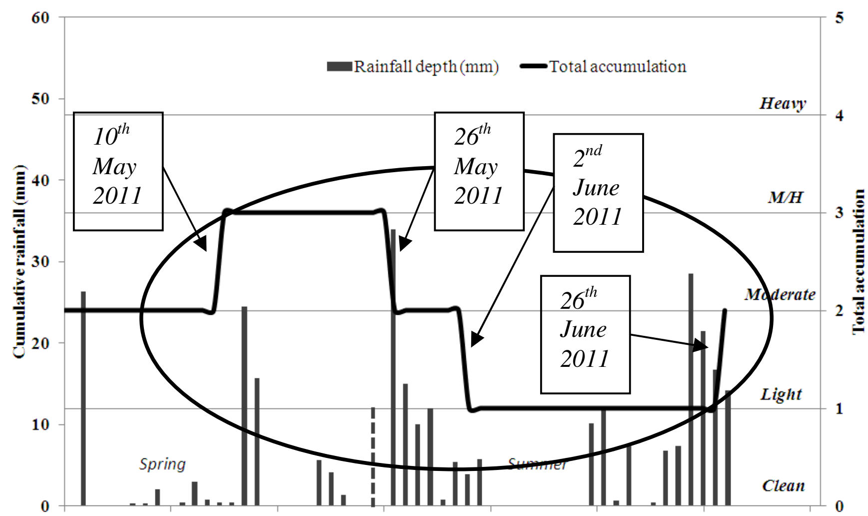


Figure 13 – Ibrox system detritus accumulations, incident 2.

5 Summary of site results

It can be seen from the images taken of the National Records building that, depending on the orientation of the building, outlets can become blocked by detritus relatively quickly. The rate of accumulation is clearly dependent upon the time of year. It has been observed that operational problems and system failures do occur when flow to the outlet becomes restricted by blockages and rainfall events follow; potentially leading to gutter overtopping. For the National Records building, all the information recorded suggests additional checks related to bird nesting activities would be prudent.

The information recorded from the Ibrox site, has observed that its proximity to the city and the influence of the local topography means that system outlets seldom, if ever, become blocked to an extent that might cause concern to the local maintenance team.

6 Conclusion

From the weather parameters recorded and site images for site 1, it may be concluded that the two monitored outlets became blocked relatively quickly. Also, from the analysis of site images there were six distinct levels of accumulation built up at both outlets. For site 2, the siphonic system ran smoothly with marginal detritus build-up. This study has therefore established detritus quantities found at outlets throughout the year. It has additionally been established that certain weather parameters, specifically precipitation and temperature, have greater influences on outlet blockages.

Detritus typically found at the outlets of the National Records building has been established as leaves (birch & beech), feathers, twigs and emulsified sediment. Whilst at Ibrox, detritus at the outlet consisted of sediment with some feathers and leaves. It was observed that operational problems at Site 1 did occur, but only as a result of restricted outlets and not from design faults. Site 2 did not fail during the monitoring period suggesting it is adequately sized and detritus levels do not interfere with the systems operation.

7 References

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8 Presentation of Authors

Mr. Richard K Beattie is a PhD student in the School of the Built Environment at Heriot-Watt University. His research includes environmental and outlet blockage effects on the performance of siphonic rainwater systems and how projected climate change predictions will affect such systems. Richard is also a Research Assistant investigating air pressure mitigation in drainage and vent systems.

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Adaptation of a property-based rainwater drainage system to accommodate climate change impacts

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Abstract
Records of observed weather show that rainfall is becoming heavier and more variable. Projections of future climate change suggest that, not only will rainfall become more frequent and intense, the number of extreme rainfall events will increase overall. This will undoubtedly place significant pressure on the capacity of property-based rainwater drainage systems in preventing water ingress to the building and in avoiding localised flooding. However, at present there remains limited guidance on how climate change impacts should be incorporated into the design of these systems. The stark reality is that if rainfall events change as expected due to climate change, then property-based rainwater drainage systems that were built in the past, or which are currently being designed, may not have adequate capacity in the future. Adaptive measures are therefore needed in order to ensure these systems have the flexibility to cope with changing rainfall patterns and to minimise their vulnerability to extreme rainfall events.

This research evaluates the effectiveness of various adaptive measures through the analysis of the performance of a case study site in Edinburgh using numerical modelling techniques. First, by using gutter overtopping as an indicator of failure, a system-specific rainfall intensity threshold is defined, against which future exceedance is assessed within the context of the UK Climate Projections 2009. System under-capacity is found to increase, in most cases, by up to two or three times under varying future climate change scenarios. However, appropriate system adaptation measures, such as increasing gutter depth, increasing pipe diameter, or installing a green roof are found to provide sufficient additional capacity and system flexibility to either minimise or completely avoid system failure. Through only minor system adjustment, planned adaptation measures are shown to have the potential to enhance the future resilience of property-based rainwater drainage systems.

Keywords
Property rainwater drainage system, climate change, adaptation

1 Introduction

Recent extreme rainfall events have increased localised flooding throughout many parts of the UK. Analysis of observed rainfall data (Fowler and Kilsby, 2003) suggest a trend towards increased rainfall and enhanced variability which, in light of recent climate change projections which indicate that both the frequency and intensity of future rainfall are likely to increase (Murphy *et al.*, 2009), focus attention on implementing suitable flood mitigation measures and understanding and preparing for the impacts of a changing climate. For these measures to prove effective, innovative flood management must first begin with appropriate rainwater conveyance at the property level.

The property-based rainwater drainage system intercepts all rainwater that falls within the property boundary and consists of three main components: roof drainage (conventional gravity or siphonic); surface drainage; and the underground drain network. At present, the design procedure for property-based rainwater drainage systems takes little account of climate change, only going as far as to state that the potential impacts should be considered, but providing no guidance on how this should be undertaken (BS EN 12056-3:2000). Furthermore, it is rare that the components of the property-based rainwater drainage system are designed as an integrated system, due mainly to the fact the each component is governed by a separate design guide, each stipulating specific rainfall profiles, event durations, and appropriate return periods.

Therefore, at present, there exists no guidance or methodology for the holistic design of property-based rainwater drainage systems and especially none that include information on how the potential impacts of climate change should be implemented. Previous work by the authors (Kelly and Jack, 2011; Jack and Kelly, 2012) has proposed an integrated approach to system design that not only allows use of a common rainfall profile for simulation purposes, but that facilitates an exploration of the impacts of climate change using UKCP09 Weather Generator data. This paper advances that work by evaluating the effectiveness of appropriate system adaptation measures to enhance system resilience and, therefore, minimise projected changes in frequency of system under-capacity within varying future climates. This is achieved through the use of the Heriot-Watt University developed numerical model ROOFNET which is used to establish system-specific and adapted system-specific rainfall intensity threshold values, based on a case study site located in Edinburgh.

2 Climate scenarios: UKCP09

The UK Climate Projections 2009 (UKCP09) provide estimates of future climate change for the UK across three different scenarios representing High, Medium and Low greenhouse gas emissions averaged over seven overlapping 30-year time periods which cover the whole of the twenty-first century. The UKCP09 Weather Generator provides synthetic time series data over 5km grid squares at either a daily or hourly timescale. These datasets have been provided by the UK Government through partnership with the UK Climate Impacts Programme and the UK Met Office and can be freely accessed online. As the latest and most advanced set of UK climate change information available, UKCP09 provides a sounds basis for assessing the impact of, and vulnerability to, an increasingly unpredictable and changing climate.

UKCP09 takes account of the inherent uncertainties associated with developing future climate projections by presenting the data as probabilistic estimates of future climate based on the strength of current evidence. A 10% probability indicates a change which is ***very likely*** to be exceeded, a 50% probability (known as the ***central estimate***) indicates a change which is just as likely to be exceeded as it is not, and a 90% probability indicates a change which is ***very unlikely*** to be exceeded.

Projections of change (expressed relative to a modelled 30-year baseline period of 1961-1990) are presented in terms of location, time period, temporal and spatial averages, emission scenario and probability level. In applying the UKCP09 datasets to the assessment of rainwater drainage system design and adaptation planning, it has been important to establish a suitable method of extracting relevant rainfall information from the extensive quantity of data available, whilst also ensuring that the probabilistic integrity of the data is not compromised. To this end, the UKCP09 Weather Generator was used to generate hourly rainfall data representative of Edinburgh; over three expansive time periods: the 2040s (2030-2059), 2060s (2050-2079) and 2080s (2070-2099); for all three emission scenarios (Low, Medium and High); and across a range of probability outcomes (10^{th}, 50^{th} and 90^{th}). The data generated includes both baseline (1961-1990) and future rainfall data which, to ensure the probabilistic characteristics of the datasets, are provided as 100 sample files of each 30-year time period.

By providing projections of future rainfall intensities, the data derived from the UKCP09 Weather Generator can hence be directly applied to the performance assessment of property-based rainwater drainage systems. Establishing a system-based rainfall intensity threshold, beyond which the system is known to fail, allows future exceedance levels to be identified when compared with the UKCP09 data. This method also facilitates an approach whereby system adaptation measures can be assessed against their effectiveness in enhancing system resilience and minimising failure.

3 Numerical model: ROOFNET

To assess system performance under a range of future climate conditions and to investigate the benefit of various adaptation options, the ROOFNET model developed at Heriot-Watt University under previous research (Arthur and Swaffield, 2001) was used for the simulation of the case study building. ROOFNET enables the simulation of rainwater flows for the entire property-based drainage system by integrating components for the simulation of flow from the roof and surrounding surface areas through to the underground pipe network.

The roof drainage component simulates the flow of rainfall from the roof surface, along the gutter, and through the system pipework down to ground level. The rainfall event applied to drive the model is user specified allowing either observed or synthetic rainfall events of varying duration, intensity and profile to be easily applied. Additional flexibility is provided by the ability to specify roof dimensions, gradients, and surface types, as well as pipe diameters and gutter geometries such as shape and slope. Furthermore, by incorporating the Horton infiltration formula, the model can also simulate the basic attenuating effects of a green roof by calculating the quantity of rainfall that would infiltrate into a green roof instead of entering the gutter. Finally, the local area drainage component simulates the runoff from surrounding surface areas (both pervious and impervious) and routes this, via gully connections, together with inflow from roof drainage downpipes, to the underground pipe network.

By aligning all of the component parts of a property-based rainwater drainage system, ROOFNET enables a holistic representation of the integrated network. The flexibility offered by the model facilitates the application, and impact assessment, of the UKCP09 climate change data on system performance, as well as providing a tool whereby informed adaptation-based decisions can be made to ensure future system resilience.

4 Case study: The National Records of Scotland (NRS)

In order to demonstrate the application of the UKCP09 data to the impact assessment of climate change on property-based rainwater drainage systems, the research reported herein details the derived methodology applied to a case study site in Edinburgh. Thomas Thompson House was chosen as a case study site as it offered a good example of a system configuration consisting of roof (siphonic), surface (permeable and impermeable), and underground drainage (Figure 1). The site was constructed in 1994 and is owned and operated by the Scottish Government as a document repository and conservation unit for the National Records of Scotland. A full site survey was carried out to determine the configuration and dimensions of the roof and siphonic rainwater system, the surrounding surface areas, and the underground pipe network.

There are eight siphonic rainwater systems serving a total roof area of 2794 m^2. The roof has a curved profile and is finished in polished aluminium. The gutter is 200 mm high x 360 mm wide and the stainless steel siphonic pipework has a diameter of 50 mm. The surrounding impermeable surface areas (including roads, car-parks and walkways) totalled 5091 m^2 and were connected via gulley entry points to the underground pipe network which consisted of almost 60 pipes with diameters ranging from 100 to 400 mm. Permeable surface areas totalled 7539 m^2 and were assumed as being dry at the start of the simulation. Within the ROOFNET model, a Manning's roughness coefficient of 0.02 was applied to the gutter condition, and roughness coefficients of 0.15 mm and 1.0 mm were applied to the siphonic pipework and underground drainage pipework, respectively.

Figure 1: Thomas Thomson House, Edinburgh (Source: ©2011 Google Imagery)

5 Determination of a common rainfall event

Within the UK, there are three British Standards that govern the design of the component parts of the property-based rainwater drainage system. Roof drainage systems are designed in accordance with BS EN 12056-3:2000, siphonic roof drainage systems in accordance with BS EN 8490:2007, and local drainage and sewer systems to BS EN 752:2008. The design process in all three documents is similar in that they require a suitable rainfall intensity to be determined in order to calculate runoff. Roof drainage systems, both conventional and siphonic, are designed using an averaged rainfall intensity figure which represents the most intense part of a longer storm. Determination of the intensity figure first requires specification of the property location, as well as an appropriate event duration and return period. The design of the surface and underground drainage system is similar, however, for catchments greater than $4000m^2$ rainfall intensities are obtained from the Wallingford Procedure (1981) which, instead of applying an averaged rainfall intensity, recommends applying a symmetrical single-peaked rainfall intensity.

Previous work (Kelly and Jack, 2011; Jack and Kelly, 2012) has focused on identifying an appropriate common rainfall event applicable to the analysis of overall system performance. Findings showed that despite the different approaches advised by both the roof and local drainage design guides, comparison of design rainfall events of equal duration and return period demonstrated similar values for rainfall depth and average intensity. Interestingly, however, the time-varying profile was shown to produce a slightly worst-case event when applied as input to the ROOFNET model. It is, therefore, this time-varying profile which was selected as the common rainfall event in this study. The event duration was set as 60 minutes to allow direct correlation with the hourly UKCP09 Weather Generator data.

6 Simulation Results

To allow analysis of system performance under varying climate conditions, the case study site was simulated using the ROOFNET model using the common rainfall event as the input driver. To compare changes in frequency of system under capacity, it was first important to determine the system-specific rainfall intensity threshold which identifies the maximum capacity of the system. Once this rainfall intensity is known, the impacts of climate change upon system performance could be explored within the context of the UKCP09 projections. Where threshold exceedance was found to increase, the effectiveness of various adaptive measures could then be assessed against their ability to minimise system failure.

6.1 **Determining system threshold**

The system threshold was determined by increasing the intensity of the common rainfall event incrementally within the ROOFNET model until system failure was detected. The definition of what constitutes a system failure is dependent upon the system and the level of protection required by the property. Examples include: gutter overtopping; surcharge of the underground pipework; and localised surface flooding. In this case, gutter overtopping was selected as, not only is this visibly identifiable, it can also lead to the ingress of water and localised flooding. The rainfall intensity threshold for Thomas Thompson House was found to be 19 mm/h. Figure 2 puts this threshold within the context of standard design return periods for 60 minute events for Edinburgh derived from the Wallingford Procedure (1981).

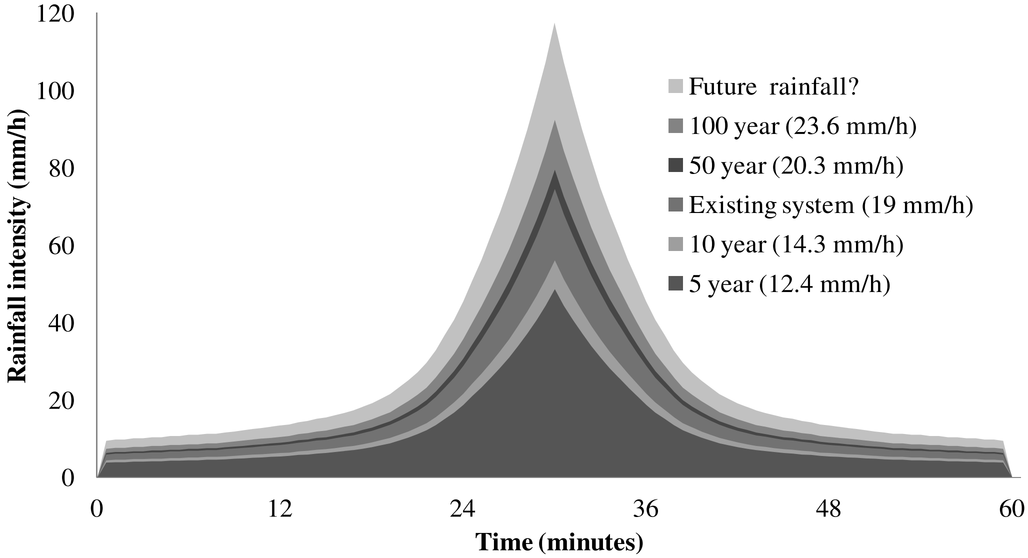

Figure 2: Comparison of the system rainfall intensity threshold with standard design return periods

It can be seen that, having a rainfall intensity threshold of 19 mm/h places the system capacity just below the 50 year event (20.3 mm/h). What is also clear is that system capacity is already exceeded by both the 50 year and 100 year storms and potentially by more extreme events as a result of climate change, putting the performance of this system under considerable strain. Please note that quoted rainfall intensities are based on the average intensity over the duration of the event for ease of discussion.

6.2 Using UKCP09 to establish future threshold exceedance

Having established the system-specific rainfall intensity threshold as 19 mm/h, the UKCP09 Weather Generator data could then be analysed to determine the likelihood of this threshold being exceeded under future climate change scenarios. A computer program was written to analyse all of the Weather Generator datasets in order to determine the maximum number of times the system rainfall intensity threshold is exceeded within the 100 sample files of each 30-year time period. This was carried out for each future scenario as well as for the baseline period. Figure 3 shows the maximum number of events that exceed the system rainfall intensity threshold cast against emission scenario and probability level.

The baseline period (1961-1991) yields a maximum of four threshold exceedances per year, and thus provides a "benchmark" against which future system performance can be compared. Although the results show some variability, which can be expected due to the probabilistic nature of the UKCP09 data and the large array of future climates analysed, the maximum occurrence of annual system threshold exceedance increases with time. Under the Low emission scenario, for example, projected maximum threshold exceedance increases by between two or three times that of the baseline period by the end of the century. By the 2060s, under the Low emission scenario, maximum system threshold exceedance is very likely to occur more than 10 times per year and very unlikely to occur more than 13 times per year.

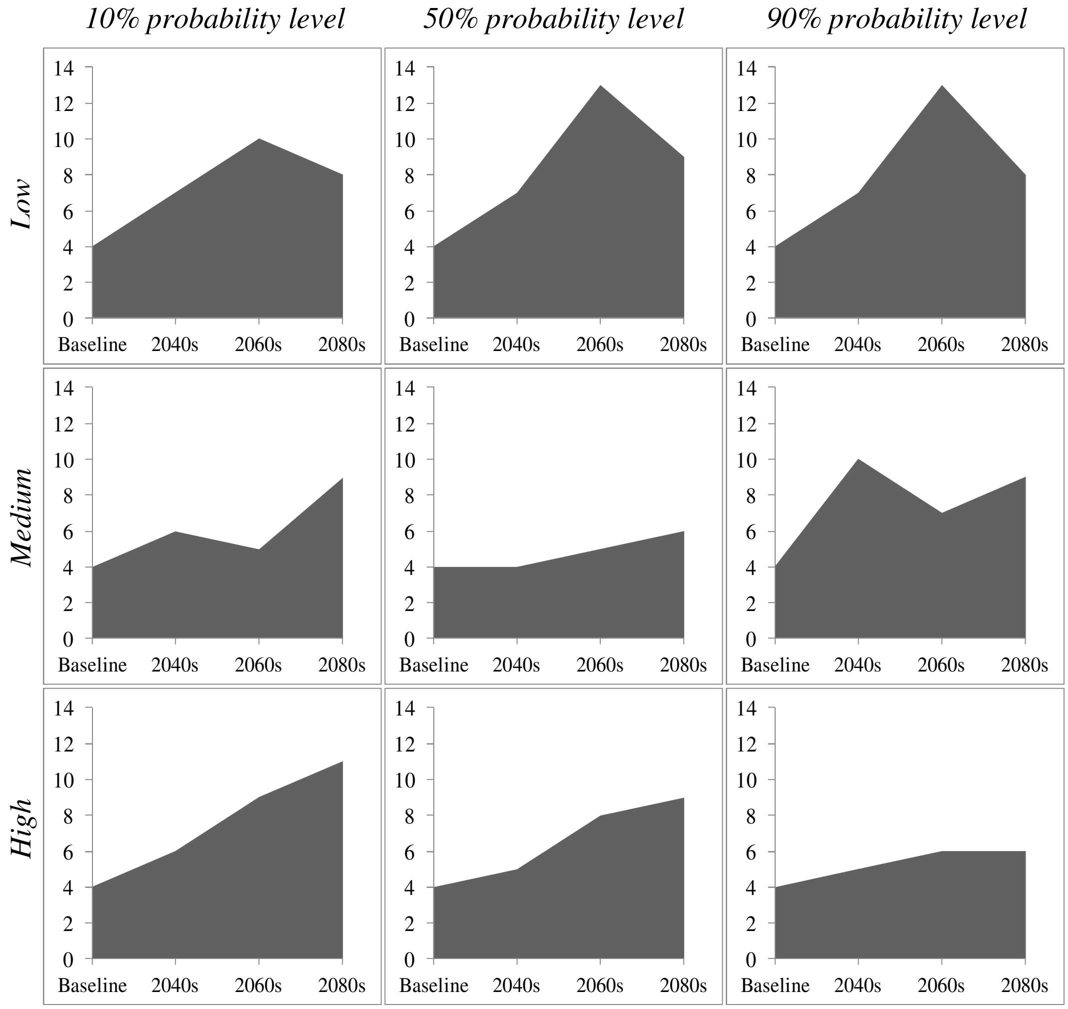

Figure 3: Maximum number of events that exceed the system-specific rainfall intensity threshold (19 mm/h)

There is, however, no definitive relationship between maximum system threshold exceedance and emission scenario. In some instances, maximum system threshold exceedance is greater under the Low emission scenario than it is under the Medium and High emission scenarios. Furthermore, the lower-band 10% probability level returns maximum system threshold exceedance values which are greater than the upper-band 90% probability level. These seemingly anomalous results are a consequence of deriving the *maximum* system threshold exceedance from the 100 30-year generated sequences of each climate scenario. However, the maximum is selected here in order to provide a link between the climate projections and the relative risk of future system failure. This point also highlights the importance of sampling across the range of data provided by UKCP09 (i.e. emission scenarios, time periods and probability levels) when making any assessment of climate change impacts. What is clear from these results, however, is that under the majority of cases, the increased frequency of system under-capacity in the future is significant when compared with the baseline dataset. The following section will look at ways of building resilience into the system through applying appropriate adaption options.

6.3 **Building resilience through adaptation**

With system under-capacity expected to increase in the future, the current rainwater drainage system at Thomas Thomson House would need to be adapted in order to maintain, or indeed improve, the current level of protection provided by the system. As gutter overtopping has been used as the indicator of system failure in this research, focus is therefore aimed at adaptation options which deal directly with the roof drainage system. These include: increasing gutter depth, increasing system pipe diameter, and installing a green roof.

6.3.1 Increase gutter depth

In order to accommodate greater runoff from the roof surface, the gutter depth could be increased to improve gutter capacity. This would allow a greater maximum depth of flow to develop within the gutter before the occurrence of overtopping. The ease of implementing this adaptive option would generally vary from building to building, depending on the gutter construction, accessibility, and materials used. For Thomas Thomson House, having a gutter which is integrated within the roof structure, this option could prove costly. The gutter depth at Thomas Thomson House is currently 200 mm. To investigate gutter depth adaptation benefits, gutter depths of 225 mm, 250 mm and 300 mm were modelled.

6.3.2 Increase pipe diameter

To ensure the adequate conveyance of rainwater from gutter to sewer, the existing system pipework could be replaced with pipes of a greater capacity. This would clearly alter the operational performance of the siphonic rainwater system, increasing the design condition which defines the maximum system capacity, which in turn, will mean that the system would operate as a conventional system during a greater range of rainfall events. Again, the ease by which this adaptive option can be implemented would depend upon the individual building. The system pipework at Thomas Thompson House is external and, therefore, could readily be replaced without many issues. The system pipe diameter at Thomas Thomson House is currently 50 mm. Two increments in pipe diameter were modelled: 70mm and 100 mm.

6.3.3 Install green roof

By providing a means of reducing and attenuating rainfall runoff from the roof surface, a green roof can help to mitigate the effects of impervious surfaces by intercepting and retaining rainwater. The rainwater retention capability of a green roof is dependent upon a number of factors such as: the number of antecedent dry days, rainfall intensity, ambient temperature, and the water holding capacity of the growing media. An extensive review by Gregoire and Clausen (2011) concluded that green roofs can provide runoff reduction benefits of between 34% and 69%. With a total roof area of 2794 m^2, installing a green roof at Thomas Thomson House could significantly reduce roof runoff. Four green roofs of various surface types were modelled: (i) course textured soil; (ii) medium textured soil; (iii) fine textured soil; and (iv) clay soil. Table 1 lists the initial infiltration rate, f_o, and final infiltration rate, f_c, associated with each soil type used within the ROOFNET model.

Table 1: Typical Horton parameters for various soil types

Green roof	Soil type	f_o (mm/h)	f_c (mm/h)
A	Course textured soil	250	25
B	Medium textured soil	200	12
C	Fine textured soil	125	6
D	Clay soil	75	3

6.3.4 Discussion of adaptation options

The performance of these various adaptation options and their ability to increase system resilience were implemented and analysed for Thomas Thompson House using the ROOFNET model. Table 2 summarises each of the nine adaptive measures investigated and shows the updated rainfall intensity threshold for each adapted system.

Table 2: Investigated adaptation options for Thomas Thompson House

Adaptation option	Gutter depth (mm)	Pipe diameter (mm)	Roof type	System threshold (mm/h)
Existing	200	50	Polished aluminium	19
1	**225**	50	Polished aluminium	20
2	**250**	50	Polished aluminium	22
3	**300**	50	Polished aluminium	24
4	200	**70**	Polished aluminium	32
5	200	**100**	Polished aluminium	72
6	200	50	**Green (Course soil)**	124
7	200	50	**Green (Medium soil)**	103
8	200	50	**Green (Fine soil)**	71
9	200	50	**Green (Clay)**	50

Increasing the gutter depth increased the system rainfall intensity threshold, but not significantly above that of the existing system. An increase in gutter depth from 200 mm to 300 mm increased the system threshold by just 5 mm/h. Increasing the pipe diameter, however, improved the system threshold quite considerably. Upgrading the system pipework to 70 mm and 100 mm diameter increased the system threshold to 32 mm/h and 72 mm/h, respectively. By far the greatest improvement in system threshold was provided by the installation of a green roof with a coarse textured soil type, which increased the system threshold to a substantial 124 mm/h. This value can be seen to decrease as the soil type becomes finer and more densely packed.

Having defined a new rainfall intensity threshold for each adapted system, the effectiveness of each adaptive measure in reducing the frequency of future system under-capacity could be determined through comparison with the UKCP09 Weather Generator datasets. The datasets were analysed to establish the maximum number of times the adapted system rainfall intensity threshold was exceeded. For comparison, Figure 4 shows the maximum number of events that exceed the adapted system rainfall intensity threshold with that of the existing system. Adaptation options 5 to 8 (with reference to Table 2) are not shown in Figure 4 as all indicate complete system resilience to both current and future climate change with no threshold exceedance detected due to the improved system capacity they provide.

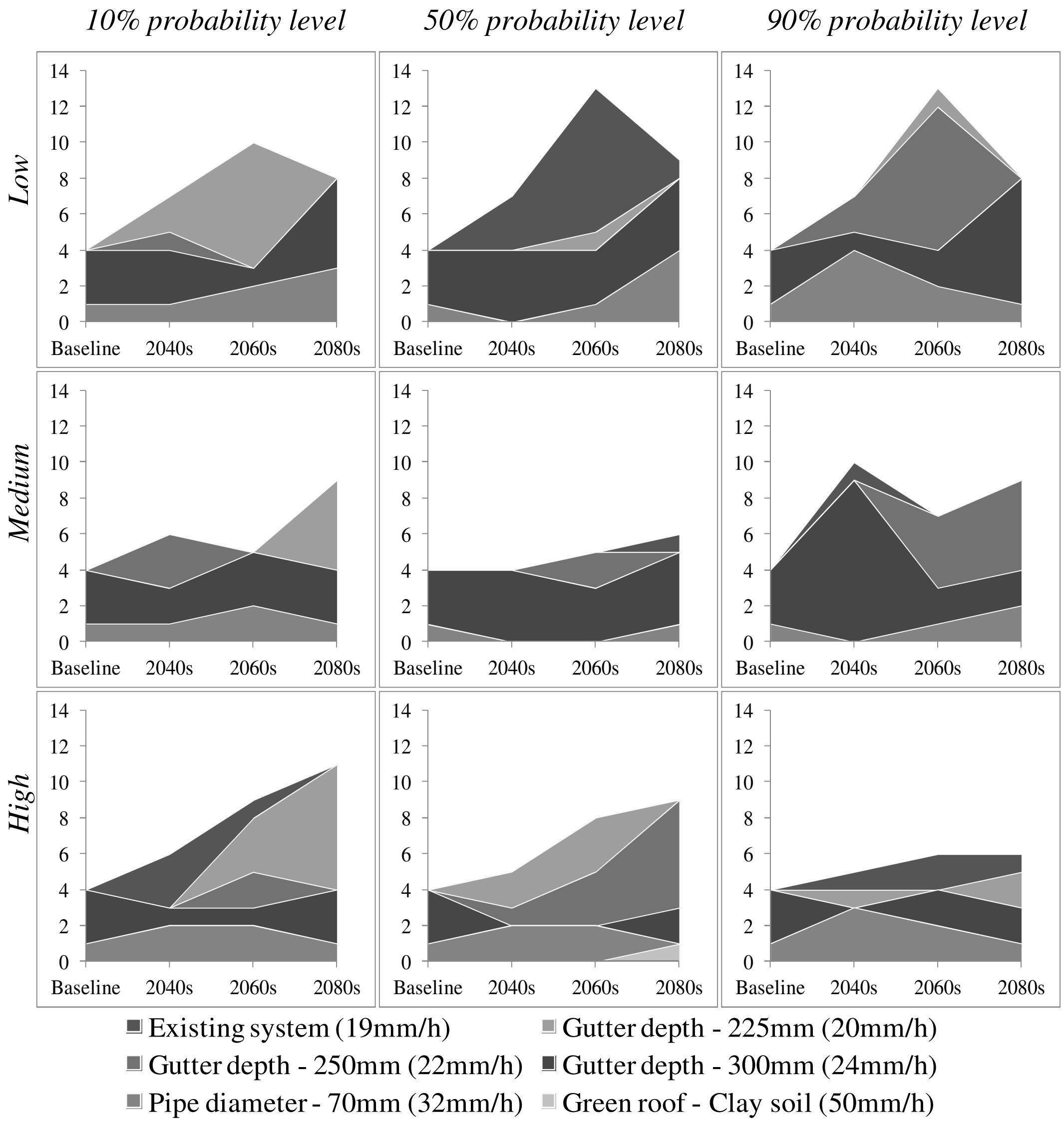

Figure 4: Maximum number of events that exceed the adapted system rainfall intensity threshold

While the increased gutter depths of 225 mm and 250 mm show only a minor reduction in the number of events that exceed the adapted system rainfall intensity threshold, the gutter depth of 300 mm shows a more marked reduction with, for example, a reduction from eight threshold exceedances to just two for the 50% probability level under the High emission scenario for the 2060s. Increasing the pipe diameter to 70 mm shows an even greater reduction, with all but two counts of maximum threshold exceedance being significantly lower, or completed removed, when compared with that of the baseline period. Only the green roof with clay soil is included in Figure 4 as despite indicating complete system resilience for the majority of cases, there was one instance, i.e. the 50% probability level under the High emission scenario for the 2080s, where a single event that exceeded the adapted system threshold was detected.

The results of adapted system performance indicate that implementing just minor system adjustments could accommodate many of the projected changes in future rainfall. Although, as a single adaptive measure, the gutter depth would need to be increased relatively significantly in order to reduce the frequency of system under-capacity, it could be used in conjunction with other measures, including increasing the gutter width, to improve system resilience. For the case study site in question, the projected increase of future system under-capacity can be significantly reduced or even avoided completely by increasing the system pipe diameter or installing a green roof.

7 Conclusion

This paper has assessed the performance of the property-based rainwater drainage system under both current (baseline) and future climate conditions and has evaluated the effectiveness of various system adaptation measures in minimising the potential for system under-capacity in the future. Through application of the numerical simulation model, ROOFNET, and the availability of time series rainfall data from the UKCP09 Weather Generator, the potential impacts of climate change on the performance of the property-based rainwater drainage system of a case study site in Edinburgh has been assessed holistically. First, the system-specific rainwater intensity threshold of the existing system was determined and found to be 19 mm/h. Next, probabilistic rainfall data generated from the UKCP09 Weather Generator was analysed to identify how often system under-capacity is likely to occur during both the baseline and various future climate scenarios. Taking gutter overtopping as an appropriate indicator of system failure, the findings revealed that the potential increased frequency of system under-capacity is, in most cases, quite significant, with a number of examples showing increases of between two or three times that of the baseline period.

The implementation of system adaptation measures, such as increasing gutter depth, increasing pipe diameter, and installing a green roof, was then modelled in order to determine the extent of system changes that would need to be incorporated to allow the system to accommodate these changes in rainfall and to minimise potential system under-capacity. By far the most effective adaptation measure was the installation of a green roof which, in almost all cases, completely removed any risk of system under-capacity, as did increasing the system pipework diameter to 100 mm. Smaller increases in pipe diameter, and increases of gutter depth, demonstrated notable reductions of system under-capacity and so could be considered as part of an overall integrated adaptation approach. It is clear that changes are needed in order to allow the design of property-based rainwater drainage systems to, not only facilitate a holistic approach to system design, but also to include clear guidance on how climate change impacts should be assessed. Without such advances in system design, the projected changes in future rainfall will undoubtedly increase the occurrence of system failure and localised flooding. However, this research has shown that with appropriate adaptive planning, the vulnerabilities to the impacts of climate change can potentially be minimised or avoided through only minor system adjustments.

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An Investigation into the Measurement of Flow Proportionality through Multi-Outlet Siphonic Roof Drainage Systems

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Abstract

Recent trends in the development of our urban landscape have seen the introduction of larger buildings with vast roof areas. It is anticipated that the onset of climate change will see increased intensities and volumes of rainfall which will place significant pressures on the roof drainage systems for these buildings potentially leading to failure and major flooding. There is an urgent need to adapt and the principal solution is the use of siphonic roof drainage systems. However, it has been identified that there is a universal lack of understanding of the hydraulic performance of siphonic systems Current design methodologies assume that the proportions of flow through each outlet within a common gutter are the same, previous research has reported that this is not the case.

An experimental study has been undertaken using the full-scale test facility at the University of Sheffield to improve the understanding of the hydraulic performance of multi-outlet siphonic roof drainage systems. This paper presents the results from the feasibility tests and an assessment of the suitability of the experimental measurement methods. The reported tests include a series of novel experiments using high speed image velocimetry and a unique approach that uses a flourescein tracer to measure the flow component through each outlet. Proposed future tests are also reported including a systematic study of changes to the configuration of the outlets within the common gutter.

Keywords

Siphonic Roof Drainage, Priming, Flow Measurement

1 Introduction

We are living in a changing world and recent trends in the development of our urban landscape have seen the introduction of larger buildings with vast roof areas. It is anticipated that the onset of climate change will see increased intensities and volumes of rainfall which will place significant pressures on the roof drainage systems for these buildings potentially leading to failure and major flooding. There is an urgent need to adapt and the principal solution is the use of siphonic roof drainage systems. However, it has been identified that there is a universal lack of the understanding of the hydraulic performance of siphonic systems, particularly when flow conditions are time varying.

Conventionally, roof drainage systems have been designed to safely convey the rainfall that runs off roof surfaces to the below ground drainage system. It is usual for the rainfall to be collected in a gutter and then conveyed to a downpipe, or series of downpipes, that are used to transfer the water from roof level to ground level. These gravity driven systems have worked well for many years and, in the UK, their design is based on methodologies outlined in BS EN 12056-3: 2000 Part 3: 'Gravity Roof Drainage, Layout and Calculation' (BSI 2000). However, in recent years the footprint of many buildings has increased significantly leading to large buildings with vast roof areas. Similarly architectural practice has changed with the use of new materials and exterior surface finishes which provide elegance and intricate aesthetic appearance that incorporates concealed roof drainage systems. The use of conventional roof drainage for such buildings requires large gutters and a large number of downpipes and associated pipework.

As a consequence the worldwide construction industry has seen the introduction of siphonic roof drainage systems. These have the advantage that their capacity is significantly greater than that of conventional systems and hence can drain much larger volumes of rainfall in a shorter period of time. They also require less pipework as a single carrier is used to drain several outlets within the gutter. Siphonic systems also have the advantage that they can be more easily upgraded or retro-fitted onto existing buildings to accommodate future increases in the frequency and severity of extreme rainfall events with the onset of climate change.

Previous research has reported the benefits of siphonic systems (Arthur and Swaffield 2001; Wright et al. 2002). However, to achieve these benefits, the system must prime. The priming mechanism is extremely complex and existing design standards (BSI 2000; BSI 2007), recognise that there is no available analytical method that satisfactorily describes the process. Of equal significance and concern is that it is not certain that any given system will prime (Arthur and Wright 2007). Guidance is given in Section 8.8 of BS 8490:2007, 'Guide to Siphonic Roof Drainage Systems', but this has been demonstrated to be based on a number of fallacies (Arthur and Wright 2007).

Whilst some current design methodologies assume that the proportions of flow through each outlet within a common gutter are the same, previous research has reported that this is not the case. Furthermore, under time-varying flow conditions it has been shown that pressure fluctuations may cause the system to deprime with the catastrophic consequence that there is a rapid rate of the rise of flow depth within the gutter resulting in system failure.

An experimental study has been undertaken using the full-scale test facility at the University of Sheffield to improve the understanding of the hydraulic performance of multi-outlet siphonic roof drainage systems. This paper presents the results from the feasibility tests and an assessment of the suitability of the experimental measurement methods. The reported tests include a series of novel experiments using high speed image velocimetry and a unique approach that uses a flourescein tracer to measure the flow component through each outlet. Proposed future tests are also reported including a systematic study of changes to the configuration of the outlets within the common gutter.

2 Experimental Study

The full scale siphonic roof drainage experimental test facility is positioned on the mezzanine roof of the structures laboratory of the Sir Frederick Mappin Building of the University of Sheffield. Figure 1 provides a schematic of the experimental test facility.

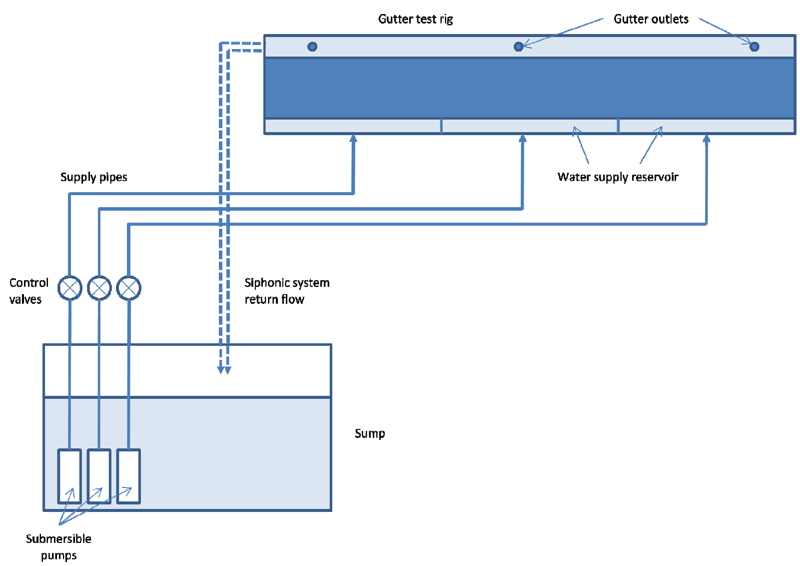

Figure 1 Schematic of the Experimental Test Facility (not to scale)

The test facility has a gutter length of 35 m and a working head of 9.5 m. The supply of water to the rig is transferred from a 272 m^3 sump via three independent pumps highlighted in Figure 1. Each supply pipe incorporates a computer controlled butterfly valve controlled using real time control technology and recorded using LabView software. The water is supplied from the pipes into three supply reservoirs from where it spills over a knife-edged weir, onto the roof section and into the gutter.

The gutter dimensions are 600 mm wide by 150 mm deep with a 1.2 m wide roof section constructed from profiled roofing sheet at a pitch of 6°. Both the roof and gutter are fitted according to standard construction industry practice (Bramhall 2006).

The tailpipes and carrier pipes are manufactured from annealed cast acrylic with a wall thickness of 5 mm. The sizing and configuration of the pipework was completed using commercially available software based on the Bernoulli Energy Equation and the Colebrook White Equation. The system was designed as a primary system with three commercially available siphonic outlets fitted within the gutter sole. Design flow and operating pressure of the system was 30.0 l/s and -3.23 mH_2O respectively with an ultimate flow of 35.1 l/s and ultimate operating pressure of -4.67 mH_2O (Table 1).

Table 1 Summary of Outlet Inflows and Reserves

Outlet	Design inflow (l/s)	Reserve m	Reserve %	Ultimate inflow (l/s)	Reserve m	Reserve (%)
A	10.0	2.69	27	11.7	0.000	0
B	10.0	2.60	26	11.3	-0.025	0
C	10.0	2.70	27	12.1	0.024	0

2.1 Methodology

A series of feasibility tests were undertaken to assess, review and optimise the methods of flow measurement. The tests were completed to refine the measurement and data collection techniques and to determine the relative proportions of flow passing through each outlet. A number of tests were undertaken covering a range of flow rates that included both sub-prime and primed siphonic action. It was important to examine and understand the hydraulic performance over this flow range as siphonic systems predominantly perform at sub-prime conditions (Öngören and Materna 2006). Each section of the gutter was supplied with the same flow rate from 2 l/s to 14 l/s in 1 l/s increments. This is equivalent to a total flow rate through the system from 6 l/s to 42 l/s.

For each feasibility test, the following measurements were recorded:

1. Water depth within the common gutter
2. System pressure within the horizontal carrier pipe
3. Flow rate within the horizontal carrier pipe measured using flourometry
4. Flow velocity within the horizontal carrier pipe measured using high speed image velocimetry

2.1.1 Water Depth Measurements

Water depth measurements were made using a digital depth micrometer fitted to a frame that could be moved along the length of the gutter (Figure 2).

Figure 2 Digital Depth Micrometer and Frame

Water depth measurements were made 150 mm either side of each outlet in accordance with Section B.2.6 of BS 8490:2007 Guide to Siphonic Roof Drainage Systems (BSI 2007). Two further depth measurements were made at 50 mm around the perimeter of the outlet to monitor the effect of draw down. Five water depth measurements were also made between each outlet including the midpoint, 0.5 metres and 1 metre either side of the midpoint. Two further water depth measurements were also made 0.5 metres and 1 metre from each gutter end.

2.1.2 System Pressure

Five pressure transducers were installed within the system to monitor pressure with a range of -1 Bar to 0.6 Bar (equivalent to -10 m to 6 m pressure head) with an accuracy of 0.15%, equivalent to 24 mm. Three transducers were positioned 2 metres downstream of where each tail pipe entered the horizontal carrier pipe. This distance from the junction was selected to reduce the risk of high pressure fluctuations closer to the fittings. A further transducer was located at the end of the horizontal carrier pipe and at the system outlet.

To record an average pressure around the circumference of the pipe, a unique collar was designed and manufactured. The collar featured two rubber o-rings either side of a 6 mm by 6 mm bevel. Four 4 mm holes were drilled into the carrier pipe at the crown, invert and horizontal sides of the pipe wall and the collar slid over the pipe so the holes were positioned in the bevel. Sealant was then applied between the edge of the collar and the carrier pipe to create an airtight seal. Each pressure transducer was positioned at the invert of the collar and a simple bleed valve attached to the crown to enable the removal of any air blocks (Figure 3). This configuration enabled the average pressure to be taken around the circumference of the carrier pipe.

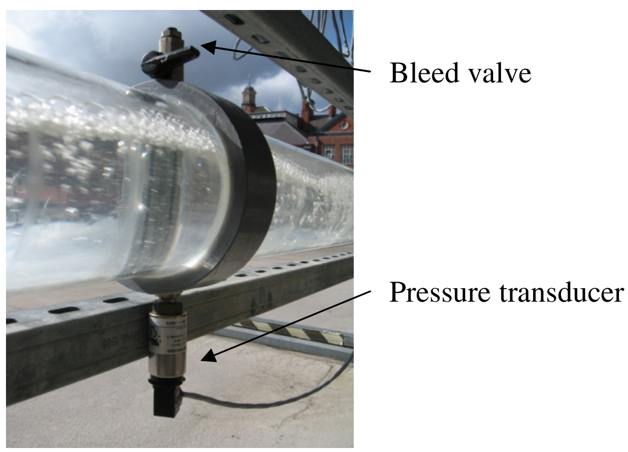

Figure 3 Pressure Transducer Collar In-Situ

2.1.3 Flourometry

To measure the flow rate within the horizontal carrier pipe a unique approach using a flourescein tracer was used to measure the flow component through each outlet. Three submersible fluorometers were fitted within the horizontal carrier pipe downstream of each tail pipe such that the sensor was exposed to the main body of the flow, but with a minimum of disruption. A further flourometer was fitted within the supply reservoir to record the background solute levels.

The flourometers are able to detect a change in solute concentration of Rhodamine WT with a sensitivity of 4 ppb. A temperature probe with an accuracy of ±0.3°C was also fitted within the supply reservoir to allow for temperature correction. For the feasibility tests, Rhodamine WT dye was injected into the outlet bowl of the upstream outlet using a dosing pump. The configuration of the apparatus is shown in Figure 4.

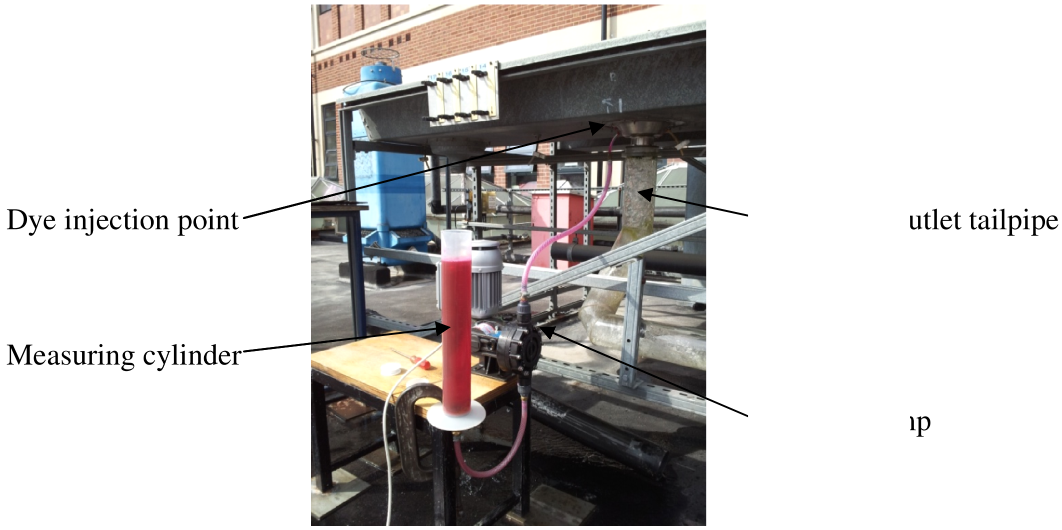

Figure 4 Feasability Tests Dye Injection Apparatus Configuration

For each feasibility test, 1 litre of Rhodamine WT dye at a concentration of 5x10^{-4} (C_{in}) was pumped from the measuring cylinder into the bowl of the upstream outlet. The turbulence within the outlet bowl and tail pipe was sufficient to ensure the dye was fully mixed before reaching the first measurement point. The dye injection rate (q_{in}) was measured volumetrically recording the time taken to dose every 100 ml of dye.

The raw values recorded by each flourometer were first resolved to a common temperature according to the following calculation (Wilson, 1968):

$$F_r = F_s e^{[n(T_s - T_r)]}$$

Where F_r is the calculated fluorescent reading at the reference temperature, F_s is the observed fluorescence reading of the sample at the time of reading the sample temperature, e is the base of natural log, n is the temperature coefficient of the dye used (0.026 for Rhodamine WT), T_s is the sample temperature at the time of reading F_s and T_r is the reference temperature.

For the feasibility tests the observed fluorescence readings were resolved to a common temperature of 20°C. The appropriate calibration was then applied to the resolved readings to calculate the concentration of dye (C) at each measurement point.

The position of each of the flourometers within the test facility was selected to assess the flow rate through each outlet based on the measured dilution of the dye:

$$q_{in} C_{in} = Q_{F1} C_{F1}$$

Where q_{in} is the dye injection rate, C_{in} the concentration of dye injected, Q_{F1} the flow rate at flourometer point 1 and C_{F1} is the concentration of dye at *F1*. This equation can be rearranged to:

$$Q_{F1} = \frac{q_{in}C_{in}}{C_{F1}}$$

The background solute level was measured to accurately determine the flow rate at the location of each flourometer:

$$Q_{Fn} = \frac{q_{in}C_{in}}{C_{Fn} - C_{FB}}$$

Where C_{FB} the concentration of the background solute level, C_{Fn} and Q_{Fn} is the concentration of dye and flow rate at each flourometer location respectively.

2.1.4 High Speed Image Velocimetry

High speed image velocimetry feasibility tests were necessary to assess the quality of image produced within the test environment and the flow velocity results following Particle Image Velocimetry (PIV) analysis.

The feasibility tests were completed using a Photron Fastcam XLR high speed camera to record images of the flow within the horizontal carrier pipe. To reduce distortion of the images as a result of the curvature of the pipe, a glass fronted water box was designed, manufactured and installed at three points along the length of the carrier pipe downstream of each tailpipe. The configuration of the apparatus is shown in Figure 5.

Figure 5 Configuration of the High Speed Image Velocimetry Apparatus

For each test, the flow was seeded using inert, white, plastic particles with a diameter of 150 μm and density of 1000 kg/m^3. Blackout material was fitted to the pipe behind the water box to provide sufficient contrast for the particle seeding to be observed. Additional lighting was required to be able to view the images being recorded at the required frequency.

Prior to testing, the water box was filled with water and a graduated steel rule placed along the crown of the pipe. The rule was required to be able to scale the images for analysis. The camera was positioned in front of the water box and the image field adjusted to include the pipe and steel rule. An example image is shown in Figure 6.

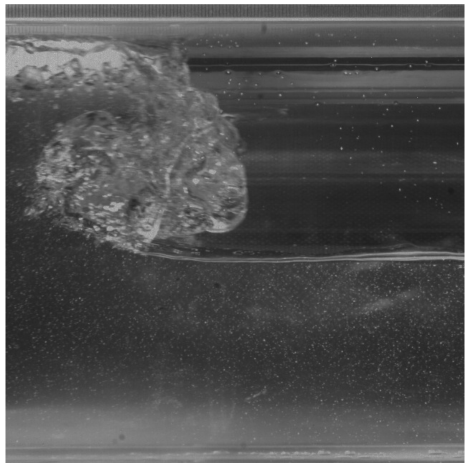

Figure 6 Image of Seeded Flow within the Horizontal Carrier Pipe

For the feasibility tests the camera was set to record images at a frequency of 2000 Hz. 10 consecutive images every 1000 were selected for analysis representing a flow measurement point every 0.5 seconds. The images were then analysed using PIV software to determine the local flow velocity within the horizontal carrier pipe at each measurement point:

1. For each set of images the field of view was adjusted for the size of the image
2. Cross-referencing of each image relative to the next one was completed producing nine vector analysis results
3. Range validation was applied to the vector analysis results to eliminate spurious readings detected outside of the flow field
4. Statistical analysis of the validated, vector analysis results was completed. One result was generated of the average flow velocity from the nine, validated, vector analysis results.
5. The average of the flow velocity results from was calculated. Any results less than 0.01 m/s were excluded from the average so that stationary objects within the image did not skew the resulting mean.
6. The average flow velocity for that half second interval was plotted.

2.2 Results

2.2.1 Water Depth Results

The water depth along the length of the gutter was recorded three times for each steady flow test in accordance with the methodology outlined in Section 2.1.1. Figure 7 shows the average water depth along the length of the gutter at the different test flow rates.

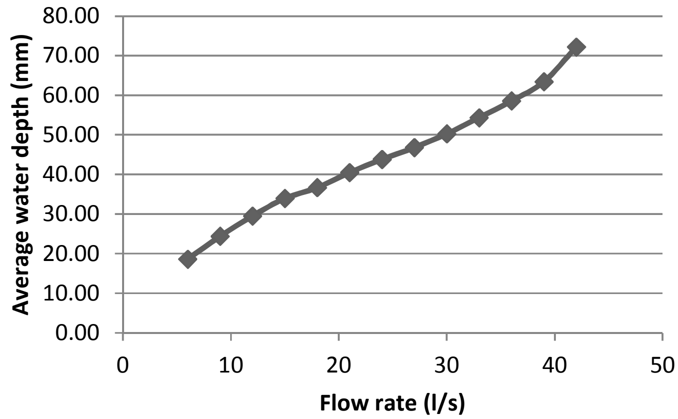

Figure 7 Average Water Depth within the Gutter

2.2.2 System Pressure Results

Figure 8 shows a plot of the mean pressure values at each measurement point for the series of feasibility tests.

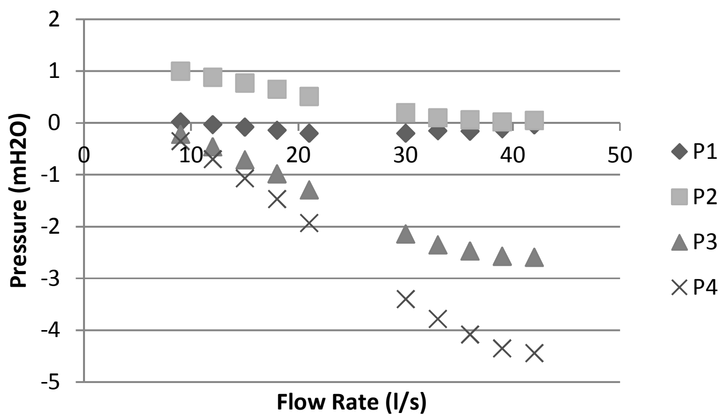

Figure 8 Plot of Feasibility Test Pressure Measurements

The results show that at the upstream monitoring position (P1), there was minimal change in pressure irrespective of the flow rate through the system. A maximum pressure of -0.2 mH_20 was recorded during the tests completed at 21 l/s and 30 l/s. The system pressure after the second tailpipe (P2) steadily decreased from a positive pressure of 1 mH_20 to less than 0.1 mH_20 at test flow rates greater than 36 l/s. The pressure transducer located downstream of the third tailpipe (P3) showed a steady pressure decrease throughout the tests from -0.22 mH_20 at 9 l/s to -2.59 mH_20 at 42 l/s. The transducer located at the top of the downpipe (P4) showed the most significant change in system pressure. The results decreased from -0.35 mH_20 at 9 l/s to -4.44 mH_20 at 42 l/s.

Table 2 provides a comparison of the calculated and measured system pressures at the design and ultimate flow rates outlined in Section 2.

Table 2 Calculated and Measured System Pressure Comparison

Flow Rate (l/s)	Calculated System Pressure (mH_20)	Measured System Pressure (mH_20)
30 (Design)	-3.23	-3.40
35.12 (Ultimate)	-4.67	-4.00 (extrapolated)

The results in Table 2 show that although the calculated and measured system pressures at the design flow rate of 30 l/s were similar, there is a difference in the ultimate flow results. Even at a flow rate of 42 l/s, the measured system pressure of -4.44 mH_20 was less than the calculated pressure at ultimate flow.

2.2.3 Flourometry Results

Figure 9 provides an example of the results measured using flourometry. The graph shows the individual components of flow measured by each flourometer at the design flow rate of 30 l/s.

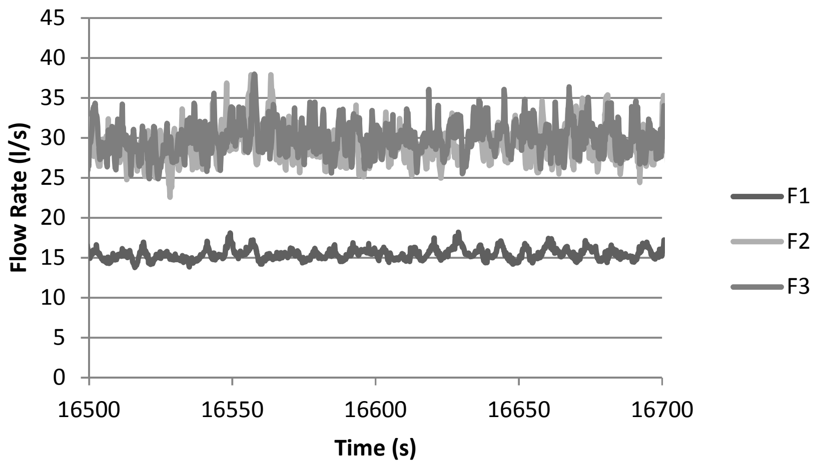

Figure 9 Flow Proportionality Measured at the Design Flow Rate of 30 l/s

Table 3 shows the average flow rate and flow proportionality measured by each flourometer for the series of feasibility tests.

Table 3 Flow Proportionality Measured using Flourometry

Test	F1		F2		F3
l/s	l/s	%	l/s	%	l/s
9	4.82	52.1	8.85	95.7	9.25
15	7.42	48.8	15.4	101	15.2
18	8.99	49.7	19.2	106	18.1
21	9.95	47.2	20.1	95.3	21.1
30	15.6	51.8	29.6	98.3	30.1
33	18.9	59.6	32.4	102	31.7
36	20.0	57.3	33.5	96.0	34.9
39	20.5	52.6	33.3	85.4	39.0
42	21.0	50.0	35.0	83.3	42.0

The results in Table 3 show that equal proportions of flow were not measured through each outlet. For the design flow rate of 30 l/s, 51.8% of the flow was measured through the upstream outlet (A) and a further 46.5% through Outlet B. This is a consistent observation for each of the tests. The total flow through the system measured downstream of Outlet C (F3) was within 4% of the volumetrically calibrated flow input.

2.2.4 High Speed Image Velocimetry Results

Figure 10 shows the flow velocity results based on the PIV analysis of the images collected using the high speed camera positioned downstream of Outlet A.

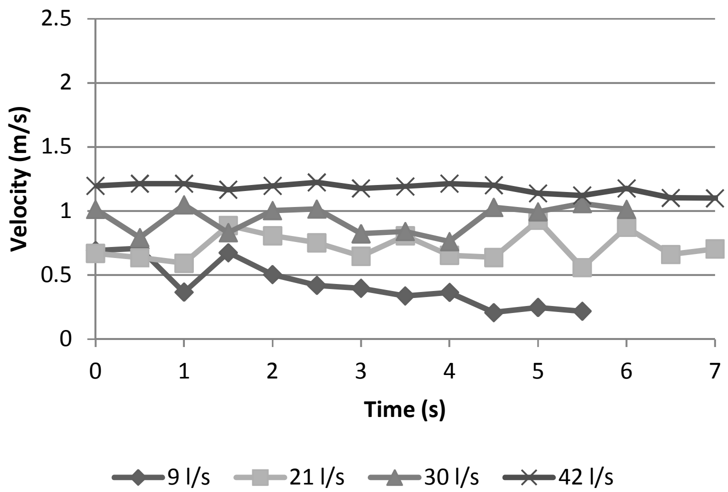

Figure 10 Flow Velocity Results Measured using Flourometry (Outlet A)

The results are limited in terms of the duration of each test at less than 7 seconds. However, clear difference can be seen in terms of the flow velocity profile for each of the tests reported. Fully primed flow conditions were observed during the 42 l/s test which is reflected in the velocity results. Sub-prime conditions were observed in each of the other tests which demonstrate a greater degree of flow variation.

Figure 11 shows the flow velocity results based on the PIV analysis of the images collected using the high speed camera positioned downstream of Outlet B.

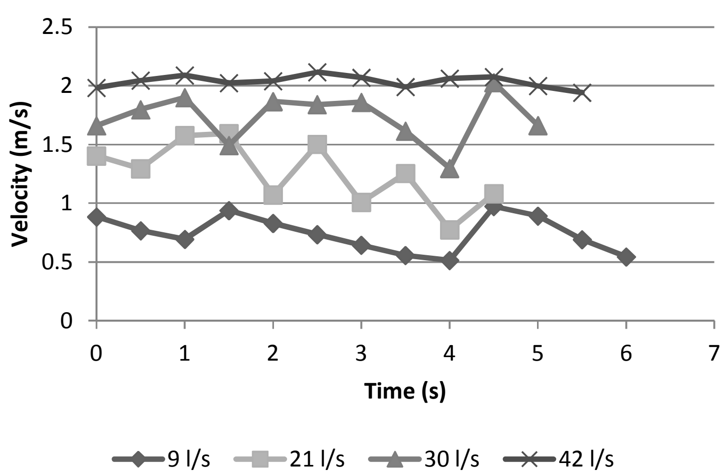

Figure 11 Flow Velocity Results Measured using Flourometry (Outlet B)

Similar to the results observed in Figure 10, fully primed flow conditions were evident during the test completed at 42 l/s. For each of the other tests reported, the flow velocity varied in comparison. The flow velocity measured during the 9 l/s test demonstrated a profile indicative of pulsed or plug flow. This was not observed downstream of Outlet A (Figure 10). This would suggest that within a multi-outlet siphonic system, different flow phases occur along the length of the horizontal carrier pipe.

2.3 Proposed Future Tests

During the feasibility tests, the methods of measurements were conducted independently to refine each scientific technique. The next phase of steady state tests will involve running each method of flow and pressure measurement simultaneously. This will provide a direct, temporal and spatial comparison between each of the methods of measurement. Furthermore, this will enable an evaluation of the interaction of flow and system pressures on proportionality and priming within a multi-outlet siphonic system for both sub-prime and primed conditions. Following this phase of testing and analysis, a systematic study of changes to the configuration of the outlets within the common gutter will be undertaken.

Acknowledgments

The authors would like to thank the help and support of Dr Martyn Bramhall of Fullflow Group Ltd, Dr Terry Lucke of the University of the Sunshine Coast and Professor Simon Tait of the University of Bradford.

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Study on new style trap and application in building drainage system

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Abstract
Trap in drainage systems acts as an integral part of a hygiene system in high-rise residential building, and provide an essential component in order to minimize the possible infection risk due to the transmission of contaminants from the drainage system. Generally, a drain trap is constructed with a minimum depth of 50mm seal water. Inappropriate design of the drainage system within existing buildings can cause some sanitary problems including air transient caused by discharges in the drainage stack and trap seal depletion. Nowadays, people are more aware of the importance of drainage system design and maintenance due to the SARS epidemic in 2003. The rapid spread of the SARS virus at Amoy Gardens housing in Hong Kong which provides a great lesson in the potential health risks attributed to the appliance trap seal depletion in the drainage system. Accordingly, the purposes of this research are developing a new style trap and confirm the device performance through investigate and experiment. A new style trap device which can improve seal trap depletion problem and enhance people's quality of life will be proposed and presented in this paper.

Keywords
trap, building drainage system, air pressure, building drainage system, trap seal depletion

1. Introduction

Building drainage system is one of the most essential facilities in building service engineering. The importance of building drainage system, which is a humble but very substantial issue, must not be ignored. However, Inappropriate design of the drainage system within existing buildings can result in some sanitary problems including air transient caused by discharges in the drainage stack and trap seal depletion. Nowadays, people are more aware of the importance of drainage system design and maintenance due to the SARS epidemic experience in 2003. The rapid spread of the SARS virus at Amoy Garden housing complex in Hong Kong provides a great lesson in the potential health risks attributed to a drainage system by highlighting the cross-contamination route caused by the appliance trap seal depletion. Therefore, the fundamental requirement of a building drainage system is to carry away sanitary appliance drainage and preventing foul odors into the habitable space from drainage network, which is important for the healthiness and comfort of living environment. Trap seal water in a drainage system acts as an integral part of a hygiene system in existing residential buildings, and provides an essential component in order to minimize the possible infection risk due to the transmission of contaminants and to safeguard occupied space from stench and vermin from the drainage network. Therefore, the building Technical regulations require that all sanitary equipment must install the trap.

According to the research point out [(1)], in the research of Heriot-Watt University, UK, uses a variable frequency generator to provide frequencies from 0.5 Hz to 30 Hz to assess the performance of drainage system. When the frequency is lower than 2.0 Hz it would generate large oscillations in the water surface of the trap, and the worst oscillations found at 0.5 Hz and 1.0 Hz. In 1997, Japanese research team also pointed out that the seal depth related with air pressure fluctuations in drainage stacks.

In order to enhance the performance of building drainage system, this research would integrate enterprise collaboration and focuses on the innovation of new technique of building water drainage equipment. The purposes of this project are developing a confluent unit device and confirm the performance of this new style trap through investigation and experiment. The practicability and relevant technical issues would be validated in this research. Meanwhile, the regulation proposal and certification process would be verified and proposed. A technique which can improve seal depletion of trap problem and enhance people's quality of life will be proposed and presented in this research.

2. Methodology

2.1. Mechanism and prototype

Generally speaking, the building drainage system design which is usually adopts "one sanitary with one trap". It was due to complicated construction processes that caused lose installing a trap. And if person need to clean the trap, it will affect the residents in one story below. In recent years, almost bathroom adopts wet-dry separation design. So if no one uses the bathroom space for a long time, it will cause seal depletion of trap problem and the odor leaks into the interior through pipes. Therefore, this study is developing a new style trap which can improve the seal depletion of trap problem. Up to the present, several types of the new style trap device have been developed and used in buildings. The concept of the new style trap is from oil/grease interceptor as shown in Figure 1. This device adopts centralizes water supply mechanism by collect the sewage from all sanitary equipment. For solve blocked drains pipes problem and cleaning needs, this device also has screens designed to filter impurities. The water outflow when the surface of the water reaches the line effluence out of the system. All sanitary equipment only needs install one trap device which can avoid problem of complicated drainage system, reduce waste materials and assures the water-tightness According to the development prototype of oil/grease interceptor theorem [11, 12], the advantages of the new style seal trap are water supply immediately and the drainage system simple as shown in Figure 2. It can improve the seal depletion problem and suitable for bathroom space use in house.

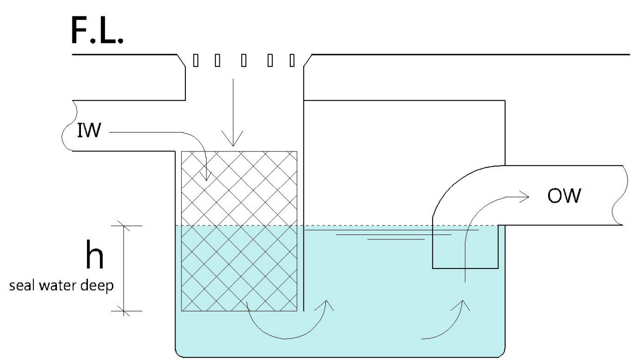


Figure.1 The concept of the oil/grease interceptor

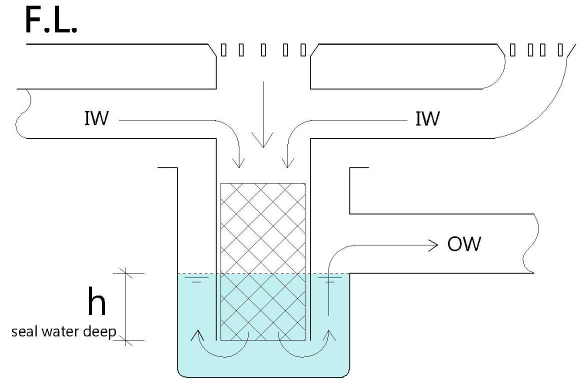


Figure.2 the concept of the simplify oil/grease interceptor

2.2. Trap device and piping system

Figure 3 shows the plumbing drainage design for toilet which was usually adopts "one sanitary with one trap". If the sanitary equipment not be used about 4-5 days, it will cause the seal depletion and the sewage odor into the interior environment trough the drain. Figure 4 shows the new plumbing drainage design for the new style trap in toilet. All sanitary equipment which is used only one new style trap in a toilet. And this device adopted centralizes water supply mechanism by collect the sewage from all sanitary equipment for improve the seal depletion problem. This device has steady seal water and simple drainage system design. If needs to install the new style trap, it must increase the thickness of floor and this device shall be installed among the floor or exposure pipe design which can let us maintain drainage system more easily. The overall drainage system design is simpler as shows in figure 5. It can reduce the waste plumbing materials and complicated drainage system.

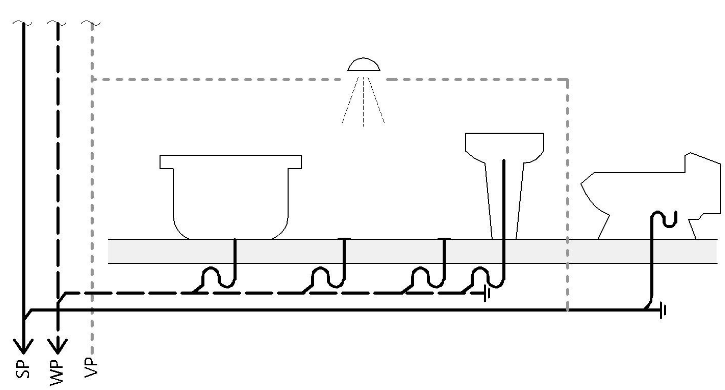


Figure.3. Traditional plumbing configuration in bedroom(11)

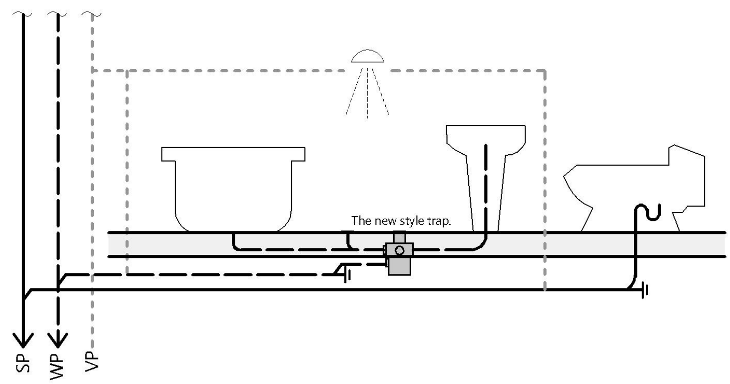


Figure.4 the plumbing configuration of the new style trap in bedroom(11)

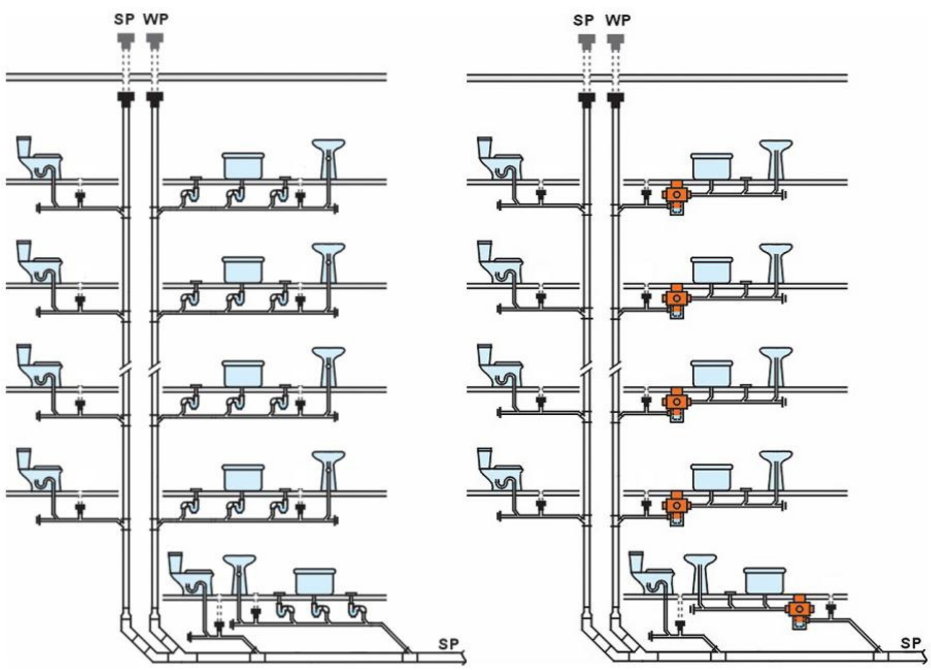


Figure.5. Comparison of differences of the plumbing design between the trap and new style trap(11)

2.3. Structure and construction.

There are four installed type in new style trap which can accord the user needs to select the construction method. Designer must take into account overall drainage system design for the new style trap in design stages. First, the construction of the embedded type which is must increase the thickness of floor and the new style trap shall be installed among the floor as shows in figure 6. On the other hand, if the trap breakdown or water-tightness reduced, it will be difficult to find drainage system problem and maintain as shown in the Fig.6.

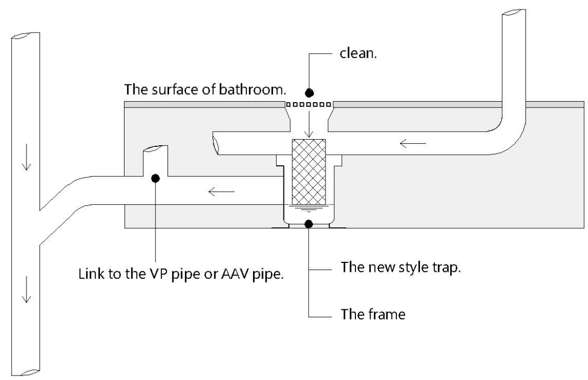


Figure.6. Embedded (lower panels) (11)

Second, this type adopts the double-floor and the trap shall be installed above the second floor as shows in figure 7. The second floor can be as partition for the householder in one story below. So, in order to assure the performance of drainage system, person can open floor drain cover to make routine maintenance which can not affect the residents in one story below. It's more suitable for householder with high indoor environmental quality space and more frequent interior design updates.

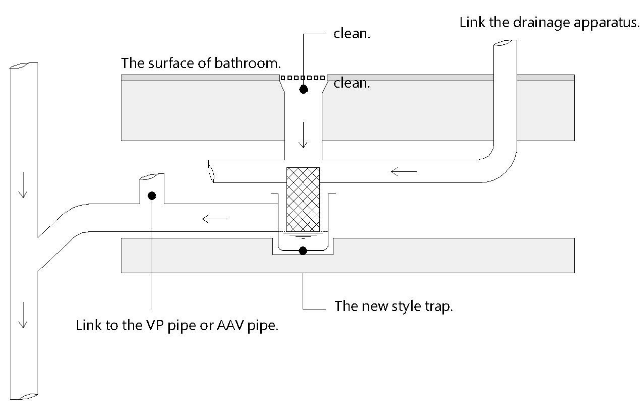


Figure.7.The embedded type (double floor) (11)

According to the existing research point out, some country often adopts exposure pipe design which can easily find drainage system problem and maintain. In this construction method, it adopts the suspended type as shows in Figure 8. The new style trap shall be installed under the floor. But limited in residential floor height in Taiwan, the exposure pipe which would affect use of interior space; lead to the interior space is uncomfortable. It's more suitable for the space with sufficient the indoor height, such as office building or department store. Finally, figure 9 shows the half-buried type. The plumbing design is similar with the suspended type. The half part of trap shall be installed among the floor. It's more suitable for residence house use.

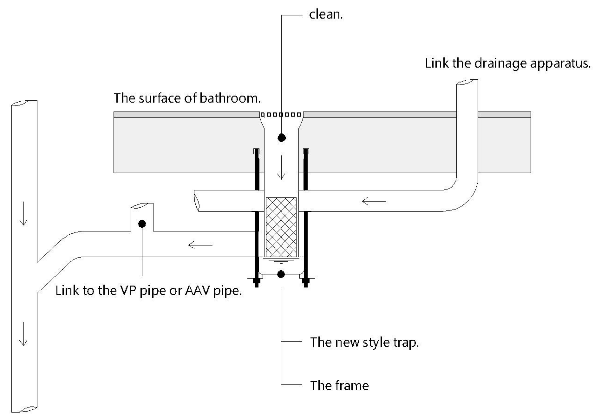


Figure.8. The suspended type(11)

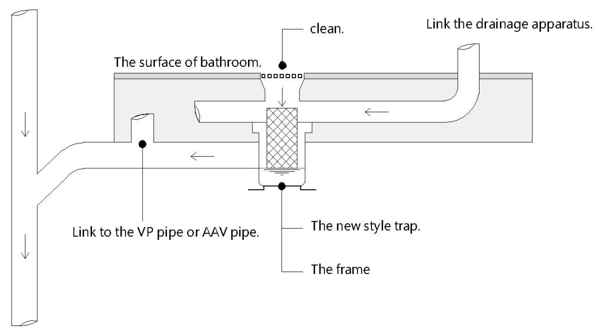


Figure.9. The Half buried type(11)

3. Investigation and case study

In recent years, due to the improvement of building technology and upgrade quality of the life, the function of building not only provide a shelter for external climate but also have to satisfy all demands for daily life. As we know, the construction needs to combine with the equipment system effectively in the building which can offer the convenience and comfort. Therefore, this research is focused on the new style trap developing and confirms the performance of this new style trap through investigation and experiment .To compares the drainage performance between the different kinds of the trap.

According to investigate result point out, the new style trap has been used in new buildings since 2006. Designer must take into account overall drainage system design for the new style seal trap in design stages. So the new style tarp mostly used in new buildings which cases is no more than 10 years and concentrated mainly in central and southern Taiwan. So far, other derivative of the problem has not been found in the survey.

In this study, we choose one of the companies to visit the new style trap device as shows in figure 10.And use the shower simulation to analysis the performance of the new style trap within the bathroom space. The result shows that the seal water depth is steady when sewage discharges from sanitary equipment. On the other hand, having blocked drains pipes by hairs is a very regular home issue. So this device has screens design to filter impurities. People only need to open the floor drain cover to clean your own trap.

Figure.10. Simple facilities of the new style trap device

In this case, the new style tarp has been installed in toilet space. Turn the faucet on to test the device performance as shows in figure 11. The result shows that the trap seal water is not easy to depletion by centralizes water supply design. Besides, this device has screens design to filter impurities which can help us maintain drainage system more easily.

Figure.11. Observation of the new style trap

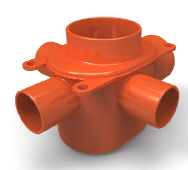
According to the existing research point out, the max flow rate of sanitary equipment is the bathtub. In order to assure the performance of the new style trap, we used the bathtub with full water and bubble to test the performance of trap seal when full drainage load in drain. The result shows that the new style trap has the steady seal water depth and the bubble has not backflow in low-rise building as shown in Figure 12.Besides, the trap installation and cleaning is more easily . In the future, this research will use a test tower as well as an existing building (around 40-meters high) to confirm the performance of the new style trap in high-rise building

Figure.12.Performance test of the new style trap

4. Analysis and discussion.

Owing to the new style rap has simple plumbing design, this device which can improve problem of the building drainage system including the complex plumbing , difficult to installed seal trap and water-tightness is not good. Besides, this device has screens design to filter impurities for solve the problem of drains pipes blocked which without damage to the floor. But designer must take into account overall drainage system design for the new style trap in design stages. So the new style trap would be used in new buildings. Because the new style rap device has not yet guided the legalization, this unit device has not been universality in Taiwan.

Table.1 Compare the performance of seal trap in difference type

type	The type seal trap.	The new style seal trap
photo		
The seal water depth in law	50mm	-
the number of apparatus	1	1~4
Noise	loud	quiet
The installed location	installed under the floor	installed under/ among the floor
The piping system	complicated	simple
Cleaning needs	difficult	more easily
object	Used in all buildings	Used in new buildings.

5. Conclusion

The major function of the building drainage system is to ensure proper operation and to keep a clean and health interior space for human's life. Therefore, there usually exists an interior health problem from trap seal depletion in general building in Taiwan. This project has developed the new style trap device and preliminary confirms the performance of trap seal in low-rise buildings. So far, there is no Law and regulation for test the performance of the new style trap including seal water depth and permit drainage flow. Therefore, this research will use a test tower as well as an existing building (around 40-meters high) to confirm the performance of the new style trap in high-rise building. All research results will be the contribution and guideline of legalization procedure which can assist to development of new technique and new construction method.

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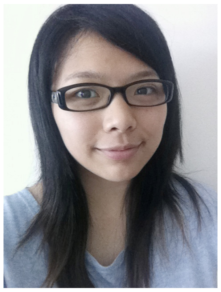

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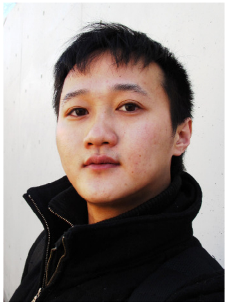

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Vibration Reply Relations of Pressure in Drains and Trap Seal Water

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Abstract

SHASE-S 218 (Heating, Air-Conditioning, and Sanitary Standard) stipulates that the evaluation standard for performance of drainage system fall within ±400 Pa. However, the vibration and loss of trap seal water should be regarded as a vibration reply phenomena, which is produced by a compelling force of pressure in pipe, and the standard value cannot necessarily be considered optimal.

Therefore we built a stack vent drainage system in an actual size drainage experiment tower to carry out an experiment under constant discharge load. We analyzed the relationship between the pressure in pipe vibration and seal vibration obtained in three types of test traps, and classified pressure vibration into three categories: pulse wave, consecutive wave and standing wave. Then we clarified influences that each type of pressure vibration exerted on seal vibration.

Keywords

Drainage system, trap, induced siphonage, vibration reply phenomena

1 Introduction

Pipe diameters in a drainage system are determined based on the estimate of discharge load (discharge flow rate) in such a way that discharge load in each pipe should not exceed its permissible flow rate. In application to induced siphonage, permissible flow rates of drainage stack are determined based on permissible seal loss in trap or permissible pressure in drain pipe. "Pneumatic pressure in drain pipe" is simply referred to as "pressure" below. In Japan permissible seal loss is specified as half (25 mm) the minimum seal depth (50 mm), permissible pressure as ±400 Pa, and water full ratio (the ratio of flow cross section to pipe cross section) as 0.2 to 0.3 depending on the type of ventilation. Permissible flow rate is regarded as annular flow within a drainage stack. SHASE-S 206 stipulates the predicting method of discharge load and calculating method for drainage pipe diameters based on water full ratio, while SHASE-S 218 stipulates permissible seal loss and pressure.

SHASE-S 218 describes the test method of determining drainage capacity (permissible flow rate) in drainage systems with special drainage fittings (single drainage stack system with special fittings), and both permissible seal loss of 25 mm and permissible pressure of ±400 Pa are used as the judging standard. To obtain the maximum and minimum permissible pressures, the measurement data have been low-pass filtered (LPF) at 3 Hz. This frequency was selected based on the natural frequency of trap (2 Hz) and the response characteristics (3 Hz) of pen recorders that had been generally used when the standard was established.

On the other hand, as studies into performance of trap against pressure fluctuation revealed response characteristics of seal vibration represented as consecutive phenomena, it became evident that pressure could not be properly evaluated in terms of amplitude values alone.

That being the case, the authors conducted a series of experiments in a real-scale drainage tower and analyzed the obtained data of pressure fluctuation and seal fluctuation to clarify the effects of pressure waves on seal fluctuation.

2 Drainage experiments in a real-scale drainage tower

2.1 Purpose

The purpose of the experiments was to obtain data on pressure fluctuation in horizontal branch pipes on each floor, and seal fluctuation and residual seal depth in each type of test trap when steady discharge load as designated in SHASE-S218 was applied.

2.2 Experimental drainage system

Figure 1 indicates the outline of the real-scale drainage tower. Three types of test drainage systems were prepared: a single 8-story stack vent system with JIS fittings (referred to as the JISF system below), an 8-story drainage system with special drainage fittings (the SDF system), and a 15-story SDF system.

2.3 Test traps

Three types of traps, P trap, bell trap, contrary bell trap, were used as test traps. Their basic parameters are shown in Table 1.

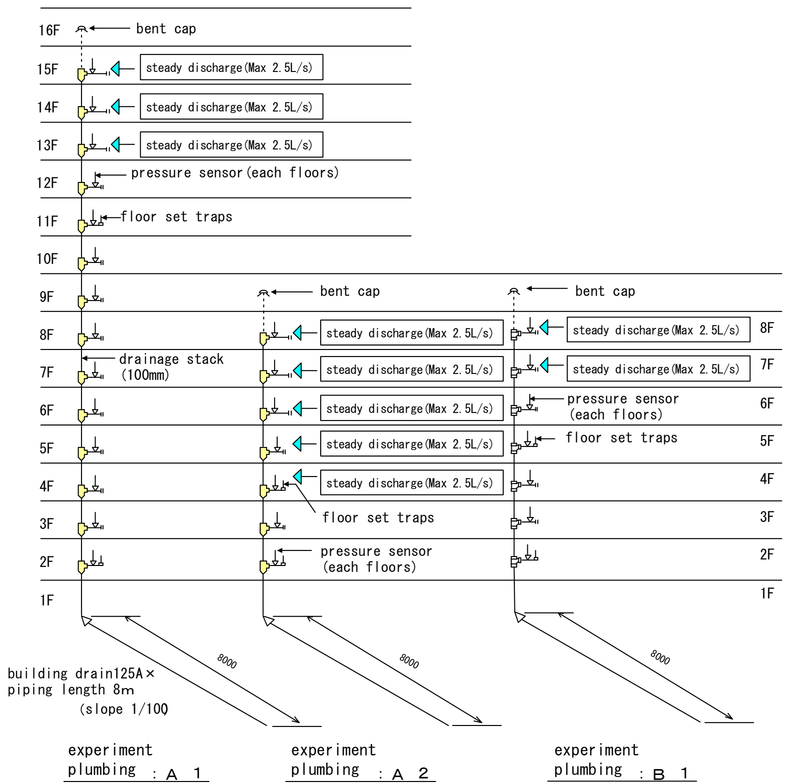

Figure 1 - Outline of the real-scale drainage tower

Table 1 - Basic parameters of traps

Test traps	Seal volume [cc]	Seal depth [mm]	Ratio of leg's sectional areas
P trap	150	60	1.00
Bell trap	550	53	1.41
Contrary bell trap	410	50	1.26

2.4 Method

A test trap filled with water was placed on the floor where maximum negative pressure was predicted, and steady discharge load based on target pressure values was applied. The raw data on pneumatic pressure fluctuation and seal fluctuation were collected and processed with sampling interval of 20ms without LPF. Measurements were made within a period of one minute after discharge flow became stable.

The target pressures were set at -200 Pa and -400 Pa for the 8-story JISF system and 8-story SDF system, and -100 Pa, -200 Pa, -300 Pa, -400 Pa for the 15-story SDF system. These values were achieved by adjusting discharge load. Table 2 shows discharge flow rate (Q_w) set for each drainage system. For instance, the discharge flow rate at -400 Pa in the SDF system was 10.0ℓ/s, three times as large as that in the JISF system (2.9ℓ/s), revealing an extremely high performance of the SDF system.

Table 2 - Discharge flow rate of drainage system

8-story JISF system		8-story SDF system		15-story SDF system	
Target pressure [Pa]	Discharge flow rate [ℓ/s]	Target pressure [Pa]	Discharge flow rate [ℓ/s]	Target pressure [Pa]	Discharge flow rate [ℓ/s]
-100	—	-100	—	-100	2.4
-200	1.8	-200	6.5	-200	4.1
-300	—	-300	—	-300	5.0
-400	2.9	-400	10.0	-400	7.0

3 Analysis of pneumatic pressure and seal fluctuation

3.1 Relationship between maximum negative pressure and seal loss

3.1.1 Purpose

Previous studies demonstrated a high correlation between seal loss and maximum negative pressure. The maximum negative pressure was obtained by low-pass filtering experimental data at 3 Hz. As described above, the cut-off frequency of 3 Hz was determined based on the response characteristics of pen recorders. In order to select an appropriate cut-off frequency, maximum negative pressure at each cut-off frequency were compared, and then a correlation between maximum negative pressure and seal loss of trap was confirmed.

3.1.2 Method

Pressure data obtained from the experiments using the real-scale drainage tower were low-pass filtered at 3 Hz, 4 Hz, and 5 Hz, and a comparison was made between the low-pass filtered maximum negative pressure and those that weren't low-pass filtered. Then the relationship between the low-pass filtered maximum negative pressure and seal loss was expressed in a linear regression equation and coefficient of determination for each trap (referred to as R^2 below) was obtained to confirm the correlation.

3.1.3 Results

Figure 2 indicates fluctuations of maximum negative pressure at each cut-off frequency. There were no significant differences among drainage systems in the changes in low-pass filtered maximum negative pressure value for each test trap. The linear regression equation for maximum negative pressure and seal loss without LPF treatment is shown in Figure 3, and the mean R^2 values of each drainage system at 3 Hz, 4 Hz and 5 Hz in

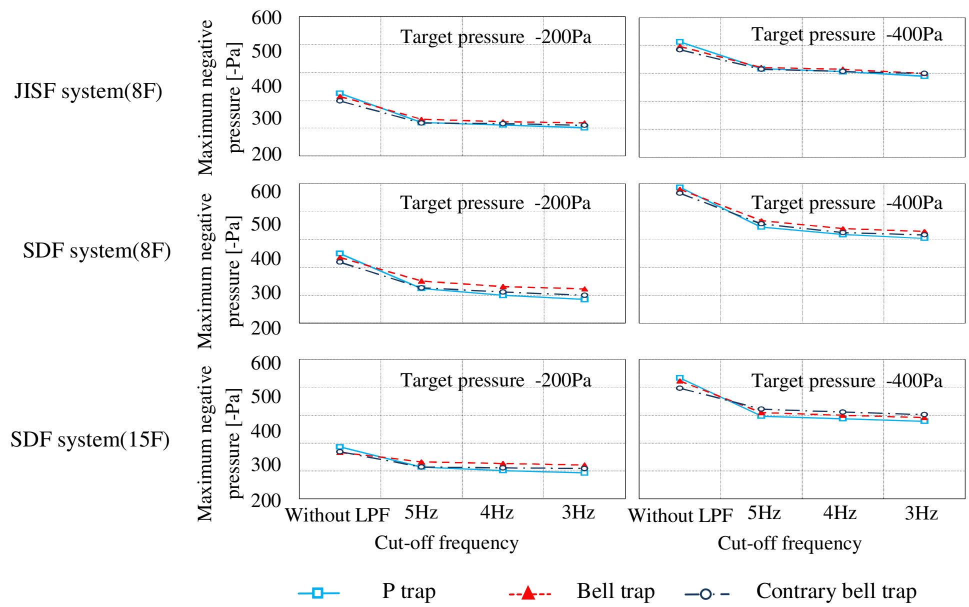

Figure 2 - Fluctuations of maximum negative pressure at each cut-off frequency

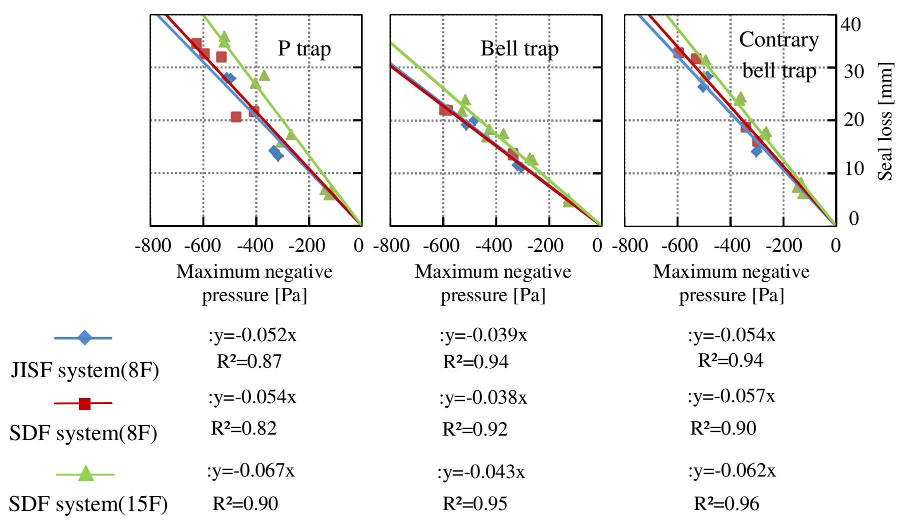

Figure 3 - Linear regression equation for maximum negative pressure and seal loss without LPF treatment

Figure 4. As seen in Figure 3, R^2 based on the entire data exceeded 0.82 confirming a strong correlation between maximum negative pressure and seal loss. Figure 4 indicates that although the average values of R^2 went up after LPF treatment, there was no significant difference in R^2 among cut-off frequencies. Therefore the most appropriate cut-off frequency for LPF was found to be 3 Hz.

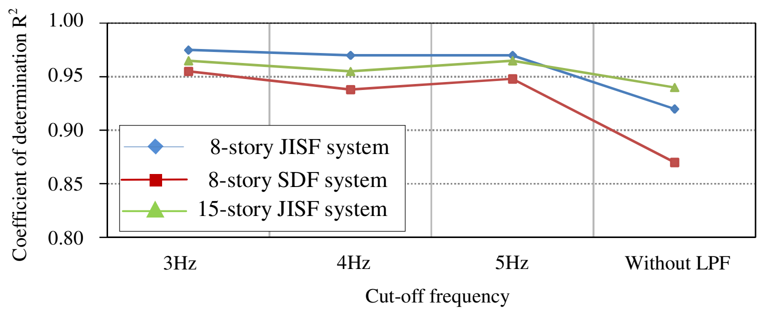

Figure 4 - R^2 values of each drainage system at 3 Hz, 4 Hz and 5 Hz

3.2 Relationship between pressure fluctuation and seal fluctuation

3.2.1 Purpose

Vibration of trap seal water is a complex response phenomenon caused by pneumatic pressure fluctuations inside drainage pipes, and vibrational characteristics are expected to vary depending on the types of trap or the makeup of a drainage system. To shed some light on the matter, the authors collected data on pneumatic pressure fluctuation and seal water fluctuation in traps from experiments using a real-scale drainage tower for comparison.

3.2.2 Method

Based on the data obtained from experiments with a real-scale drainage tower, the authors graphically superimposed the wave profile of pressure fluctuations and that of seal water fluctuations. The authors then analyzed response characteristics of seal water in trap to pneumatic pressure fluctuations for each type of trap, fitting and conditions of drainage systems on the different floors.

3.2.3 Results

Figures 5 show the pneumatic pressure fluctuations and seal fluctuations for each experiment condition.

(1) Comparison by the type of trap

P traps showed more pronounced fluctuations at -400 Pa, and fluctuations tended to grow larger with time than bell traps or contrary bell traps. This may be attributed to the fact that P traps, having a simple tubular structure, sustained seal fluctuation longer than other types of trap helped by inertial force.

On the other hand, bell traps and contrary bell traps that have complex structures produced smaller range of seal fluctuations than P traps at all the target pressures, and fluctuations remained within a certain range of amplitude while pressure were applied.

(2) Comparison by the type of drainage system
The authors compared the seal fluctuation wave patterns of the 8-story SDF system with those of the 8-story JISF system, and found out that the SDF system tended to produce larger seal fluctuations than the JISF system in all of test traps. This tendency may be attributed to different pressure fluctuation ranges in each drainage system. As pressure fluctuation range is thought to be proportional to discharge flow rate, we divided the standard deviation of pressure fluctuation σ by discharge flow rate (Q_w) to obtain σ'（ =σ/Q_w） . As is shown in Table 3, σ in the SDF system was approximately twice as large as that in the JISF system. It was also found that σ changed proportionally with discharge flow rate. There was a large difference in σ' between the JISF system and SDF system with σ' of the JISF system 20 and that of the SDF system 11.

(3) *Comparison by the different scales of drainage systems*
The authors compared the fluctuation wave patterns of the 8-story SDF system with those of the 15-story SDF system, and found out that the 8-story SDF system produced larger seal fluctuations than 15-story SDF system. σ and σ' of pressure fluctuation are shown in Table 3. Though σ at each target pressure was larger in the JISF system than in the SDF system, there was no significant difference in σ' between the systems. From this and the results described in (2) above it can be assumed that large amplitudes of seal fluctuation are produced with large discharge loads even when the minimum pressures remain the same and that amplitudes of pressure fluctuation depended heavily on the type of drainage system (kind of drainage fitting) used.

3.3 Pulse wave and consecutive wave

3.3.1 Purpose
Two different types of waves have been observed in the previous studies: one that indicates sudden upward thrusts of pressure in a very short period of time (the pulse wave) and the other that results from large fluctuations of seal water rather than pressure (the consecutive wave). However, these two types of waves have never been clearly distinguished. The authors reconsidered the criterion of distinguishing pulse waves from consecutive waves, and analyzed their effects on seal water inside traps.

3.3.2 Method
The authors divided up the data of pneumatic pressure and seal fluctuation into segments approximately 2 seconds each, and distinguished pulse waves from the consecutive waves by the difference between the minimum pneumatic pressure P_i[mmAq]

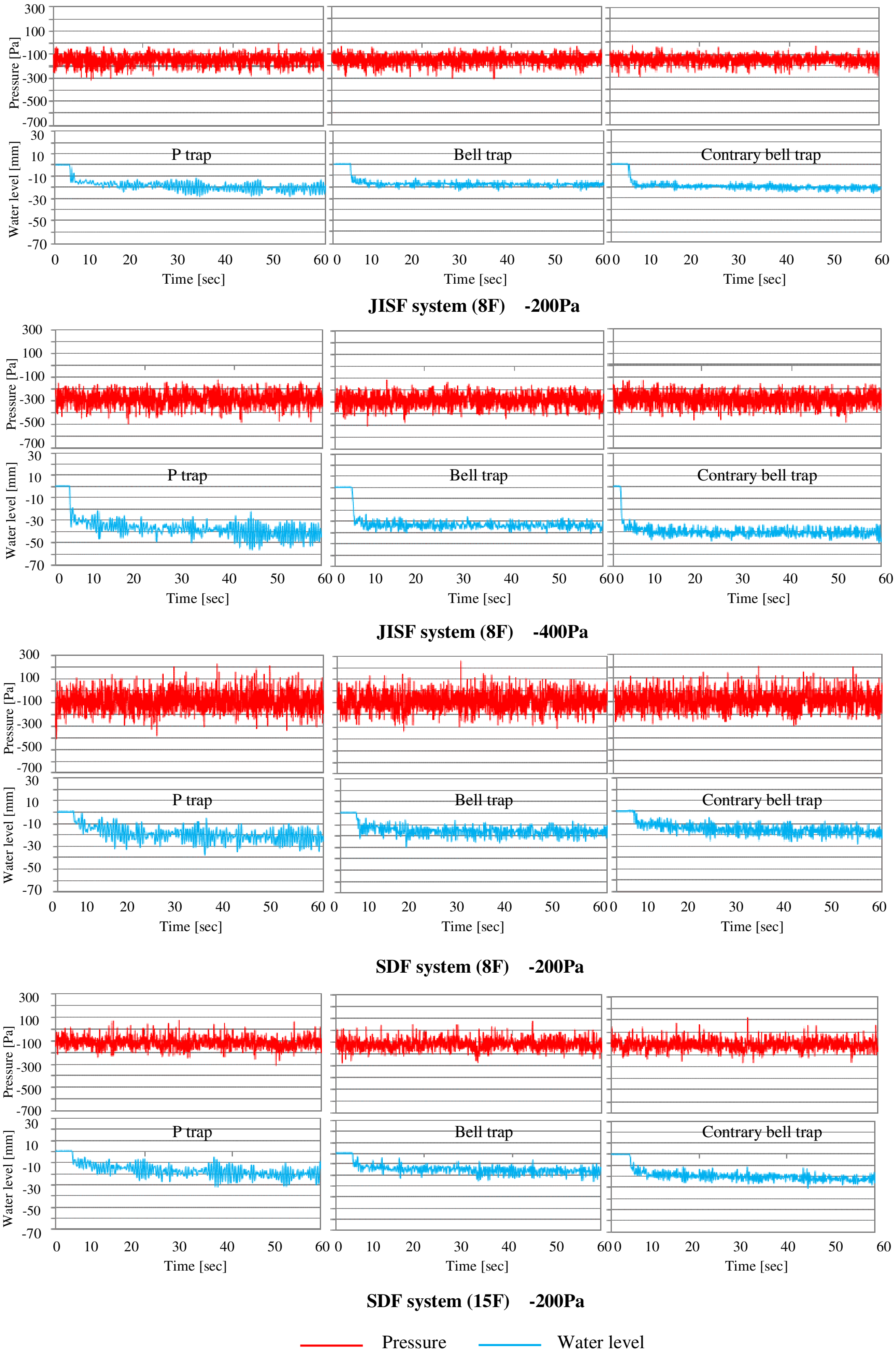

Figure 5-1 - Pneumatic pressure fluctuations and seal fluctuations (1)

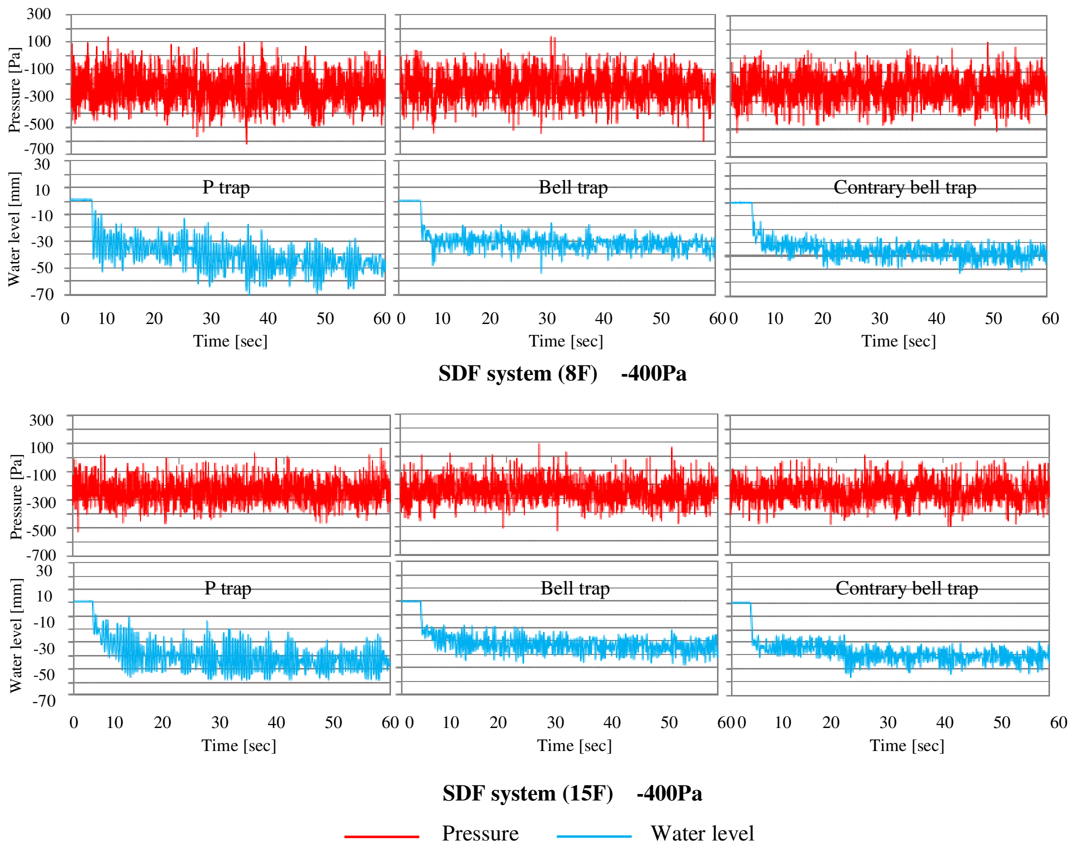

Figure 5-2 - Pneumatic pressure fluctuations and seal fluctuations (2)

Table 3 - Standard deviation of pressure fluctuation

Optimum Pressure[Pa]	JISF System(8F)			SDF System(8F)			SDF System(15F)		
	σ	Q_w[ℓ/s]	σ/ Q_w	σ	Q_w[ℓ/s]	σ/ Q_w	σ	Q_w[ℓ/s]	σ/ Q_w
-100	—	—	—	—	—	—	24.1	2.4	10.0
-200	39.5	1.8	21.9	76.4	6.5	11.8	43.3	4.1	10.5
-300	—	—	—	—	—	—	56.1	5.0	11.2
-400	52.7	2.9	18.2	121.6	10.0	12.1	75.6	7.0	10.8

and the minimum seal water level H_i[mm]. The measurements with $P_i - H_i \geq 5$ were categorized as pulse waves, those with $H_i - P_i \geq 5$ as consecutive waves. In addition those with $|P_i - H_i| < 5$ were classified as steady waves, and the authors checked for correlation between pressure and seal level at points when pulse waves, consecutive waves and steady waves were produced.

The authors also analyzed the effects that pulse waves and consecutive waves had on seal water, and compared them with the effects of steady waves on seal water by obtaining the ratio of the regression coefficient of pulse and consecutive waves to the regression coefficient of steady waves.

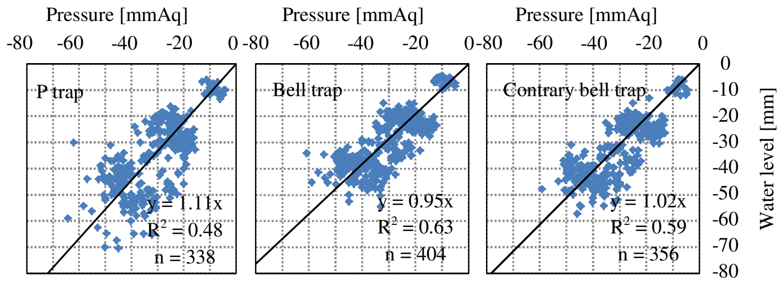

Figure 6 - Scatter diagram of pneumatic pressures and seal levels for each test trap

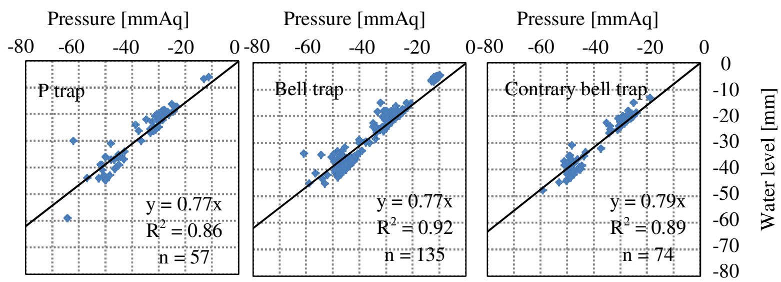

Figure 7 - Scatter diagram of pneumatic pressures and seal levels for each test trap (pulse wave)

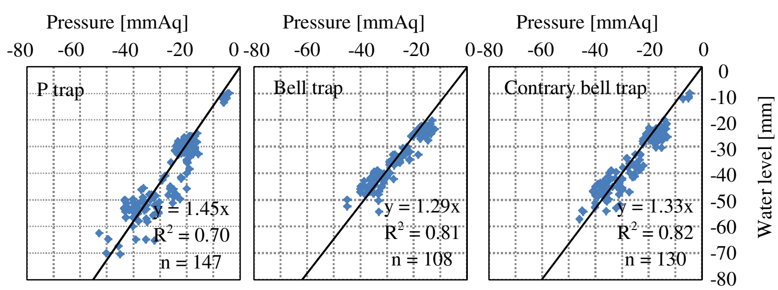

Figure 8 - Scatter diagram of pneumatic pressures and seal levels for each test trap (consecutive wave)

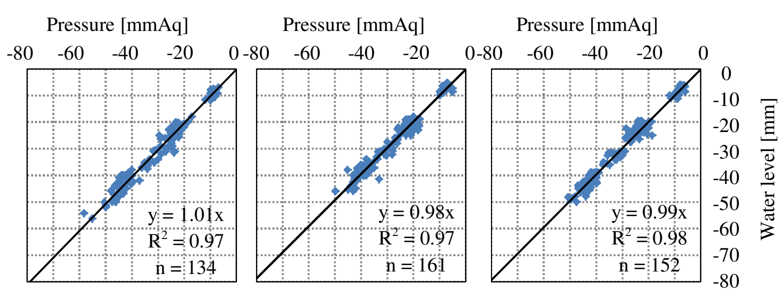

Figure 9 - Scatter diagram of pneumatic pressures and seal levels for each test trap (standing wave)

3.3.3 Results

Figure 6 indicates a scatter diagram of pneumatic pressures and seal levels for each test trap before classification, and Figures 7 ~ 9 show scatter diagrams after the measurements were divided up into pulse, consecutive and steady waves. R^2 values of all pulse and consecutive waves were 0.70 or larger confirming a high correlation. This seems to lend credence to the appropriateness of the selection standard described in 3.3.2.

Table 4 shows the ratios of regression coefficient. Since the regression coefficient ratios of pulse and consecutive waves in each trap were in rough agreement, it can be safely assumed that pulse waves and consecutive waves have similar effects on seal water regardless of the type of trap used.

Table 4 - Ratio of regression coefficient on each test traps

Test traps	The ratio of regression coefficient(pulse wave)	The ratio of regression coefficient(consecutive wave)
P trap	0.76	1.43
Bell trap	0.79	1.33
Contrary bell trap	0.80	1.34

4 Conclusion

The authors have drawn the following conclusions based on the results of the present study:

1) Although a higher correlation was seen between maximum pressure load and seal loss after LPF treatment, no significant difference attributable to cut-off frequency was observed. Therefore the standardized frequency of 3 Hz seems appropriate.
2) Seal fluctuation relative to pneumatic pressure fluctuation varies considerably depending on the structure of trap.
3) The amplitude of seal fluctuation becomes larger along with increase in discharge flow rate even when pressure remains the same.
4) R^2 values for each types of wave (pulse, consecutive, steady) were larger than 0.70 indicating a high correlation between the maximum pressure load and seal water level. In addition, it can reasonably be assumed that the effects of pulse waves and consecutive waves on seal water were similar regardless of the type of trap used for regression coefficient ratios of pulse and consecutive waves for each trap were generally in agreement.

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The development and drainage performance evaluation of a swivel air-admittance Valve fitting for drainage systems for detached houses

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Abstract

In Japan, there is not a well-established method for installing vent pipes used in drainage systems for detached houses, and therefore, there is a high risk of broken trap seals within the drainage system. The authors developed a special fitting ("air-admittance valve fitting" hereafter), which enables better drainage performance, by combining two functions of the air-admittance valve; the suction function and the ability to moderate the airflow resistance generated by the influx of drainage water in to the stack, and presented the advantageous effects of the air-admittance valve fitting at the 35th International Symposium of CIB W062 in Germany in 2009.

This paper presents the development of a new swivel air-admittance valve fitting with further improvements and better work efficiency, and examines its effectiveness by

setting up a condition similar to that of drainage piping for the real housing, which is subjected to the application of constant flow load and fixture drainage load.

Keywords
Detached house; Swivel Air Admittance Valve; Drainage System

1. Background

In Japan, unlike for high-rise buildings, there is no clear guideline provided by any standards for the design and construction of single-family houses. This has been causing some problems to drainage systems for single-family houses, as shown in Fig. 1 (1)-(5), and these problems were indicated and an evaluation method was reported at the International Symposium of CIB W062 held in Portugal in 2011[5)]. Among these problems, particularly challenging is (2) Reduction of resistance to the airflow in the fitting section of the drainage stack; the fitting section is likely to be blocked by drainage water, causing a considerable amount of resistance to the airflow. To address this problem, a swivel air-admittance valve fitting ("previous-developed fitting" hereafter) was developed with an effect of easing airflow resistance, and the results of laboratory testing on drainage performance using the fitting were reported at the International Symposium of CIB W062 held in Germany in 2009[4)].

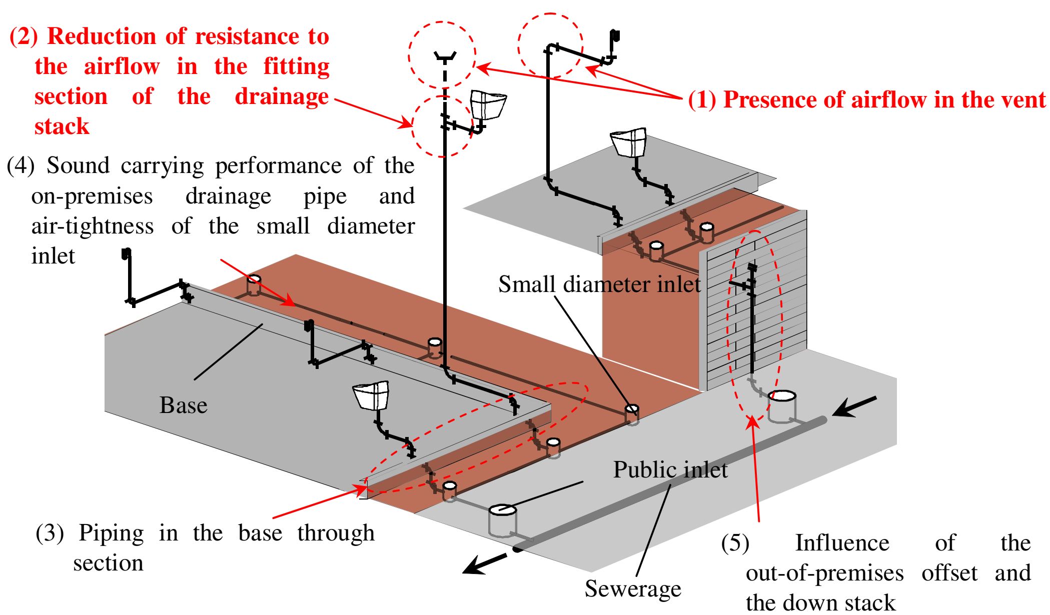


Fig. 1 Problems with the common drainage system for detached houses [5)]

2. Objectives

With the abovementioned background, this study discusses the following four points, using a newly-developed small swivel air-admittance valve fitting ("improved fitting" hereafter), with the main focus on two-storey houses, which are approx. 81% of the detached houses built in Japan, and three-storey houses, which are much in demand for the purpose of accommodating two families in one and are 3% of the detached houses built in Japan.

(1) Comparative examination of the commonly available JIS-DT fitting, the previously reported previously-developed fitting and the improved fitting in relation to drainage performance

(2) Comparison among the commonly available JIS-DT fitting, the previously reported previously-developed fitting and the improved fitting in relation to the influence thereof on drainage performance when applying the fittings to an offset pipe respectively

(3) Examination of drainage performance by using experimental drainage piping models, which are supposed to be of a sewage system and a miscellaneous drainage system, with the improved fitting is applied thereto

(4) Examination of drainage performance by using the improved fitting installed to the drainage system of a real two-storey detached house, and the evaluation of the effectiveness of the improved fitting

3. Experiment overview

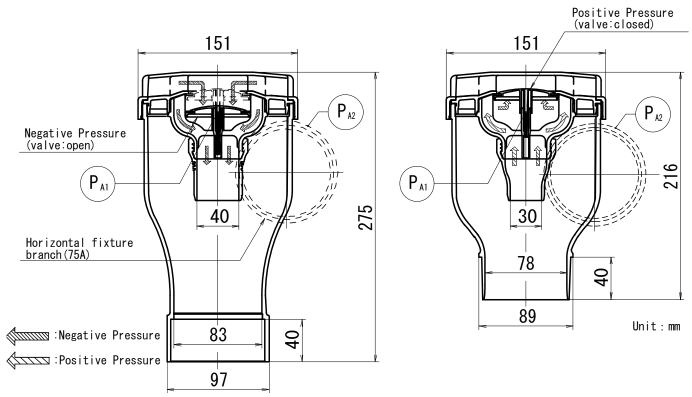
3.1 Swivel air-admittance valve fittings

Fig. 2 shows the structure and dimensions of the swivel air-admittance valve fittings, both the previously-developed type and the improved type, while Photo 1 shows the exterior appearance thereof. The fittings are connected to a horizontal fixture branch or a plumbing fixture pipe on the top floor of a drainage stack system. These fittings are provided with the function of an air-admittance valve, from which the air is allowed to flow, whereby providing an advantage of eliminating the need for installing a vent pipe. These fittings are also space savers. Furthermore, additional ideas are also implemented with the fittings, i.e. positioning the drainage inlet and the drainage stack off-centre, which allows the drainage water to flow in a swirling manner, and providing an air passage in the centre part of the stack, which eases airflow resistance.

Fig. 2 (1) shows the previously-developed fitting. The height of the fitting is 275 mm, which is taller than the improved fitting, and this has always caused problems, in practical terms, i.e. making it hard to confirm the proper connection of the fitting from the floor thereabove, as shown in Fig. 3 (1), and requiring some adjustment to under-floor installation. To solve the abovementioned problems, the height is reduced to 216 mm in the improved fitting, as shown in Fig. 2 (2), to enable above-floor plumbing, i.e. better workability, as shown in Fig.3(2).

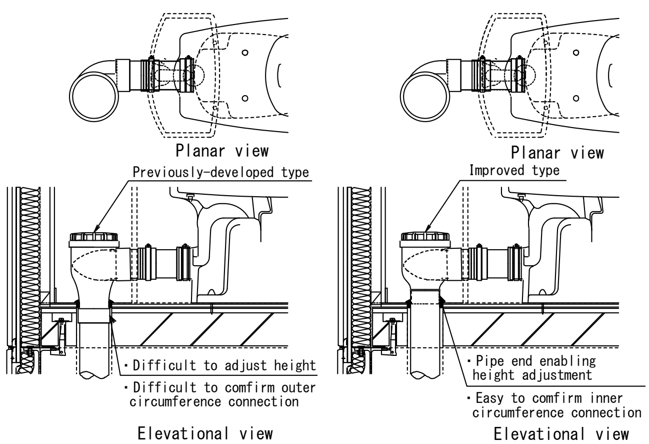
(1) Previously-developed type (2)Improved type

Photo 1 Exterior appearance of swivel air-admittance valve fittings



(1) Previously-developed type (2)Improved type

Fig.2 Structure and dimensions of swivel air-admittance valve fitting



(1) Previously-developed type (2)Improved type

Fig.3 Workability before and after improvement(above-floor plumbing)

3.2 Verification overview

The experiment includes two types of testing; testing on drainage piping models in the laboratory and testing on the drainage system of a real detached house.

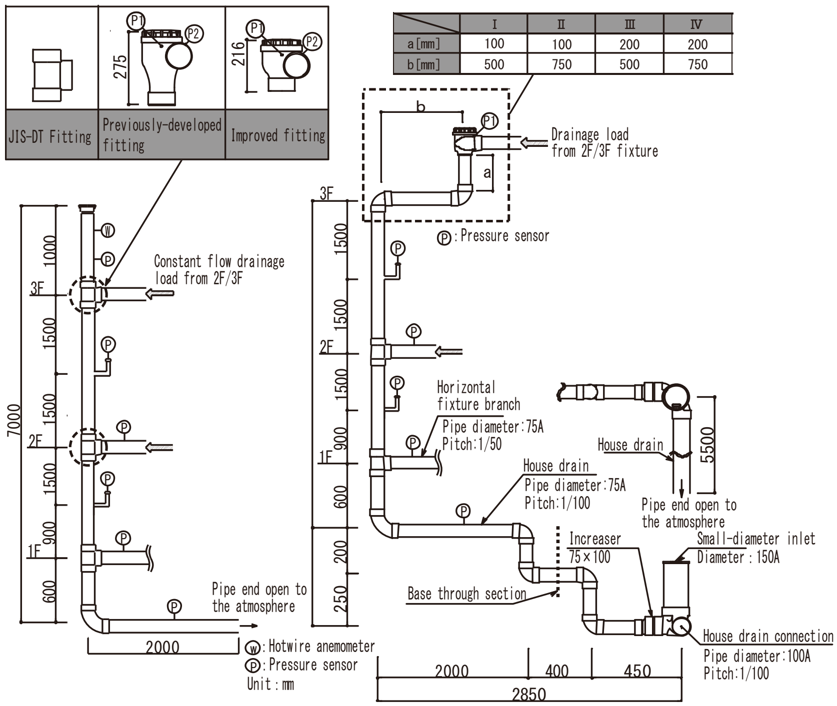
The laboratory testing includes two tests; a constant flow load test (1) and a fixture drainage load test (2). The constant flow load test (1) uses three types of fittings to understand how different shapes of fittings affect drainage performance. The fixture drainage load test (2) uses plumbing fixtures and examines how drainage performance is affected by fixture drainage loads, simulating that the loads are applied to a real sewage system and miscellaneous drainage system.

The testing on the real house drainage system uses the sewage piping of a two-storey detached house in Tokyo to evaluate the effectiveness of the improved fitting which is installed immediately underneath the 2nd floor toilet.

3.3 Experimental drainage stack systems

3.3.1 Laboratory testing

Fig. 4 shows experimental drainage stack systems used for the testing. The systems each have three storeys above ground and employ a single stack system using the JIS-DT fitting. The diameter of the stack is 75A, and the diameter of the horizontal fixture branch is 75A (pitch: 1/50), and the diameter of the house drain is 75A (pitch: 1/100). The constant flow load test (1) uses the stack system in Fig. 4 (1), and the JIS-DT fitting, the previously-developed fitting and the improved fitting are used respectively in the fitting section of the stack system. When the JIS-DT fitting is installed, two configurations are provided for the test; with a bellmouth attached to the top end of the vent pipe, and with the top end closed allowing no ventilation. The fixture drainage load test (2) uses the stack system in Fig. 4 (2) and two configurations are provided for the test; with the stack straight down, and with offset plumbing, as shown in Photo 2, in consideration of realistic plumbing conditions. Incidentally, four different dimensions of offset plumbing (portion (a) mm × portion (b) mm) are shown in Fig. 4, represented as I-IV.



(1)Constant flow drainage load test (2)Fixture drainage load test

Fig.4 Experimental drainage stack system

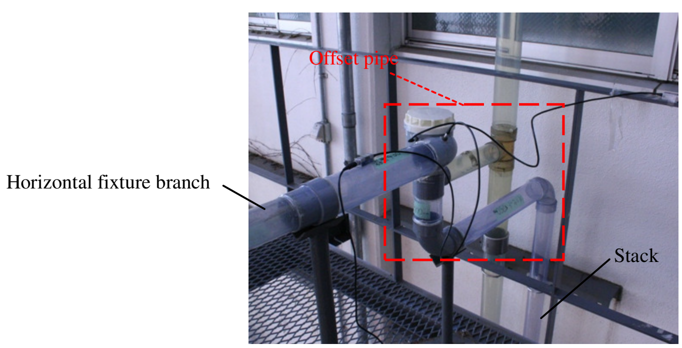
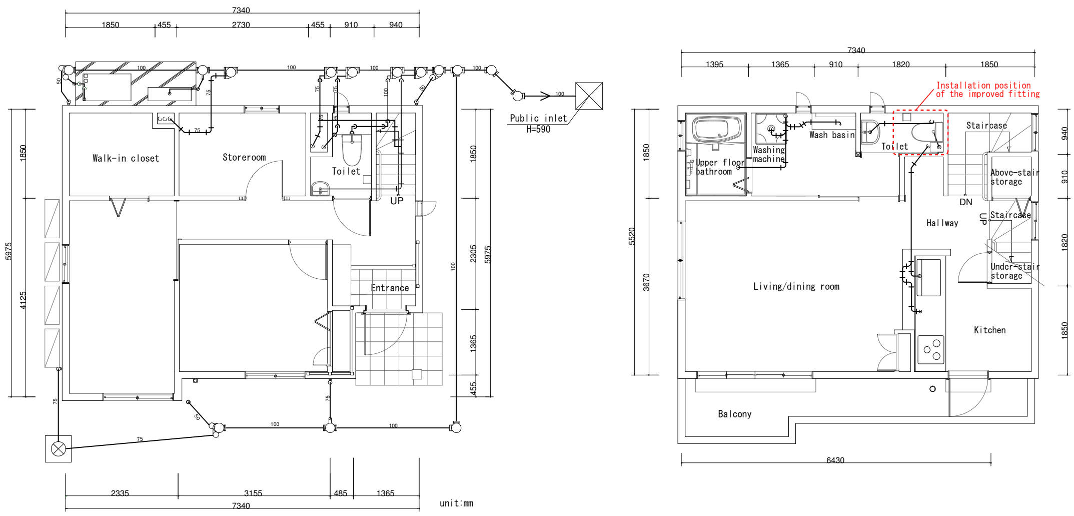


Photo 2 Experimental pipework

3.3.2 Testing on the drainage system of a real detached house

Fig. 5 shows a floor plan of a two-storey detached house comprising the drainage system used for the testing. The house is designed to accommodate a water supply system concentrated on the 2nd floor, and as shown in Fig. 6, the improved fitting is installed singly to the waste pipe immediately underneath the 2nd floor toilet. Photo 3 shows the improved fitting in the installed position.



(1)Planar view of the 1st floor (2)Planar view of the 2nd floor

Fig.5 Planar view of the real detached house for testing

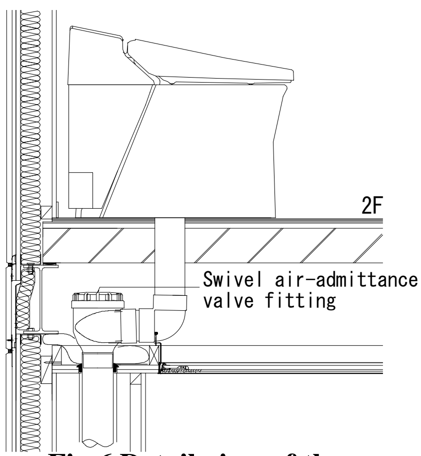


Fig.6 Detail view of the installation position

Photo 3 The fitting in the installed position

3.4 Methods of load application

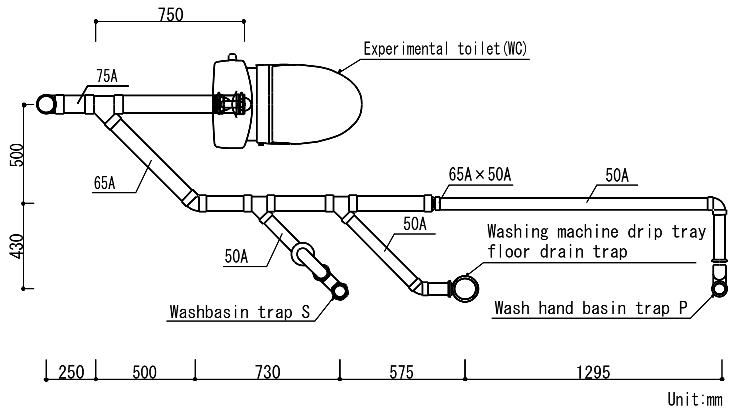
In accordance with SHASE-S218$_{-2008}$ "Testing Methods of Flow Capacity for Drainage System in Apartment Houses", a standard specification for air-conditioning and plumbing works by the Society of Heating, Air-conditioning and Sanitary Engineers of Japan, the constant flow load test (1) of the laboratory testing employs a method of applying a constant flow load of 0.5[L/s] at a time up to 2.5[L/s]. In the fixture drainage load test (2), the horizontal fixture branches shown in Fig. 7 (1) and (2) are used, which are supposed to be of a sewage system and a miscellaneous drainage system respectively, and drainage loads are applied according to the testing patterns shown in Table 1. Table 2 shows the drainage characteristics of the experimental plumbing fixtures used in the test. The characteristics of the fixtures are measured in accordance with SHASE-S 220$_{-2012}$

"Testing Methods of Discharge Characteristic for Plumbing Fixtures". For drainage load application singly from the toilet to the supposed sewage system, clean water and drainage water containing four different types of waste substitutes shown in Table 3 are used. Meanwhile, drainage loads are applied to the supposed miscellaneous drainage system from the bathtub (B), the washing machine (WM) and the washbasin (L), one at a time or all at once.

In the testing on the drainage system of the real detached house, clean water, and drainage water containing four different types of waste substitutes shown in Table 3 are applied from the 2nd floor toilet to create loads to the drainage system. Table 4 shows the drainage characteristics of the toilet used in the testing.

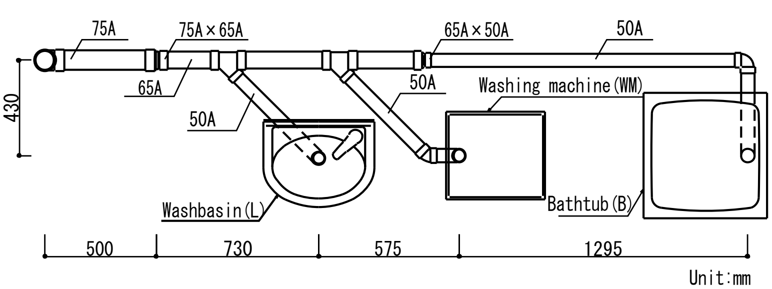
Table4 Toilet drainage characteristics (testing on the drainage system of a real house)

Plumbing fixture	Symbol	Drainage volume W[L]	Drainage time T[sec]	Avg. drainage time Td[sec]	Avg. drainage flow qd[L/s]	Instantaneous max. drainage flow qmax[L/s]
Toilet (water-saving type)	WC	5.1	60	2.6	1.2	1.7



※Base cross-section ratio and seal depth:floor trap0.78,50mm, Trap S and Trap P 1.00,60mm

(1)Piping model for single sewage load application



(2)Piping model for miscellaneous drainage load application

Fig.7 Horizontal Fixture branches for drainage load application

Table 1 Drainage load testing patters(fixture drainage load test)

<table>
<tr><th></th><th>Test No.</th><th>Drainage load</th><th>Floor</th><th>Shape of vent pipe end</th><th>Offset dimensions</th></tr>
<tr><td rowspan="7">Single load application: sewage</td><td>1</td><td rowspan="7">WC</td><td rowspan="4">2F</td><td>Closed</td><td rowspan="4">Demensions of (a) and (b) in Fig.5
◎No offset
Ⅰ (a:100mm,b:500mm)
Ⅱ (a:100mm,b:750mm)
Ⅲ (a:200mm,b:500mm)
Ⅳ (a:200mm,b:750mm)</td></tr>
<tr><td>2</td><td>Bellmouth</td></tr>
<tr><td>3</td><td>Conventional type</td></tr>
<tr><td>4</td><td>Improved type</td></tr>
<tr><td>5</td><td>3F</td><td rowspan="3">Improved type</td><td rowspan="3">Ⅳ (a:200mm、 b:750mm)</td></tr>
<tr><td>6</td><td>2F</td></tr>
<tr><td>7</td><td>3F</td></tr>
<tr><td rowspan="15">Combined load application: miscellaneous</td><td>8</td><td>B</td><td rowspan="7">2F＆3F</td><td rowspan="7">Improved type</td><td rowspan="7">Ⅳ (a:200mm、 b:750mm)</td></tr>
<tr><td>9</td><td>WM</td></tr>
<tr><td>10</td><td>L</td></tr>
<tr><td>11</td><td>B+WM</td></tr>
<tr><td>12</td><td>B+L</td></tr>
<tr><td>13</td><td>WM+L</td></tr>
<tr><td>14</td><td>B+WM+L</td></tr>
<tr><td>15</td><td>B</td><td rowspan="8">3F</td><td rowspan="8">Improved type</td><td rowspan="8">◎No offset</td></tr>
<tr><td>16</td><td>WM</td></tr>
<tr><td>17</td><td>L</td></tr>
<tr><td>18</td><td>B+WM</td></tr>
<tr><td>19</td><td>B+L</td></tr>
<tr><td>20</td><td>WM+L</td></tr>
<tr><td>21</td><td>B+WM+L</td></tr>
<tr><td>22</td><td>B+WM+L</td></tr>
</table>

Note: waste substitutes B, B´, D and D´are used for tests No. 6 andNo. 7. A house drain with a diameter of 100A (actual diameter 103 mm) is used for test No. 22.

Table 2 Drainage characteristics of the fixtures

Fixtures	Symbol	Fixture drainage volume W[L]	Drainage time T[sec]	Avg. drainage time td[sec]	Avg. drainage flow qd[L/s]	Instantaneous max. drainage flow qmax[L/s]
Toilet(water-saving type)	WC	6.0	9.9	1.9	1.9	2.1
Bathtub	B	145.7	194.8	95.0	0.9	1.4
Washing machine	WM	39.6	65.6	28.3	0.8	1.0
Washbasin	L	8.2	19.3	9.4	0.5	0.7

＊SHASE-S206-2009 specifies fixture drainage flows as follows: toilets (Siphon Z type) 2.0L/s, toilets (residential) 1.5L/s, bathtubs 1.0L/s, washing machines and washbasins 0.75L/s

Table 3 Waste substitutes

Name	Type of waste	Description of waste
Current BL standard	B	Toilet roll 6m (1ply)
Alternative option to the above	B´	Toilet roll 6m (2ply)
1 ply	D	Flat Pack toilet paper 6m (1ply)
2 ply	D´	Flat Pack toilet paper 6m (2ply)

3.5 Items to measure and evaluation criteria

In the laboratory testing, the fluctuating wind speed in the pipe centre W is measured with a hotwire anemometer in the end section of the vent pipe, and the fluctuating pipe pressure P is measured with a pressure sensor in the middle section of the house drain, the horizontal fixture branch at each floor, and the drainage stack. The fluctuating seal water H of the experimental traps in fig.7(1) is also measured with a capacitance wave gauge, and the seal loss Δh of the traps is measured with a ruler. In the testing on the drainage system of the real house, a pressure sensor is used to measure the fluctuating pipe pressure in the fitting section.

The evaluation criteria comply with SHASE-S218, whereby the pipe pressure fluctuation must be within a range of ±400Pa, and the trap seal loss must be not more than 1/2 of the seal depth. These criteria apply to both the laboratory testing, i.e. the constant flow load test (1) and the fixture drainage load test, and the testing on the drainage system of the real house.

4. Experiment results and discussion

4.1 Laboratory testing

4.1.1 Constant flow load test

Fig. 8 shows examples of pipe pressure distributions, using the JIS-DT fitting, the previously-developed fitting and the improved fitting, when a constant flow load of 2.0L/s is applied from the 2nd floor. Together with the JIS-DT fitting, a bellmouth is also fitted to the end of the vent pipe. It is evident in Fig. 8 that this configuration comprising the JIS-DT fitting (and the bellmouth) generates a considerable amount of negative pressure, approx. -400Pa, measured on the floor immediately underneath the location where the load is applied. In contrast, the negative pressure is eased to approx. -210 to -150Pa by using the previously-developed fitting and the improvement fitting, while producing very similar pressure distribution patterns between the fittings.

	JIS-DT fitting	Swivel air-admittance valve fitting	
	Bellmouth	Previously-developed type	Improved type
Min. pressure	◇	▲	△
Max. pressure	□	●	○

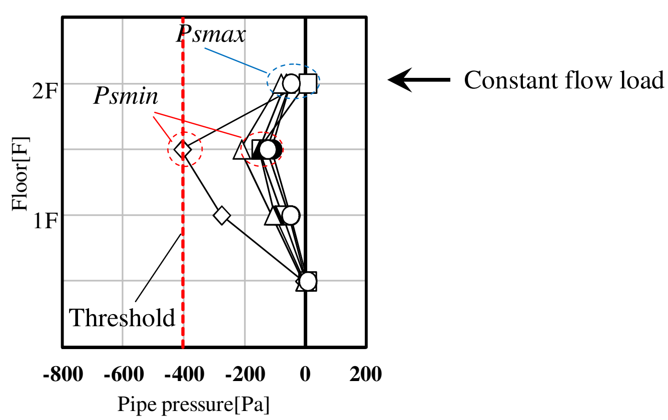


Fig.8 Examples of pipe pressure distributions

Fig. 9 shows the relationship of the drainage load flow *Qw*, when a constant flow load is applied from the 2nd floor or the 3rd floor, with the system maximum value *Psmax* and system minimum value *Psmin* of the fluctuating pipe pressure. Fig. 9 indicates that using the JIS-DT fitting (and the bellmouth), the negative pressure value exceeds the threshold thereof when *Qw* is 1.5L/s, but with the previously-developed fitting and the improved fitting, the negative pressure value remains under the threshold thereof even when *Qw* is2.5L/s which is the maximum load flow value. Accordingly, compared to the JIS-DT fitting, the previously-developed fitting and the improved fitting have a much better effect of easing negative pressure, while allowing a drainable load of 2.5L/s and more.

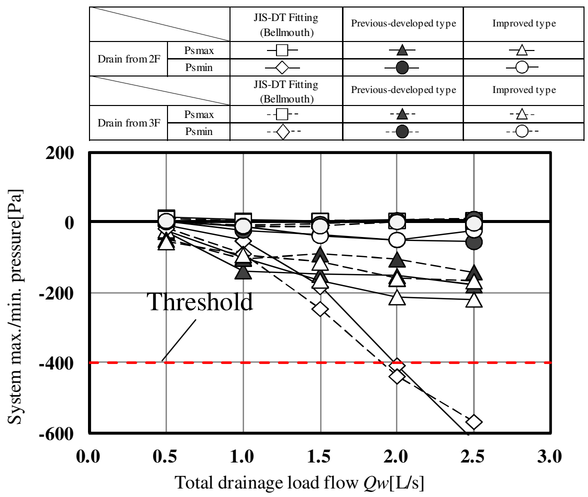


Fig.9 Total drainage load flow *Qw* in relation to *Psmax* and *Psmin*

4.1.2 Fixture drainage load test

(1) Evaluation with the sewage piping model

1) Influence of drainage load using clean water

Similarly to Fig. 8, Fig. 10 shows pipe pressure distributions when clean water is drained singly from the 2nd floor toilet. When the JIS-DT fitting is used with the end of the vent pipe closed, the pipe pressure measured at all measurement points exceeds the threshold thereof. However, when the JIS-DT fitting is used with the bellmouth attached to the end of the vent pipe, and when either the previously-developed fitting or the improved fitting is used, the pipe pressure remains under the threshold thereof in all three conditions, while creating only slight differences in measurements.

	JIS-DT fitting		Swivel air-admittance valve fitting	
	Closed	Bellmouth	Previous-developed type	Improved type
Min. pressure	◆	◇	▲	△
Max. pressure	■	□	●	○

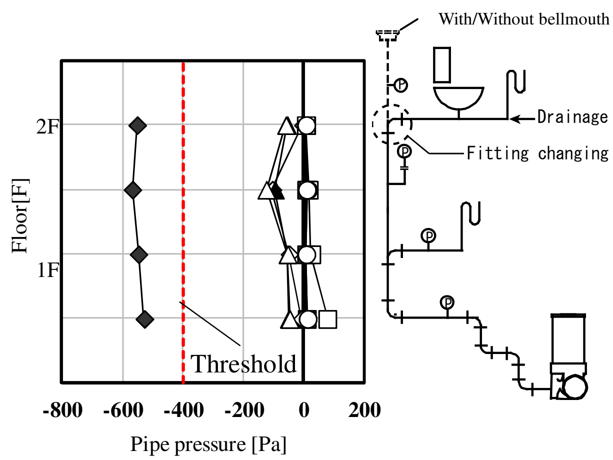


Fig. 10 Examples of pipe pressure distributions with Single drainage application from the 2F toilet

2) Influence of offset plumbing

Fig.11 shows *Psmin* values when offset plumbing is provided, immediately underneath the fitting section, with four different offset dimension's shown in Table1 and clean water is applied as a drainage load. Fig. 11 indicates that changing offset dimensions does not cause any significant difference in *Psmax* or *Psmin*. In addition, Fig. 11 shows the result of the test using the offset dimensions IV and with a drainage load applied from the 3rd floor, which is no different from the result of the test applying drainage from the 2nd floor.

	Closed	Bellmouth	Previous-developed type	Improved type
Psmin	◆	◇	▲	△

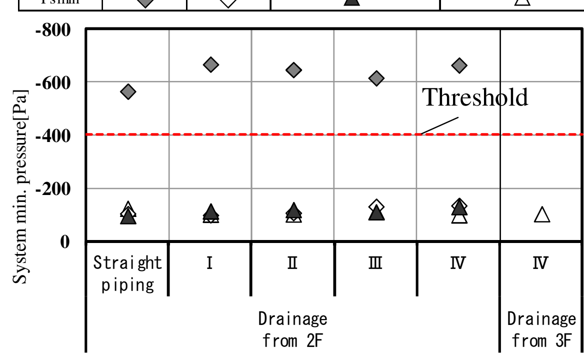


Fig. 11 *Psmin* values compared in relation to different

3) Influence of waste substitute-containing drainage

Fig. 12 shows *Psmax* and *Psmin* values when the improved fitting is used and clean water drainage and waste substitute-containing drainage are applied respectively from the 2nd floor or the 3rd floor. As for the offset plumbing, the condition IV is used, which generates the most pressure, although without creating much difference, as explained in "2) Influence of offset plumbing". Fig. 12 indicates that *Psmax* and *Psmin* values remain within the threshold range thereof when drainage is applied from the 2nd floor, using any of the test conditions, but that when drainage loads are applied from the 3rd floor under condition D' which is the most severe condition to secure carrying performance, *Psmin* becomes -430Pa, falling below the threshold thereof.

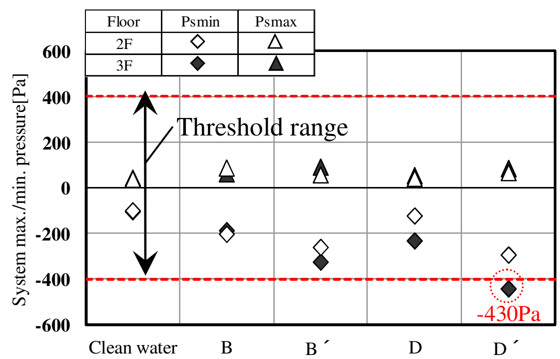


Fig. 12 *Psmax* and *Psmin* values compared using waste substitute-containing drainage

In association with Fig.12,Fig.13 shows the maximum value *Hmax* and the minimum value *Hmin* of the fluctuating seal water *H* of the experimental traps, and the trap seal loss ⊿*h*. Fig. 13 indicates that in condition D' where the fluctuating pipe pressure falls out of the threshold range thereof, ⊿*h* is approx. 26 mm, also exceeding the threshold thereof. This suggest that caution is needed when installing the improved fitting to a sewage pipework, as drainage from the 2nd floor is manageable but drainage from the 3rd floor may cause overload.

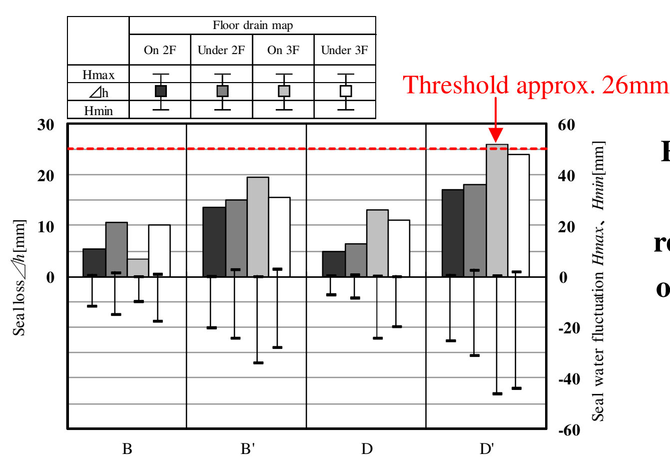


Fig. 13 Seal water fluctuation in relation to the type of waste substitute

(2) Evaluation with the miscellaneous drainage piping model

Fig. 14 shows *Psmax* and *Psmin* values when the improved fitting is installed and miscellaneous drainage is applied from the 2nd floor or the 3rd floor. The same offset dimensions are used as in “2) Influence of offset plumbing”. Fig. 14 indicates that when applying drainage from the 2nd floor, *Psmax* and *Psmin* remain under the threshold thereof in all the conditions used, but that when applying drainage from the 3rd floor, using three fixtures simultaneously, *Psmax* is approx. 1300Pa, exceedingthe threshold thereof. As Fig.15shows *Hmax*, *Hmin* and ⊿*h* of the experimental traps, water actually burst out of the 1st floor trap and broke the seal during the test.In response, the diameter of the house drain was expanded from 75A to 100A and the test was resumed, but *Psmax* still reached approx. 900Pa, and although being eased by 350Pa, the positive pressure exceeded the threshold thereof significantly, braking the 1st floor trap once again. This suggests that in a miscellaneous drainage system, the use of the improve fitting is appropriate on the 1st and 2nd floors, but could be problematic on the 3rd floor.

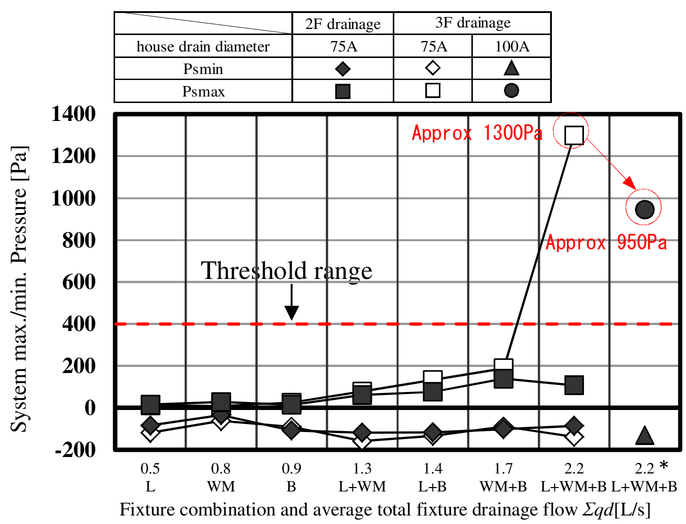


Fig. 14 Miscellaneous drainage fixture combination and *Psmax* and *Psmin* in comparison

* With the house drain diameter expanded to 100A

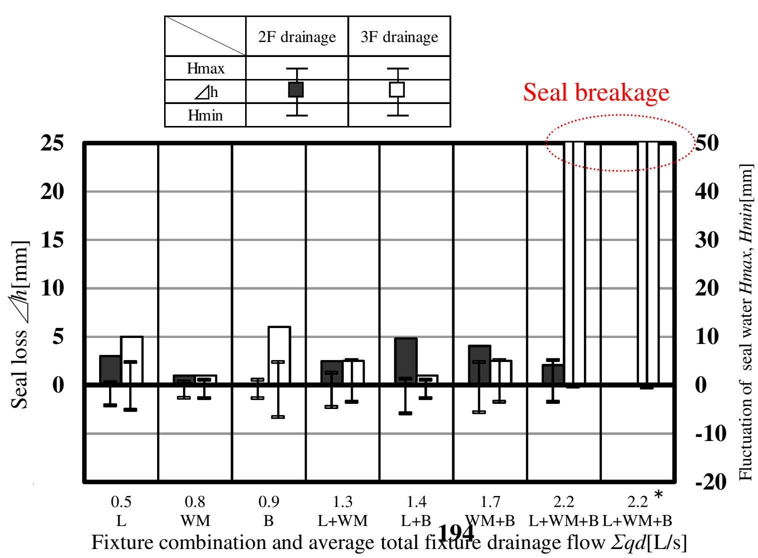


Fig. 15 Trap seal loss on the 1st floor

* With the house drain diameter expanded to 100A

4.2 Testing on the drainage system of the real house

Fig. 16 shows *Psmax* and *Psmin* values measured near the fitting section when clean water drainage and waste substitute-containing drainage are applied respectively from the 2nd floor toilet. *Psmin* is approx. -80Pa when clean water is applied, and approx. -110Pa when waste substitute-containing drainage is applied, which is approx. a quarter of the threshold 400Pa. this suggests that the improved fitting is versatile and efficient even in handling excess drainage loads in real two-storey detached houses.

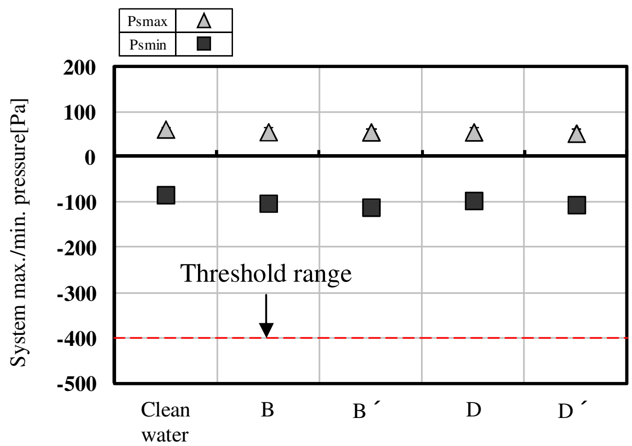


Fig. 16 *Psmax* and *Psmin* compared in different conditions

5. Summary

With the purpose of improving piping workability, the improved fitting was tested for the effectiveness thereof, using the residential drainage piping models and the drainage system of a real two-storey house, and as a result, the following knowledge was acquired:

(1) The improved fitting has more or less the same ability as the previously-developed fitting to secure good drainage performance, and ensures 1.6 times better drainage performance than the JIS-DT fitting.

(2) When installing the improve fitting to a sewage system, caution is needed since the improved fitting functions properly on the 2nd floor but may not cope with excessive loads caused by large amounts of waste contained in the drainage from the 3rd floor.

(3) Offset piping may be provided, using allowable offset dimensions, without causing any significant fluctuation to the pipe pressure.

(4) The installation of the improved fitting to a miscellaneous drainage system is feasible up to the 2nd floor but becomes difficult on the 3rd floor.

(5) On the real two-storey detached house, the improved fitting installed to the sewage system generated pipe pressure the fluctuation of which was approximately a quarter of the threshold thereof, even when excessive waste substitute-containing loads were

applied, ensuring good drainage performance.

Acknowledgements

The testing methods and evaluation methods employed in this study partially refer to Development Research of a Rational Drainage and Vent System for Low-rise houses by Otsuka Masayuki et al. ", TOSTEM foundation for Construction Materials Industry promotion, 2011.

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Defective Trap identification using the DYTEQTA System: Practical Considerations for Residential Installations.

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Abstract

The identification of water trap seal defects and vulnerabilities using the sonar-like capabilities of the DYTEQTA system has been shown to be both theoretically and practically robust. Since its inception, investigations have focussed on the ability to identify defects in water trap seals on sanitary fixtures in commercial and healthcare related buildings. Of considerable interest is the proliferation of a testing strategy in all building types, domestic included, particularly in large housing blocks where the potential for cross contamination due to defects is significant, due to high population densities. While multi-storey housing blocks may appear on the surface to be less complex than large campus style designs in healthcare buildings, research findings during the 'proof of concept' phase highlighted that this may not always be the case. The ratio of pipe diameters at system junctions plays a significant role in the sonar air pressure wave propagation dynamics, making the study of this installation type more challenging than first impressions suggest. A case study housing block is used to highlight some of the complexities involved in what appears to be a relatively simple design. An analysis of the transmission and reflection coefficient equations at junctions leads to conclusions on design decisions which need to be made at an early stage which would benefit from input from detection system engineers in order to ensure that that the drainage system is 'DYTEQTA ready', a situation which may not be optimized if conventional design methods are employed.

Keywords

DYTEQTA System, Wave propagation, Case Study, Domestic installations.

1. Introduction

The detection of defective and compromised water trap seals on sanitary fixtures has been the focus of much research and debate for many years at CIB W062 symposia. The techniques developed as a response to the SARS outbreak in SE Asia in 2002 have been well documented (Gormley *et al*, 2012, and the engineering behind the technology is now mature enough for marketable products and services to be available for general use. New phases in the development life of a technology bring new challenges as the focus changes from a laboratory setting to a real world design and installation one. Challenges which appear interesting and academic in the laboratory take on new meaning when detection engineers grapple with some of the idiosyncrasies of real designs. This paper considers some of these complexities in more detail and, with reference to a case study building, explains why a more holistic approach to design in general may be advantageous in order to optimize detection system efficiency from the initial system design concept phase.

The sonar-like capabilities of the DYTEQTA System is based fundamentally on the mechanisms of pressure transient propagation within full-bore fluid conduits and draws upon the basic understanding of the reflection and transmission of low amplitude air pressure transients within building drainage and vent systems (Swaffield, 2010). Although the study of transient propagation within these systems has traditionally focused on the suppression and elimination of such transients, due to their potentially destructive effect on trap seal integrity, the innovative approach employed by the DYTEQTA System not only uses these transients to detect and locate water trap seal defects, but applies these transients using a method which is completely non-invasive and non-destructive.

The basis of the DYTEQTA System centres on the transmission and reflection of propagating pressure transients at system boundaries. As an air pressure transient propagates through the system, it is transmitted and/or reflected by every system boundary it encounters, whether that is a branch to stack junction, and air admittance valve (AAV), a water trap seal, or an open or closed end. The reflection returned from each boundary carries important information regarding its physical characteristics and position within the system. If one of these boundaries is changed, then this shows as a change in the pressure-time history at the time taken for the changed reflection to return to the monitoring location. The loss of a water trap seal is therefore detected by the change in transient response at that boundary. A fully-primed water trap seal, analogous to a closed-end pipe, displays a +1 reflection coefficient which, in response to a positive pressure transient, generates a pressure rise in the pressure-time history, while a depleted water trap seal, analogous to an open-end pipe, displays a -1 reflection coefficient which generates a pressure drop in the pressure-time history, see Figure 1. The location of the depleted water trap seal can therefore be determined from the time taken for the pressure transient to travel from the monitoring location to the changed boundary and be returned to the monitoring station.

The non-invasive and non-destructive nature of the DYTEQTA System is due to the method used in applying the pressure transient to the system. Using a sinusoidal pressure transient with a frequency of around 10 Hz allows the test to be carried out with absolutely no risk of displacing any of the connected water trap seals due to the inertia of the water seal (Kelly *et al.*, 2008). Findings from laboratory observations (Gormley and Beattie, 2010) and numerical simulation (Swaffield, 2007) confirm the DYTEQTA System methodology as a truly non-invasive and non-destructive technique.

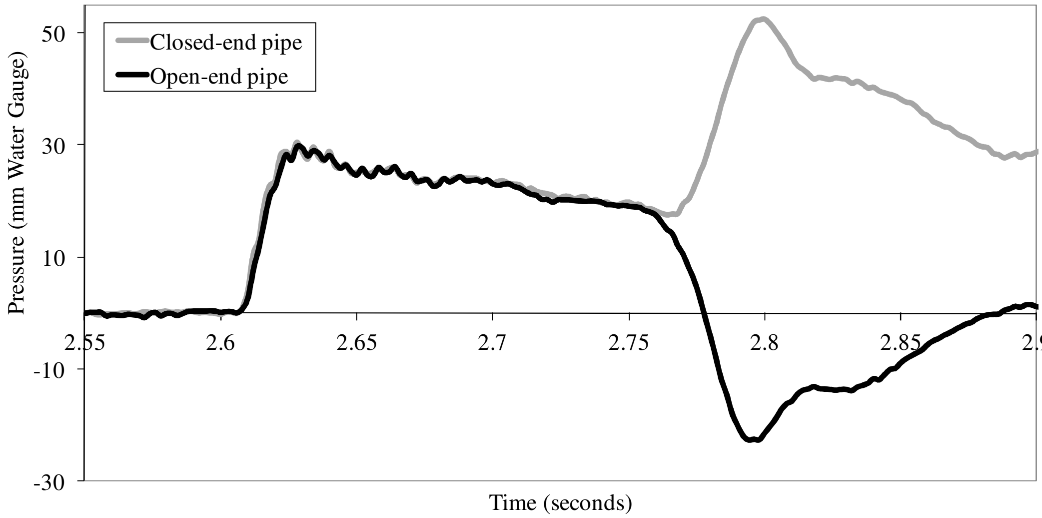

Figure 1: Demonstration of the +1/-1 reflection coefficient at a closed- and open-end termination of a single pipe in response to a positive pressure transient

As a major breakthrough in the advancement against cross-contamination of disease from the building drainage system, the development of the DYTEQTA System has centred around an extensive research program focused directly on establishing sound theoretical and practical validation of this state-of-the-art monitoring system. Since its inception, the DYTEQTA System has been tested in four different buildings: a 17-storey residential building in Dundee; a busy university building in Edinburgh; an eight-storey office building in Glasgow; and a high-occupancy hospital in Edinburgh. The different type and range, in terms of size and complexity, of buildings used to validate the DYTEQTA System have provided the understanding and knowhow which make this an effective, flexible and robust system applicable to any building drainage system.

As the first of the field trials, the tests within the 17-storey residential building in Dundee were carried out when the building was unoccupied. These initial tests were essential for proving the concept of the DYTEQTA System which, up until then, had only been trialled within the laboratory. As a single-stack drainage system with all sanitary fixtures connected directly to the stack, this multi-storey system was used first to check the ability of the DYTEQTA System to identify defective water trap seals, and then to investigate the optimal location and configuration for the test equipment. Two important test parameters were identified: (i) the route of the applied pressure transient must be unidirectional and controllable in order to prevent division of the pressure wave at the inlet junction; and (ii) the optimal location for the test equipment should be within the dry stack at the top of the building to ensure normal flow conditions within the wet part of the stack. Figure 2 shows the developed test equipment.

The second set of field trials allowed the DYTEQTA system to be validated within a busy university building. These tests focused on enhancing the DYTEQTA System to ensure that it is robust, repeatable and non-invasive within a fully occupied building.

Although spread over only four floors, this building drainage system consisted of a network of long horizontal branches, each with multiple connected sanitary fixtures at each floor level. As the number of sanitary fixtures connected to horizontal branches increases, so does the number of junctions along the travelling route of the applied pressure wave, which in turn increases the division of the wave due to the transmission and reflection characteristics of the junctions. However, the DYTEQTA System was proven to be effective in these complex-branched systems by incorporating distributed pressure monitoring points at each branch.

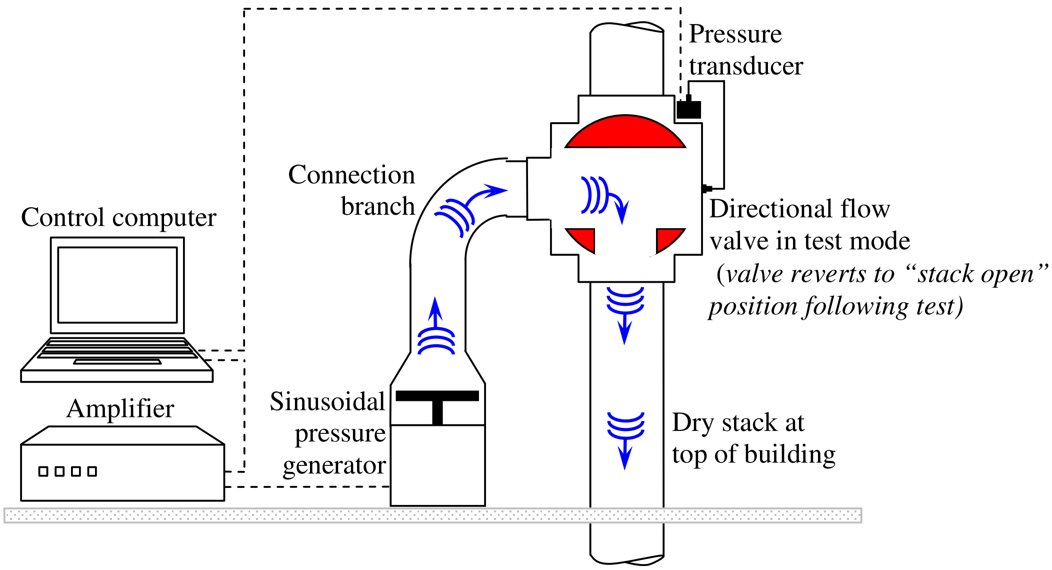

Figure 2: Developed test equipment of the Dyteqta System during "test mode"

To provide further validation of the test procedure, but in a larger and more complex building, trials were conducted within a fully operational eight-storey office building in Glasgow. This multi-stack system consisted of six single stacks, each connecting to a common horizontal drain pipe at high level within the basement and each terminated with an AAV. Two of the stacks served WCs only, whilst the others served wash hand basins only. With distributed pressure measurement points, the DYTEQTA System was able to test the whole system in a single test and by introducing the applied pressure transient at only one location. All of the 120 water trap seals were identified when defective. Furthermore, these trials validated the ability of running the test remotely over the internet from a control point at Heriot-Watt University, proving that such tests can potentially be controlled, monitored and analysed from anywhere in the World from a remote test location.

Most recently, the system was trialled at a high-occupancy hospital in Edinburgh to provide validation of its effectiveness in a busy healthcare building. Consisting of approximately 650 single stacks, the hospital drainage system is particularly complex and extensive. Although the stacks themselves were relatively simple in design and were easily testable individually, the scale of the installation and the complexity of the horizontal collection drain network proved a particular challenge. The DYTEQTA System was developed to incorporate a pipe manifold which connected the test equipment to each stack at high level. This approach allows each stack to be tested individually and sequentially, through control of the manifold valves, demonstrating that there is no limit to the size or complexity of building drainage system to which the DYTEQTA System can be applied. This series of extensive field trials have shown that the DYTEQTA System can be applied, easily and simply, to the monitoring of complex multi-stack systems as well as to those of a simple single-stack design. Validation of both the theoretical and practical application of the DYTEQTA System confirm it to be a robust, repeatable and non-invasive monitoring technique which can operate without disrupting normal building operation.

2 Junction effects

Throughout the development of the DYTEQTA System, research findings continually demonstrated the significance of the ratio of pipe diameters at system junctions on the dynamics of the sonar-like air pressure wave. The transmission and reflection characteristics of system junctions were found to have a dramatic effect on the resultant system pressure response. An explanation can be found by referring to classic pressure transient theory (Swaffield and Boldy, 1993). By considering a 3-pipe junction, such as that shown in Figure 3, it can be seen that a pressure wave arriving at a junction will be transmitted to the other pipes at the junction, while the remainder will be reflected back along the pipe from which it came.

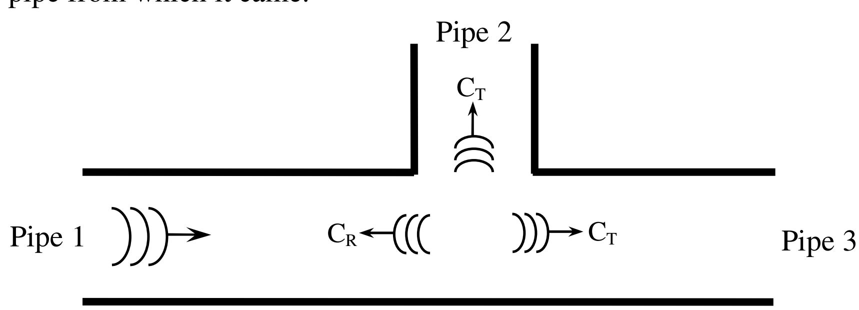

Figure 3 Pressure wave transmission and reflection at a 3-pipe junction

The division of the wave into its transmitted and reflected parts is dependent upon the area of each pipe at the junction, *A*, and the wave propagation speed, *c*, within them. Equations (1) and (2) define the transmission coefficient, C_T, and reflection coefficient, C_R, of a 3-pipe junction, respectively:

$$C_T = \frac{\frac{2A_1}{c_1}}{\frac{A_1}{c_1} + \frac{A_2}{c_2} + \frac{A_3}{c_3}} \qquad (1)$$

and

$$C_R = \frac{\frac{A_1}{c_1} - \frac{A_2}{c_2} - \frac{A_3}{c_3}}{\frac{A_1}{c_1} + \frac{A_2}{c_2} + \frac{A_3}{c_3}} \qquad (2)$$

Figure 4 demonstrates the proportion of the pressure wave which is transmitted and reflected based on a range of different branch to stack area ratios. It can be seen that a junction created by a 100 mm diameter stack and a 100 mm diameter branch (branch to stack area ratio = 1) would transmit +2/3 of the wave into the other pipes at the junction, while -1/3 would be reflected backwards.

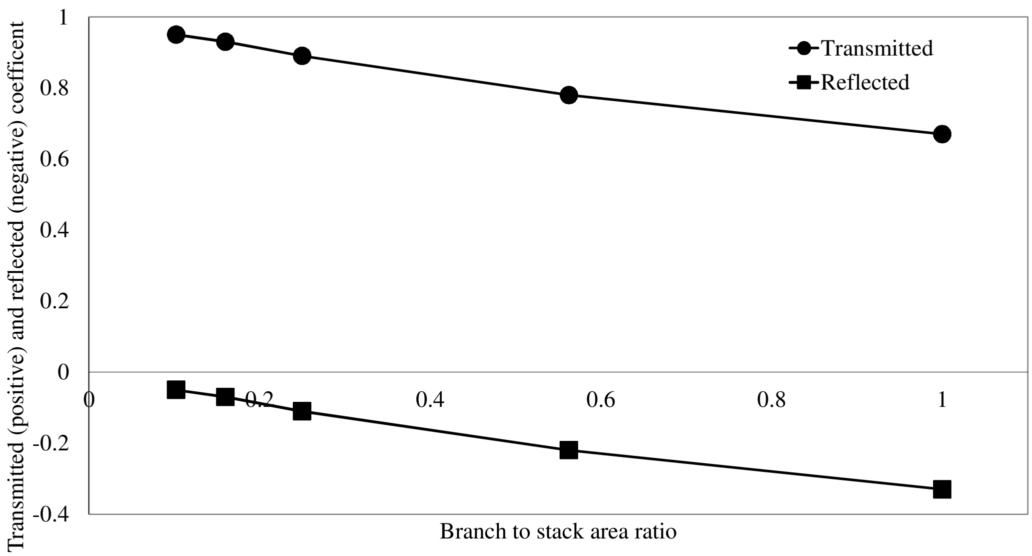

Figure 4 Proportion of the pressure wave which is transmitted and reflected at a 3-pipe junction

Figure 5 demonstrates the effect of various branch diameters on the subsequent reflection returned by a depleted water trap seal, of the same branch diameter, connected at the end of the branch. There is a significant difference between the reflections returned from different diameter branches. The larger the branch and trap diameter (branch to stack area ratio ~ 1), the larger the returned reflection.

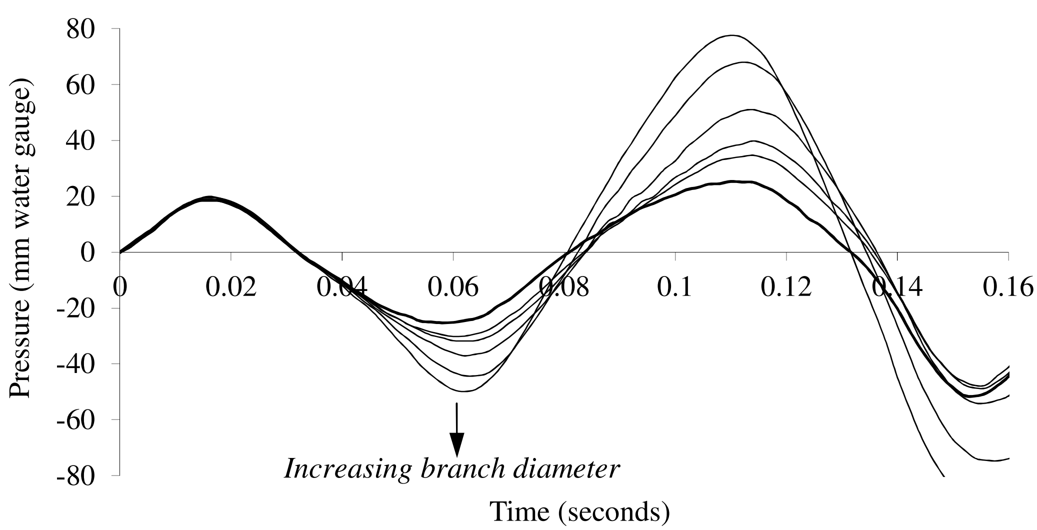

Figure 5 Effect of branch diameter on the reflection returned from a depleted trap

However, although it may appear that a large branch diameter would be most beneficial due to the larger and more detectable reflection that it generates, when traversing a large number of junctions, a large branch diameter can prove detrimental to the propagating pressure wave. By referring to Figure 4, it can be seen that as the branch to stack area ratio tends to unity, a smaller proportion of the wave is transmitted forward whilst a larger proportion is reflected backwards. As the number of junctions traversed increases, a smaller proportion of the pressure wave is then ultimately propagated along the system. Figure 6 shows that, in actual fact, junctions with a smaller branch to stack area ratio, i.e. a 32 mm branch connected to a 100 mm stack, permits greater propagation of the pressure wave throughout the system. It is, therefore, these considerations of the branch to stack area ratio that should be taken into consideration when planning for the optimum condition for the operation of the DYTEQTA System.

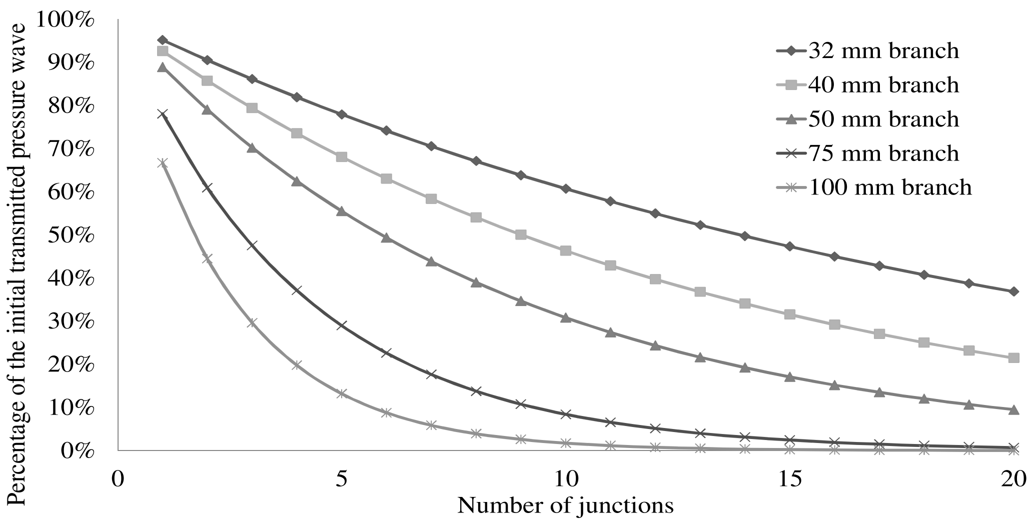

Figure 6 Percentage of a pressure wave transmitted through a 100 mm stack in relation to the number of junctions passed and the branch diameter

3. DYTEQTA installation planning: A case study

In order to put the installation of the DYTEQTA system into some perspective it is useful to consider a case study installation. Since the main focus of development so far has been on both healthcare buildings and office accommodation, it is informative to evaluate the installation of the system in a residential building. The building to be evaluated is located in Sweden and the main layout of the installation is shown in Figure 6. The living accommodation comprises apartments, arranged in blocks, ranging from 4 or 5 stories up to 20 with between 10 and 20 vertical drainage stacks per building. The approach taken on this particular building is to use one electronics cabinet with 2 separate manifolds (2 exciters and sensors). The manifold system was first trialled in the Edinburgh hospital mentioned above (Gormley, 2010) and provides flexibility of installation particularly in more inaccessible areas of the loft where space is limited. Typical buildings have a mixture of 75 mm, 100 mm and 150 mm vertical stacks, the latter size reserved for use in taller buildings. Most of the pipe work is PVC and Cast Iron. The arrangement of the DYTEQTA exciter, manifold and control system are shown in Figure 7 to give an idea of the interconnections required to test this extensive building drainage system.

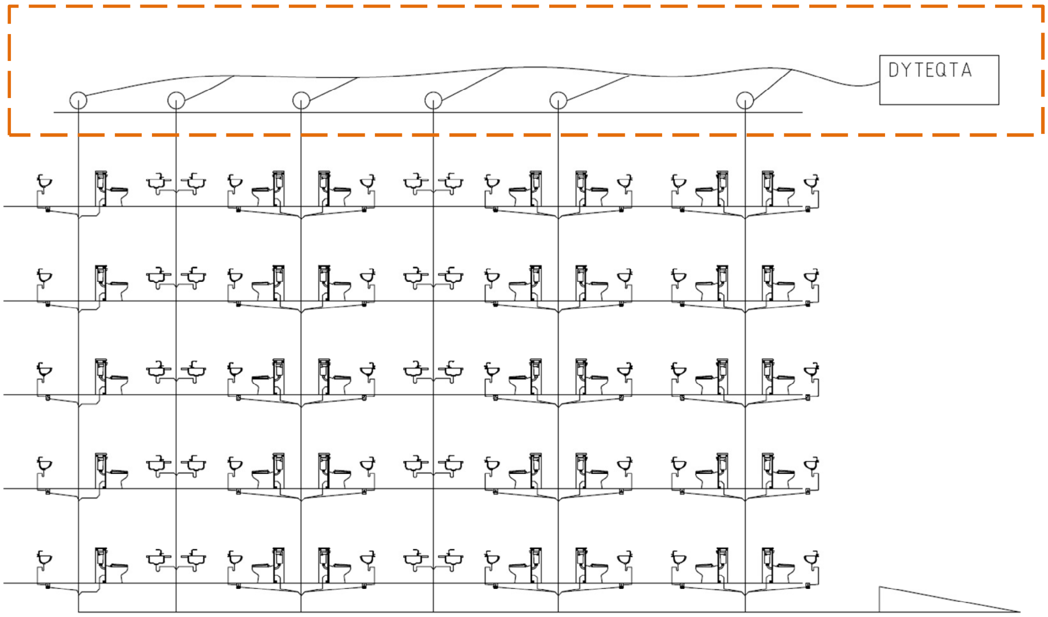

Figure 7 Case study installation

Figure 8 DYTEQTA installation showing exciter, controlled manifold and electronics control cabinet

While this installation looks reasonably straight – forward, the ability to accurately identify each of the water trap seals on fixtures with smaller diameter pipe connections depends entirely on the division of waves at pipe junctions. For, as stated above, it is not only the initially propagated wave that divides at junctions but the information carrying reflections from pipe terminations, thus complicating the analysis process. In a sense, the information on the state of the system's terminations is modulated onto the propagated wave, thus producing a complex wave pattern for the system to decipher. Luckily, the extensive research work carried at Heriot – Watt University has produced equally complex analysis algorithms which can be used to 'demodulate' the return air pressure wave and retrieve the information relating to the state of the system from the complex wave patterns.

The implications of the graphs given in Figure 4 and Figure 6 for this installation (and others like it) is that an analysis of the ratio of pipe diameters shows the effectiveness, or the modulation efficiency possible from a generated air pressure wave. For example a the tenth 100 mm branch attached to a 100 mm stack has only a 10% modulation efficiency whereas the first junction of a 32 mm branch on the same vertical stack has a modulation efficiency of 95%. While there is a need for branch pipe sizing to be large enough to cope with water flows, and to minimize the likelihood of self siphonage, there is a case to be made to expand the design requirements to look at air pressure wave propagation as well as water flow capacity.

This is not a new concept, however old misconceptions linger in design practice, giving rise to installations in which vent pipe work smaller than vertical stack pipework is specified in order to mitigate against positive air pressure transients. An analysis of this venting arrangement in the light of Figures 4 and 6 above confirm that this is absurd. So, the arrangement of pipework at junctions is not only necessary to understand air pressure wave alleviation, but also, the identification of water trap seal defects by sonar-like techniques.

4. Conclusions

The DYTEQTA system has moved from the University laboratory to the plant room of real buildings via a range of validation installations and much research and development. The planning stages of a new installation using a new technology are not without its challenges, and old paradigms may no longer be valid. It is contended here that in order to make a system 'DYTEQTA ready', detection engineers may need to be involved at the design stage in order to optimize system performance. This paper has introduced the concept of modulation efficiency – in effect, the ease with which system termination information can be communicated back to the control system for analysis by proven detection algorithms. This modulation efficiency is linked inextricably to the junction effects caused by the branch to stack cross sectional area ratio and are not unique to water trap seal defect detection. A thorough investigation of the full implications of junction effects on air pressure transient alleviation in building drainage systems is under way and is expected to yield useful results for all concerned with building drainage design. The complexities described in this paper are examples of the nature of air pressure analysis in building drainage systems. The DYTEQTA system was born out of a thorough understanding of air pressure wave generation, propagation and analysis - together with a need for a system to ensure that habitable space is kept safe and isolated from potentially harmful sewer borne pathogens. This fundamental understanding ensures that complexities such as junction effects and modulation efficiency are not impediments to system operation, since they are catered for by DYTEQTA's complex detection algorithms, but rather, they can be seen as avenues for further research to improve protection systems by influencing design practice, codes and standards.

5. References

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6. Presentation of Authors

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A Study of a Method for Predicting the Drainage Performance of Loop Vent Drainage Systems

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Abstract

Among different types of drainage vent systems, "loop vent type" stack systems, which employ a loop vent pipe connected to the vent stack and the per-floor horizontal fixture branch, are commonly used for office buildings in Japan. Although SHASE-S206-2009, a standard stipulated by the Society of Heating, Air- Conditioning and Sanitary Engineers of Japan, specifies air flow rates, drainage performance values (allowable flow rate values), etc. required for the design of loop vent type systems, these values are not on the basis of results of systematic experiments or theoretical analyses. It is therefore pointed out that these SHASE-specified values are often inconsistent with actual design conditions.

This study proposes a pipe network model of a loop vent type drainage system with the aim of predicting the drainage performance thereof theoretically by calculating the air flow rate and the pressure in the pipe. At the International Symposium of CIB W062 in Portugal in 2011, a pipe network model of a basic loop vent type drainage system (with one loop vent pipe installed to the horizontal fixture branch section) was proposed and the results of examining the drainage performance thereof were reported. Subsequent to that, this paper proposes a model, the configuration of which is close to that of real loop vent type drainage systems comprising complex loop vent piping (having a horizontal fixture branch section equipped with multiple loop vent pipes), uses the method proposed in the previous report for predicting the drainage performance of the model, and describes the effectiveness of the prediction method. More precisely, the study discusses the following points:

(1) Review of studies carried out in Japan and abroad, regarding loop vent type pipe network models
(2) Examination of a loop vent type drainage pipe network model for high-rise buildings and the effectiveness of the prediction method used on the model
(3) Comparison of the loop vent system to other vent systems in terms of drainage performance

Keywords

loop vent drainage system, drainage performance prediction method,

pipe pressure fluctuation, drainage performance

1 Introduction

Fig. 1 shows the research trend in Japan and the research trend of CIB W062, regarding drainage vent pipe network models. In Japan, the first drainage vent pipe network estimation model was proposed by Masao Ishihara[1)] in 1971. However, his model was never adopted in HASS-S206-1976 (currently called SHASE-S206-2009)[2)]. Instead, HASS-S206-1976 referred to the results of drainage performance experiments in which experimental loop vent systems with a stack diameter of 100mm were examined and the estimation of fullness ratios was made, and ever since, the fullness ratios obtained in the experiments have been used in the Wyly-Eaton equation to determine the drainage performance, i.e. allowable flow rates, of drainage systems even when different pipe diameters are used. **Table 1** lists these allowable values which are still used today. In those days, experimental conditions for calculating the drainage performance of pipe network models were inconsistent, and this is thought to be because there was insufficient preparation of drainage flow data which would have provided a basis for determining air flow resistance and air suction force in the pipe network. Later, the author[3)] of this paper proposed a single stack vent type pipe network model for high-rise buildings in 1988, C.L.Cheng[4)] proposed a single stack vent type pipe network model for super high-rise buildings in 1996, and Liwei Fu[5)] proposed a special fitting drainage pipe network model for super high-rise buildings in 2003. The progress of the author's research subsequent to the proposal of his model will be mentioned later on as part of the research trend of CIBW062.

The research trend of CIB W062 focused on the achievements by L.S.Galowin[6)] and J.A. Swaffield[7)] around 1983 up to 1992, who conducted studies mainly on vent pipe network models involving horizontal fixture branches. They have been playing a leading role in this field, and the outcomes of their studies are described in "The Engineering Design of Building Drainage Systems, Chapter 5 Vent system design". Between 2004 and 2006, C.L.Cheng[8)], L.B.Jack[9)], M.Gormley and D.P.Campbell[10)] conducted studies on loop vent systems comprising a drainage stack and determined values of generated pipe pressure and the drainage performance of the systems by analyzing vent pipe network models.

However, the biggest problem is that drainage performance values of systems, which provide thresholds (allowable flow rates) for the actual design of drainage systems, never seem to have been obtained.

Fig. 2 shows vent pipe network models proposed by the author as well as various drainage vent systems analyzed by the author by using the models. In 1988, a pipe network model was proposed in Transactions of SHASE[3)], to establish a method for predicting the drainage performance of single stack vent type systems by means of calculating the pipe pressure thereof. The prediction method was extended and examined between 2004 and 2006 when "a drainage system with a house drain for combined drainage" [12)-13)], where drainage from multiple stacks flows down into one house drain, emerged. Between 2001 and 2010, as an alternative to the conventional loop vent system, "a horizontal fixture branch type drainage system with air-admittance valves"[14)-17)], which comprises horizontal fixture branches equipped with multiple air-admittance valves, emerged, and a pipe network model thereof was proposed for drainage performance prediction by means of calculating the air flow rate and the pipe pressure thereof while the effectiveness of the prediction method was evaluated. In 2011 (in Portugal), in a related series of studies, a loop vent system comprising a loop vent path connecting a stack and only one horizontal fixture branch (a horizontal fixture branch single-loop vent system) was discussed[18)]. Furthering the abovementioned study on the single-loop vent system, this report focuses on a loop vent system comprising horizontal fixture branches equipped with multiple loop vent pipes (horizontal fixture branch multi-loop vent system) and examines the pipe pressure and the air flow rate thereof as well as evaluating the effectiveness of using a pipe network model of the system in drainage performance prediction.

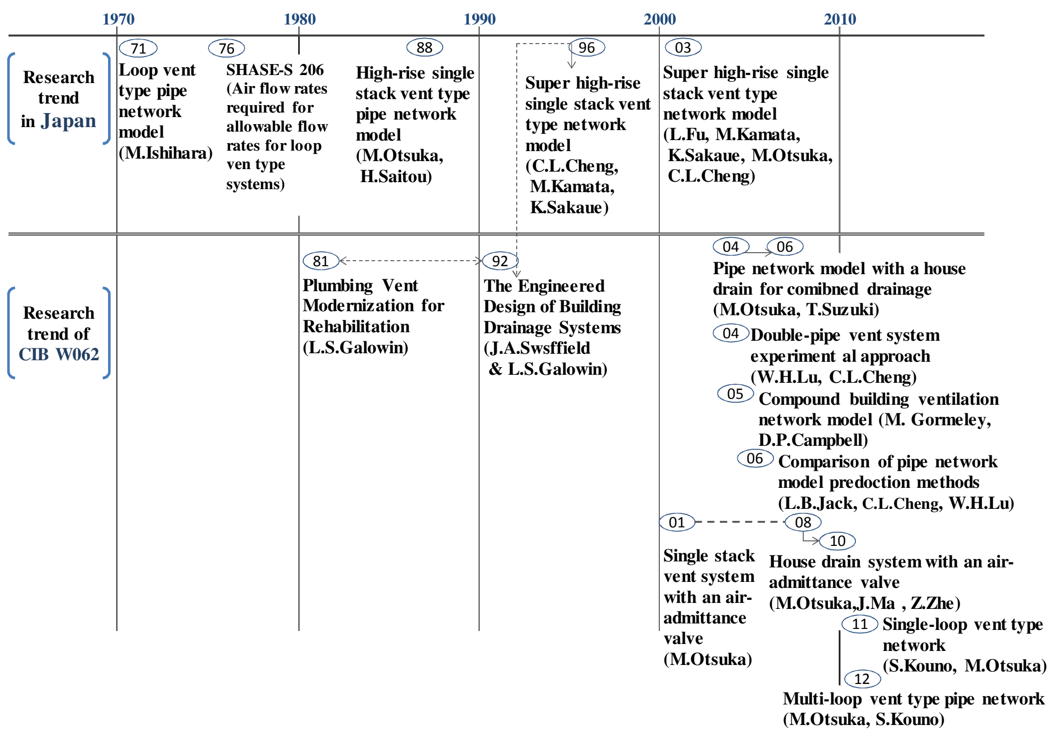


Fig. 1 Research trend in Japan and research trend of CIBW062 on drainage vent pipe networks

Table 1 Loop vent system drainage performance and required air flow rates specified by SHASE-S206

Required air flow rates: *Qa*	
Type	**Required air flow rates *Qa* [L/s]**
Loop vent pipe	Equal to the horizontal fixture branch load flow rate (=*Qw*)
Vent stack	Twice to the house drain load flow rate (=2*Qw*)
Single stack vent pipe	Twice to the house drain load flow rate (=2*Qw*)
Drainage performance*	
Stack diameter *D* [mm]	**Allowable flow rate Q_p [L/s]**
50	1.06
75	3.11
100	6.70
125	12.2
150	19.8

* Drainage performance of the stack (fullness ratio α ＝ 0.25 (continuous flow))

$Q_p = (635\pi\alpha/4)^{5/3} D^{8/3}$ (Wyly-Eaton equation) D: pipe diameter [m]

Q_a : repuired air flow rate [L/s]. Q_w : load flow rate [L/s]

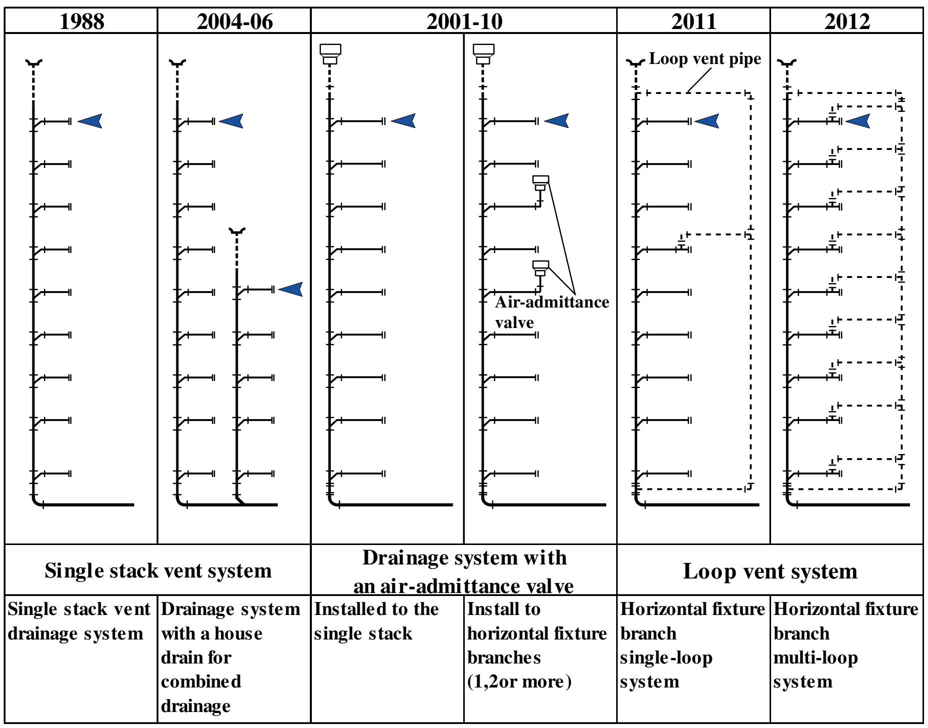


Fig. 2 The vent pipe network models proposed and the studies developed by the author (Otsuka)

2 Experiment overview

2. 1 Experimental system

The experiment was carried out using the high-rise simulation tower of Kanto Gakuin University. **Fig. 3** shows an experimental loop vent type drainage stack system. The pipework used in the experiment is also illustrated in the drawing. The house drain configuration involves three types of piping; straight piping ("straight" hereafter), piping with a bend provided 1m from the core of the stack, and piping with a bend provided 3m from the core of the stack ("1m bend" and "3m bend" hereafter). The pipe diameters used in the experiment were: the drainage stack 100mm, the vent stack 75mm, the house drain 125mm, and the loop vent pipe 75mm. Incidentally, it was feared that on the experimental drainage stack system, the gradual increase of the drainage load flow rate might cause a blockage in the house drain which would lead to significant pressure fluctuation on lower floors, possibly exceeding the pipe pressure threshold of ±400[Pa] which is specified by SHASE-S218. For this reason, a larger diameter of 150mm and 1m and 3m bends were also provided for the house drain.

Sensor	Measurement item
W : Anemometer	Measure in each section of the stack system with a anemometer
P : Pressure sensor	Measure pipe presure at each floor with a small pressure sensor
T : Tuft	Measure pipe air flow by tuft stick method

Experimental stack system	
Single stack vent pipe	100mm
Stack vent pipe	75mm
Drainage Stack	100mm
Horizontal fixture branch	75mm(1/50)
Loop vent pipe	75mm(1/50)
House drainage (Straight)	125mm(1/150)
House drainage (1m bend)*	125mm(1/150)
House drainage (3m bend)*	125mm(1/150)

*House drain diameter 150mm (pitch 1/150) is also used.

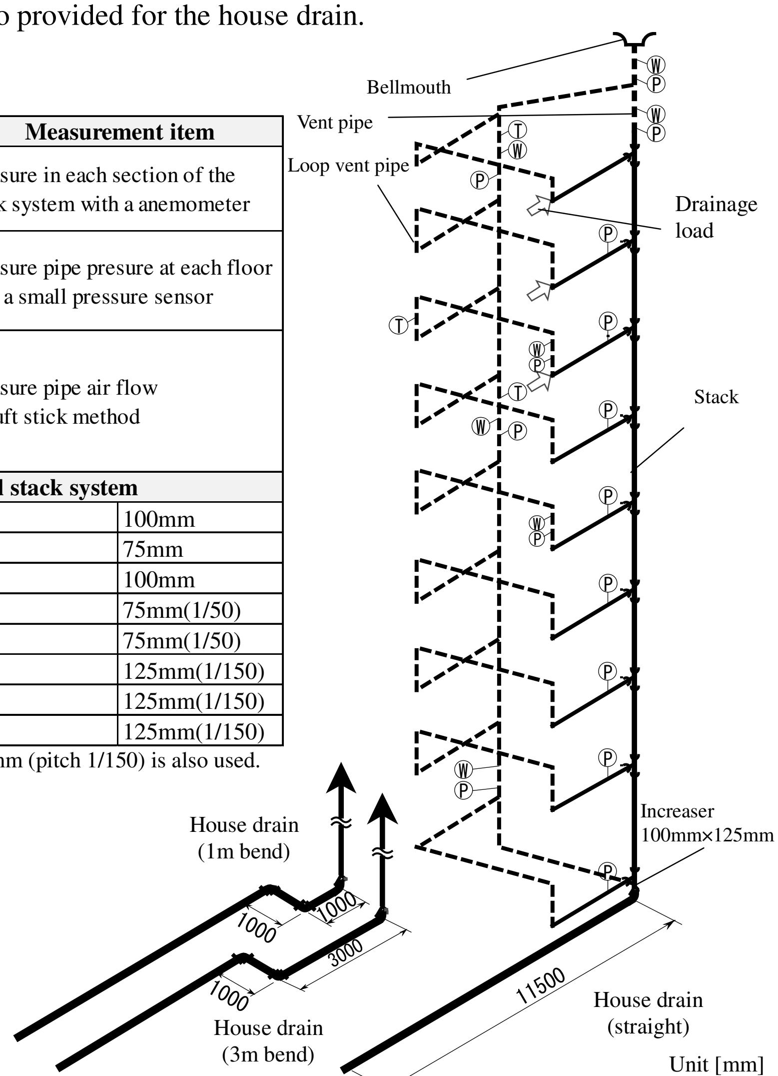


Fig. 3 Experimental loop vent type drainage stack system

2. 2 Drainage load application

In the experiment, drainage loads were applied by the patterns shown in **Table 2** and in accordance with SHASE-S218. A constant flow load was applied from the top floor (the 9th floor), 0.5[L/s] at a time up to the maximum of 2.5[L/s]. When the load application from the top floor (the 9th floor) reached 2.5[L/s], drainage load was added from the floor below (the 8th floor) in the same manner, followed by further load application from the 7th floor to eventually create a total combined load flow rate *Qw* of 7.5[L/s] which exceeds the allowable flow rate (Q_p) of 6.70[L/s] specified by SHASE-S206 for loop vent type drainage systems (stack diameter 100mm).

Table 2 Drainage load patterns and total drainage flow rates

Floor applied	Drainage load flow rate [L/s]														
	1-floor load application					2-floor load application					3-floor load application				
9F	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
8F	-	-	-	-	-	0.5	1.0	1.5	2.0	2.5	2.5	2.5	2.5	2.5	2.5
7F	-	-	-	-	-	-	-	-	-	-	0.5	1.0	1.5	2.0	2.5
Total drainage flow rate ***Qw* [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**

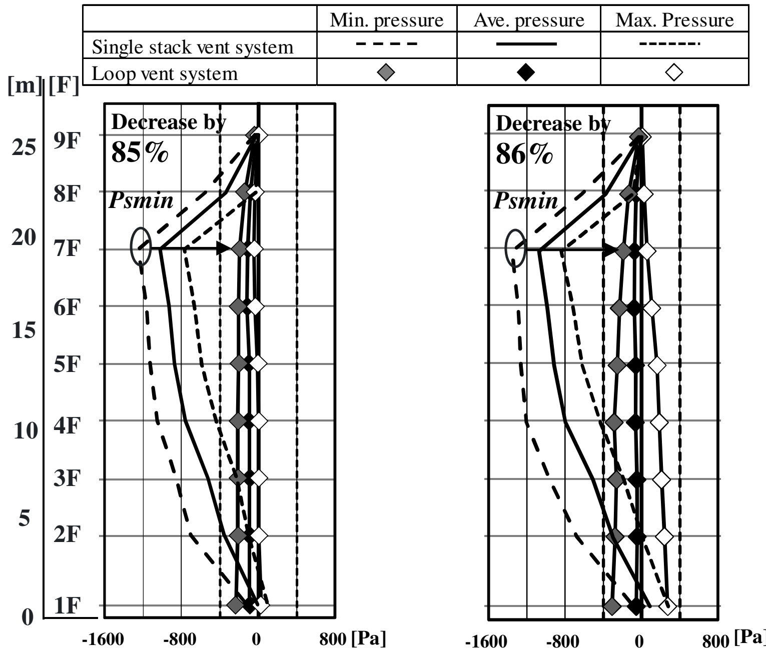
2. 3 Items to be measured and criteria

Fig. 3 lists items to be measured. The measurement items are: the stack vent pipe, the upper section and the base section of the vent stack, fluctuating wind speed Ⓦ in each loop vent pipe, ventilation direction Ⓣ, and fluctuating pipe pressure Ⓟ in the vent pipe and the horizontal fixture branch on each floor. The fluctuating wind speed was measured with a hot-wire anemometer, the ventilation direction was measured using a tuft stick method, and the fluctuating pipe pressure was measured with a pressure sensor. In addition, the air flow rate *Qa* was calculated by obtaining the average of the wind speeds in the center of the vent pipes and multiplying the average pipe wind speed by the pipe cross-sectional area. The drainage performance of the experimental system was determined by a total drainage flow rate drainable within the range of ±400[Pa], the pipe pressure threshold specified by SHASE-S218.

3 Results and consideration

3. 1 Comparison of pipe pressure distributions

Fig. 4 shows a comparative example of pressure distributions of the single vent system and the loop vent system with a drainage load flow rate of 5.0[L/s]. The diagram also shows the maximum value $Pmax_{(k)}$, the minimum value $Pmin_{(k)}$ and the average value Pave(k) of the per-floor fluctuating pressure of the drainage stack. With the loop vent system, the pipe pressure is almost evenly relaxed on each floor, and with the single stack vent pipe system, relaxation effects were found on the floor where the minimum system pressure *Psmin* was generated, which were approx. 85% (approx. 930[Pa], either straight or 1m bend) and approx. 86-59% on other floors where loop vent pipes were installed. This is considered to be because the air supplied from the loop vent pipe on each floor to the stack provided a significant effect of relaxing the negative pressure. The maximum system pressure *Psmax* generated on the lowest floor did not vary significantly with the drainage load flow rates applied in the experiments in the case of either drainage system.



(1) Straight (2) 1m bend

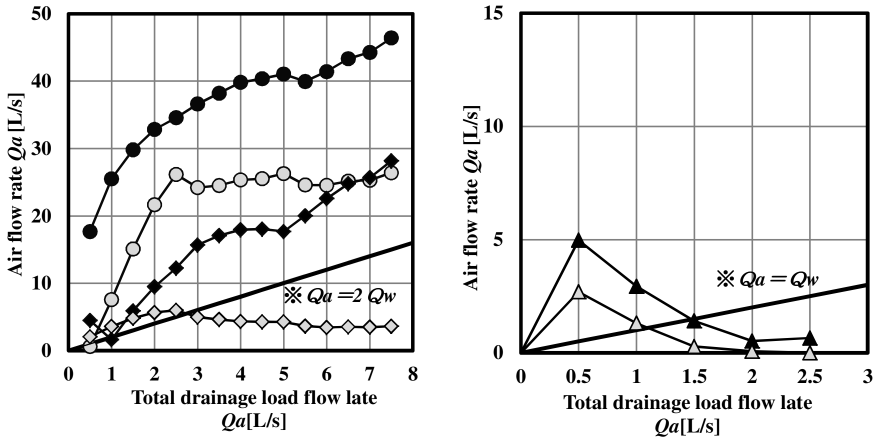
Fig. 4 Comparison of pipe pressure distributions of the single stack vent and loop vent systems (Actual measurements: load flow rate 5.0L/s, house drain diameter 125mm)

3. 2 Air flow rates for the loop vent system

Fig. 5 shows the relationship between the drainage load flow rates and the air flow rates measured in the single stack vent pipe section, the vent stack section, and the loop vent pipe section of the loop vent system. These measurements are shown in **Fig. 3**. **Fig. 5** also shows equations for calculating drainage load flow rates and required air flow rates which must be consistent with SHASE-S206. The values actually measured in both the single stack vent pipe section and the vent stack section on the upper floors exceeded the required air flow rates calculated by the equation. In contrast, the values actually measured in the vent stack section on lower floors fell below the required air flow rates calculated by the equation. In the loop vent pipe section on the 9th and the 7th floors, i.e. the load application floors, as the drainage load flow rate increased, the air flow rate decreased. This is considered to be because the horizontal fixture branch of each load application floor becomes full when the drainage load flow rate reaches 2.0[L/s] or over, and the ventilation function is lost. This clarifies that in the loop vent system, a difference can be created between a required air flow rate and an actually measured air flow rate depending on the floor for installing a vent pipe, the presence of drainage load, etc., which indicates that SHASE-S206-specified required air flow rates are not necessarily adequate.

Consequently, the experiment results suggest that air flow rates required for system design should be: approx. 6-12 times of the drainage load flow rate in the single stack vent pipe, approx. 4-8 times in the vent stack, and approx. 2-2.5 times in the loop vent pipe installed to the horizontal fixture branch.

	9F single stack vent pipe	8F vent stack	6F vent stack	1F vent stack	9F loop vent pipe	7F loop vent pipe
House drain configuration:**straight**	●	○	◆	◇	▲	△



(1) Single stack vent pipe section and vent stack section

(2) Horizontal fixture branch loop vent pipe section

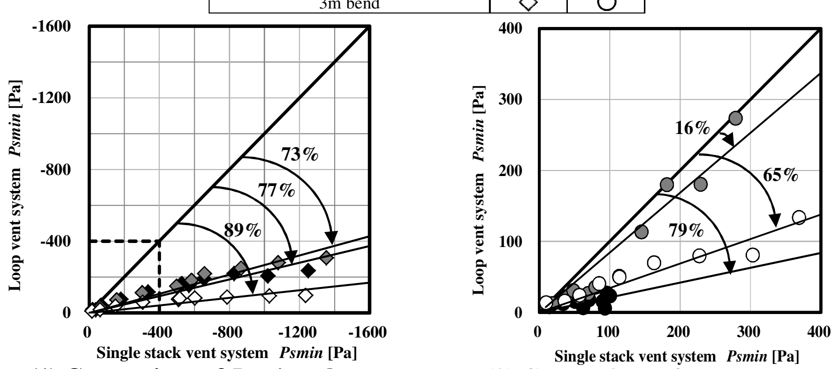
Fig. 5 Air flow rates in different pipe sections (actual measurements)

※ SHASE-S 206-specified required air flow rates - single stack vent pipe and vent stack : twice of house drain load flow rate, loop vent pipe: equal to house drain load flow rate

3. 3 Maximum/minimum system pressure, Psmax/Psmin, of the loop vent system

Fig. 6 compares *Psmin* and *Psmax* values between the single stack vent system and the loop vent system. With regards to *Psmin*, the negative pressure was relaxed in all the house drain configurations, i.e. 3m bend: approx. 89%, straight: approx. 77%, 1m bend: approx. 73%. As for *Psmax*, although the pressure was noticeably relaxed when using the straight configuration (approx. 79%) and the 3m-bend configuration (approx. 65%), the pressure relaxation effect was weak in the 1m-bend configuration (16%). This is considered to be because the horizontal bend prevented the air flow in the house drain, and the diameter and configuration of the house drain are considered to affect the relaxation of positive pressure greatly.

House drain configuration	*Psmin*	*Psmax*
Straight	◆	●
1m bend	◆ (grey)	● (grey)
3m bend	◇	○



(1) Comparison of *Psmin* values

(2) Comparison of *Psmax* values

Fig. 6 Comparison of *Psmin*/*Psmax* values between the single stack vent and loop vent systems

4 Analysis of the loop vent system pipe network

Fig. 7 shows the pipe network model of a loop vent type drainage stack system, which was used for analysis, and **Fig. 8** shows the mean pressure distribution plot, using *Pave*, which is divided into sections, while **Fig. 9** explains how to determine $Pmax_{(k)}$ (the maximum value), and $Pmin_{(k)}$ (the minimum value) in consideration of per-floor fluctuating pressure elements. The symbols used in the diagrams refer to the previous year's report.[19)]

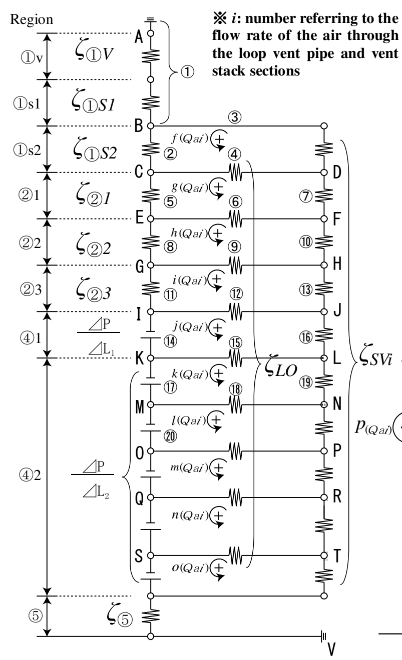


Fig. 7 Loop vent type pipe network model

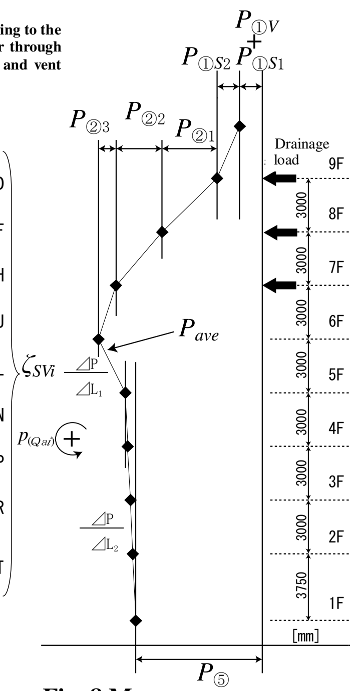


Fig. 8 Mean pressure distribution plot with *Pave* values

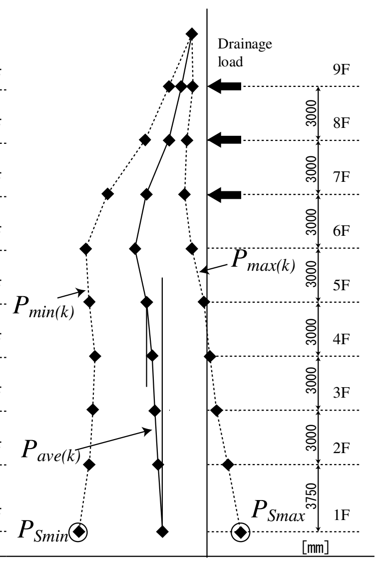


Fig. 9 Pressure distribution plot with per-floor $Pmax_{(k)}$ and $Pmin_{(k)}$ values

＊The symbols used in the diagrams refer to the previous year's report.[19)]

4. 1 Prediction of air flow rates and pipe pressures in the loop vent system

As shown in **Fig. 8**, the mean pipe pressure distribution plot (using Pave values), which is typical of the loop vent system, is divided into multiple regions. **Fig. 10** shows balance equations for air flow rates at closed loops C, D, E and F of the pipe network model in **Fig. 7**, and a balance equation $\boldsymbol{g}(Qai)$ for air flow resistance and suction force at the closed loops. Each equation is solved by successive approximation to determine the air flow rate at the corresponding closed loop. The obtained air flow rate is then used for obtaining the pipe pressure distribution ($Pave_{(k)}$) shown in **Fig. 8**. **Fig. 11 (1)** and **(2)** each show the relationship of the air flow rate with the air flow resistance $\zeta_{\square}$ and the suction force $\angle P/\angle L_1$, which are shown in **Fig. 7** and which are required for the analysis. Once the mean pressure distribution has been obtained, the pipe pressure distribution ($Pmax_{(k)}$ and $Pmin_{(k)}$) is plotted, as in **Fig. 9**, in consideration of the fluctuating pipe pressure elements acquired from equations (1) and (2), and Psmax and Psmin are finally acquired to provide drainage performance indices.

$$Pmax_{(k)} = Pave_{(k)} + \sigma_1 \times N_{1(k)} \quad \cdots (1)$$

$$Pmin_{(k)} = Pave_{(k)} + \sigma_2 \times N_{2(k)} \quad \cdots (2)$$

N: constant, σ: standard deviation

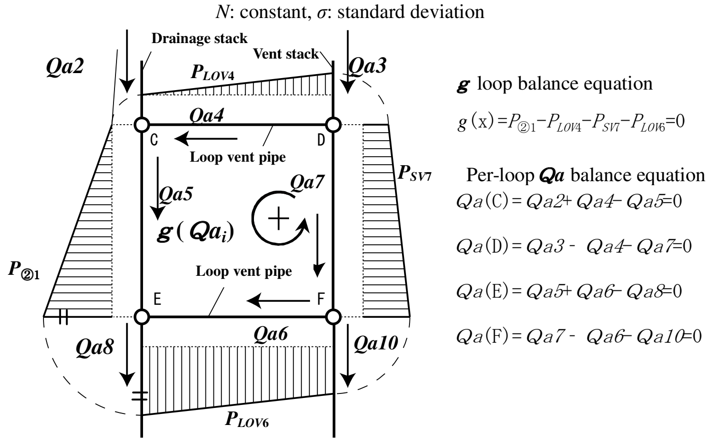
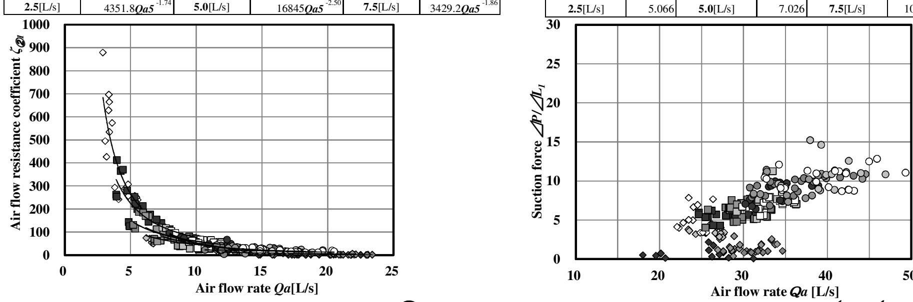


Fig. 10 Pipe network model $\boldsymbol{g}(Qa_i)$ loop, some details

◆	0.5[L/s]	◆	1.0[L/s]	◆	1.5[L/s]	◆	2.0[L/s]	◇	2.5[L/s]
■	3.0[L/s]	■	3.5[L/s]	■	4.0[L/s]	■	4.5[L/s]	□	5.0[L/s]
●	5.5[L/s]	●	6.0[L/s]	●	6.5[L/s]	●	7.0[L/s]	○	7.5[L/s]

Load flow rate	Formula	Load flow rate	Formula	Load flow rate	Formula
0.5[L/s]	$0.1091Qa5^{0.56}$	**3.0**[L/s]	$2665.4Qa5^{-1.54}$	**5.5**[L/s]	$17773Qa5^{-2.55}$
1.0[L/s]	$25.12Qa5^{1.00}$	**3.5**[L/s]	$1247Qa5^{-1.31}$	**6.0**[L/s]	$79.877Qa5^{-0.53}$
1.5[L/s]	$556.77Qa5^{-1.52}$	**4.0**[L/s]	$1523.6Qa5^{-1.40}$	**6.5**[L/s]	$295.002Qa5^{-1.00}$
2.0[L/s]	$854.57Qa5^{-1.27}$	**4.5**[L/s]	$3378.7Qa5^{-1.86}$	**7.0**[L/s]	$16917Qa5^{-2.47}$
2.5[L/s]	$4351.8Qa5^{-1.74}$	**5.0**[L/s]	$16845Qa5^{-2.50}$	**7.5**[L/s]	$3429.2Qa5^{-1.86}$

Load flow rate	Formula	Load flow rate	Formula	Load flow rate	Formula
0.5[L/s]	0.935	**3.0**[L/s]	5.521	**5.5**[L/s]	8.560
1.0[L/s]	1.019	**3.5**[L/s]	6.091	**6.0**[L/s]	9.350
1.5[L/s]	1.798	**4.0**[L/s]	6.511	**6.5**[L/s]	9.642
2.0[L/s]	3.409	**4.5**[L/s]	7.213	**7.0**[L/s]	10.763
2.5[L/s]	5.066	**5.0**[L/s]	7.026	**7.5**[L/s]	10.419

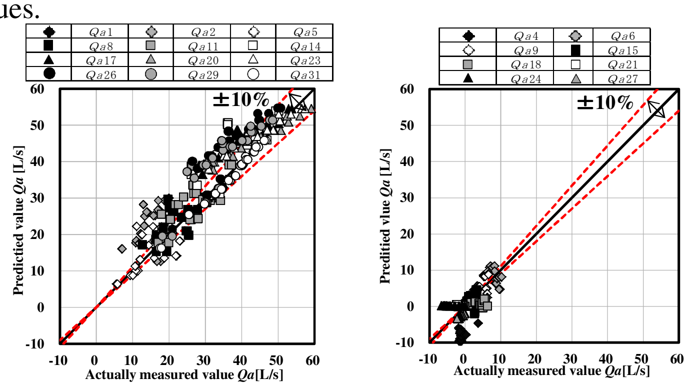


(1) Air flow resistance $\zeta_{②1}$ in region ②$_1$ (2) Suction force $\angle P/\angle L_1$

Fig. 11 Air flow resistance coefficient and suction force (pressure-gradient force) in each region

4. 2 Prediction of air flow rates

The air flow rate Qa_i of each pipe line of the model shown in **Fig. 7** was predicted by analyzing the model, as suggested in 4. 1. **Fig. 12** compares each predicted value to the actually measured value. Incidentally, *i* is a number referring to each pipe line. **Fig. 12 (1)** (the drainage stack) and **(2)** (the loop vent pipe) both show errors between the predicted values and the actually measured values. Nonetheless, the errors are within ±10%, indicating the predicted values being reasonably accurate in relation to the actually measured values.



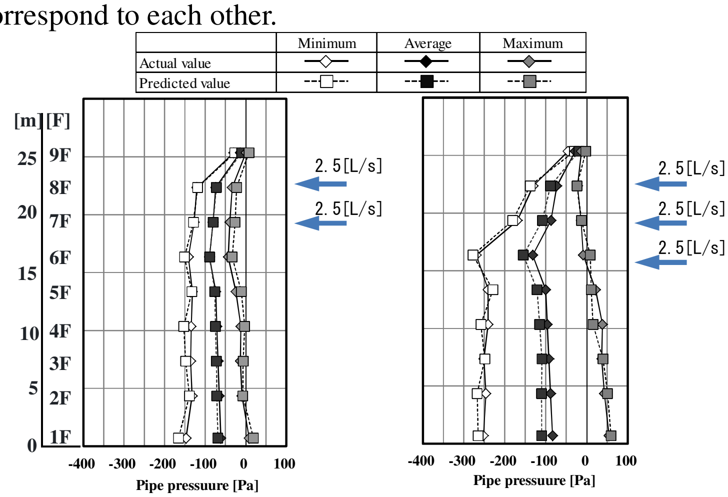
(1) Drainage stack **(2) Loop vent pipe**

Fig. 12 Comparison of predicted and actually measured air flow rates

＊*Qai*: *i* is a number referring to each pipe line.

4. 3 Prediction of pipe pressure distribution

The mean pipe pressure *Pave* is acquired from a calculated *Qa*, and constants $N_{1(k)}$ and $N_{2(k)}$ are calculated from the relationship of the difference of per-floor $Pmax_{(k)}$, $Pmin_{(k)}$ and $Pave_{(k)}$ with σ. $Pmax_{(k)}$ and $Pmin_{(k)}$ are then calculated using the abovementioned equations (1) and (2). **Fig. 13** compares actually measured values and predicted values when total drainage load flow rates of 5.0[L/s] and 7.5[L/s] are applied respectively to the loop vent system. Both graphs indicate that the predicted values and the actual values more or less correspond to each other.



(1) With 5.0[L/s] applied **(2) With 7.5[L/s] applied**

Fig. 13 Pressure distribution － actual and predicted values in comparison

5 Examination of drainage performance

Fig. 14 shows the relationship of the total drainage load flow rate *Qw* of the loop vent system with *Psmin* and *Psmax*. When the threshold is ±400[Pa], the system with the straight configuration exerts drainage performance of more than 7.5[L/s], and maintains ±400[Pa] even with a constant load flow rate of 10.0[L/s], which suggests that even greater drainage performance could be achieved. Moreover, it is evident from the graph that when the house drain is provided with a horizontal bend, *Psmax* increases. The total drainage load flow rate is 5.5[L/s] with the 1m-bend configuration and 6.0[L/s] with the 3m-bend configuration. This confirms that providing the house drain with a horizontal bend reduces the drainage performance of the loop vent system. A diameter of 150mm, which is one size larger than the currently used diameter of 125mm, was also applied as an option.

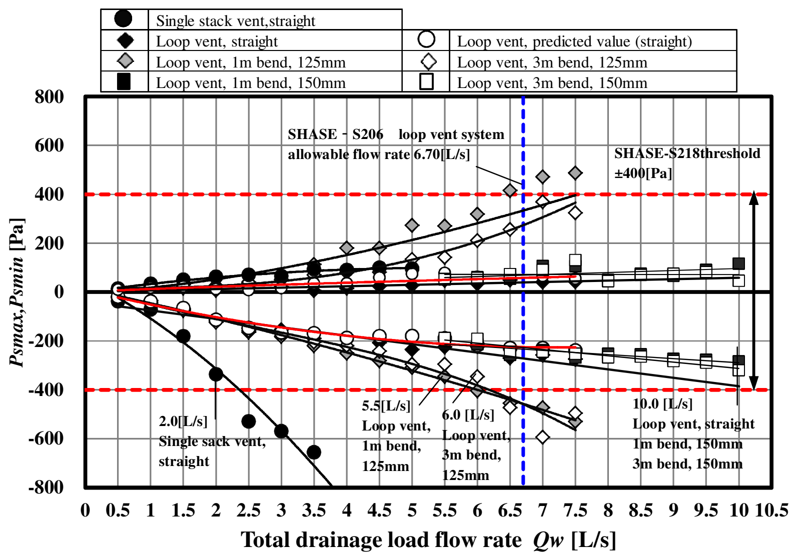


Fig. 14 Relationship of *Qw* with *Psmin/Psmax* using different drainage system configurations

6 Comparative examination of drainage performance of different vent systems

Fig. 15 shows drainage performance values of the experimental loop vent type drainage system for high-rise buildings, which were acquired by pipe network calculation. **Fig. 15** also shows how many times better the drainage performance *Qc* of the loop vent type drainage system is with each house drain configuration than the drainage performance of the single stack vent type drainage system. The graph indicates that when the house drain diameter is expanded to 150mm, the drainage performance of the system becomes more than 10.0[L/s], either with the 1m-bend configuration or with the 3m-bend configuration, i.e. as good as the drainage performance when using the straight configuration.

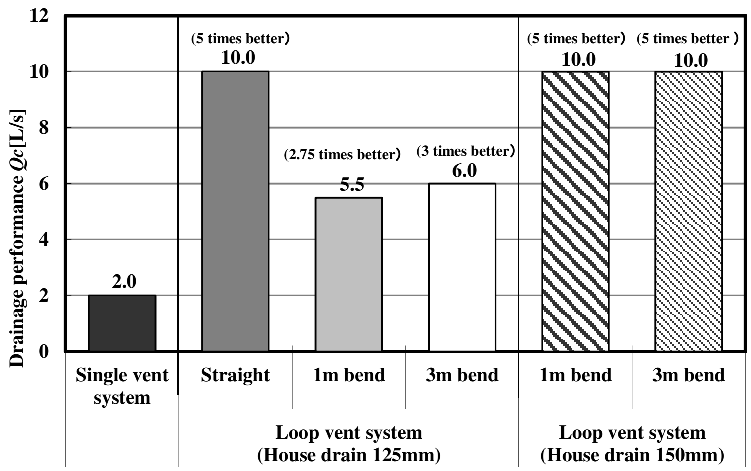


Fig. 15 Comparison of drainage performance values *Qc* of the loop vent system

( ): multiplication of drainage performance against

Furthermore, along the drainage performance results obtained from this study, **Fig. 16** shows the drainage performance values of different vent type drainage systems which were studied in the previous years. It is evident from the calculation results and the actual measurements that in relation to *Qc* of the single stack vent system being 2.0[L/s], *Qc* of the air-admittance valve system is 4.0-7.5[L/s] (approx. 2.0-3.75 times better than the single stack vent system) and *Qc* of the loop vent system is 3.5-10.0[L/s] (approx. 1.75-5 times better than the single vent system).

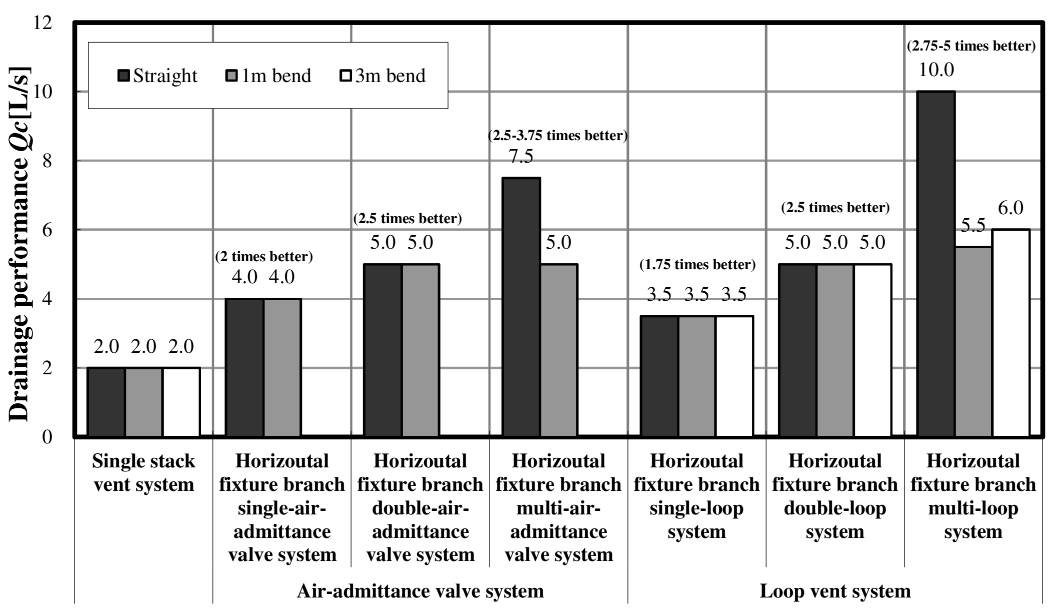


Fig. 16 Drainage performance *Qc* of various drainage vent systems

( ): multiplication of drainage performance

7 Summary and conclusion

In this study, a pipe network model of a loop vent type drainage system was proposed and the air flow characteristics and drainage performance thereof were analyzed. Subsequently, the following were clarified:

(1) The studies reported in Japan and the studies reported at the International Symposium of CIB W062 were reviewed and the current research trend was explained.
(2) A pipe network model of a loop vent type drainage system comprising complex vent piping was proposed, and the air flow rates of the vent pipes were obtained, based on which pipe pressure values and the drainage performance of the system were also estimated.
(3) Taking into consideration the results of the single stack vent system and the horizontal fixture branch air-admittance valve system in a related series of studies, drainage performance values were calculated on the vent type drainage systems and these values were proposed as design values.

Acknowledgement
This study is partially supported by "A Study on a Drainage System that Enables Free-plan Housing Technology (Masayuki OTSUKA et al.)", Ministry of Education, Culture, Sports, Science and Technology, 2009 Grants-in-Aid for Scientific Research (c), Research Number 21560621.

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Particle-based Numerical Analysis of Drainage Flow inside Building System

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Abstract

One of the impacts of water conservation in drainage building system is the reduction of discharge flow rate, which if not evaluated can reduce the drainage network performance. The aim of the present paper is to carry out a numerical investigation of flow patterns inside building drainage system. In order to model the complex free surface flow inside the pipes, a numerical approach based on Moving Particle Semi-Implicit (MPS) method is adopted. MPS method is a fully Lagrangian particle method originally proposed for the simulation of incompressible flow, in which discreted differential operators on irregular nodes and a semi-implicit algorithm is applied to solve the governing equation of the continuum. As a meshless method, MPS is very suitable to simulate the flows involving large deformation of free-surface or solid boundaries, fragmentation and merging, multi-phase and multi-physics problems. Focusing on the three dimensional transient behaviors inside drainage pipe system, simulations were carried out considering a branch drain of a water closet. The results and discussions about different wave patterns are given. For sake of simplicity, the effects of the air entrapped inside the piping system and solid transport are neglected in the present study. However, as the first step of a research on the numerical modeling of the building drainage system, the paper shows the feasibility and advantages of employing particle-based numerical approaches. This study can contribute to understand better the drainage flow inside the building system and also to reduce the drainage infrastructure using smaller diameters due to the smaller drainage flow rate.

Keywords

Drainage system; particle-based numerical analysis; water conservation.

1 Introduction

In order to conserve water in buildings, every day equipment such as taps and showers with lower flow rate and water closet (w.c.) with smaller discharge volumes are installed in existing and new buildings.

The water consumption owing to water closet usage is the major contributor of waste water from domestic and commercial buildings and hence the water closet becomes the defining appliance in terms of identifying appropriate drain sizing techniques [1].

The impact of water saving equipment coupled with the more restrained users' procedures is the reduction of flow rate in water distribution systems. Therefore smaller flow rate in drainage systems are observed. If the system sizing is not re-evaluated, especially, drains and mains clearance problems could arise from the system.

About this subject, according to Jack and Swaffield [2], the reduction in flush volume need not be accompanied by a reduction in the drainline carry performance of the network, but the conveyance can be facilitated in the main by a reduction in pipe diameter. A model to simulate and predicting flow height, flow rate and solid velocity throughout a network was developed by Heriot-Watt researchers. This model is called as DRAINET. Based on the method of Characteristics technique and finite difference approach [2], it deals with the transient analysis of partially filled, i.e. free surface, pipe flow, predominantly addressing the performance of internal building drainage systems.

Nevertheless, the complex free-surface flow inside pipes with elbows and junctions is an extremely nonlinear problem. As the presence of these singularities are relevant for the transport of waste and self-cleaning of the drainage pipes, the complete hydrodynamic modeling of the flow throughout the drainage systems and, in particular, in drains and mains is indispensable for the security of system performance. In order to model the complex free surface flow inside the pipes, a numerical approach based on Moving Particle Semi-Implicit (MPS) method is adopted in the present study. Focusing on the three dimensional transient behaviors inside drainage pipe system, simulations were carried out considering a drain pipe of a water closet. As a first step of the research, for sake of simplicity, air entrapped inside the piping system and solid transport are neglected.

In the following sections a brief description of the MPS method and the water closet drain are given. The simulation results are presented with the discussion about the transient flow behavior inside the drain, as well as some issues about the numerical modeling.

2 Numerical method

The computational method used in this study is the Moving Particle Semi-Implicit (MPS), which was proposed in [3]. MPS method is a fully Lagrangian particle-based method originally proposed for the simulation of incompressible flow, in which discreted differential operators on irregular nodes and a semi-implicit algorithm is applied to solve the governing equation of the continuum.

2.1 Governing equations

The governing equations for the incompressible viscous flow to be solved in this study are continuity equation (1) and the momentum equation (2), presented as follow.

$$\frac{D\rho}{Dt} = -\rho(\nabla \cdot \vec{u}) = 0 \tag{1}$$

$$\frac{D\vec{u}}{Dt} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\vec{u} + \vec{g} \tag{2}$$

Where ρ is density, $\vec{u}$ is fluid velocity, p is pressure, ν is kinematic viscosity and $\vec{g}$ is gravity.

2.2 Particle interaction model

In MPS method, the space domain is discretized in particles, and all the differential operators of the governing equations are replaced by operators derived from a particle interaction model based on the contributions weighting of each particle inside a neighborhood radius. The weight function is:

$$w(r) = \begin{cases} \frac{r_e}{r} - 1, & (r < r_e) \\ 0, & (r > r_e) \end{cases} \tag{3}$$

Where, r is the distance between two particles and r_e is the effective radius, which limits the region where the interaction between particles occurs.

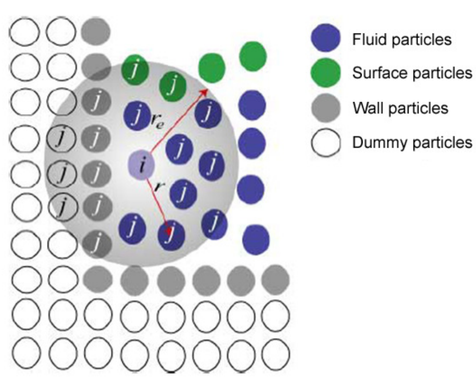

Figure 1 – The particle modeling of fluid and rigid boundary showing the effective radius of a particle *i* and its neighbor particles *j*

Considering a scalar function ϕ, the gradient vector and the Laplacian of the function at a particle i are determined by taken into account the values of the neighboring particles *j*. Within the range r_e, they are given by Eq. (4) and (5), respectively:

$$\langle \phi \rangle_i = \frac{d}{pnd^0} \sum_{i \neq j} \left[\frac{(\phi_j - \phi_i)}{\left| \vec{r}_j - \vec{r}_i \right|^2} (\vec{r}_j - \vec{r}_i) w(\left| \vec{r}_j - \vec{r}_i \right|) \right] \tag{4}$$

$$\langle \nabla^2 \phi \rangle_i = \frac{2d}{pnd^0 \lambda} \sum_{i \neq j} \left[(\phi_j - \phi_i) w(\left| \vec{r}_j - \vec{r}_i \right|) \right] \tag{5}$$

Where, d is the number of spatial dimensions, *pnd* is the particle number density, $\vec{r}_i$ and $\vec{r}_j$ are, respectively, the position vector of particles i and its neighbor particle j. λ is calculated by:

$$\lambda = \frac{\sum_{i \neq j} \left| \vec{r}_j - \vec{r}_i \right|^2 w(\left| \vec{r}_j - \vec{r}_i \right|)}{\sum_{i \neq j} w(\left| \vec{r}_j - \vec{r}_i \right|)} \tag{6}$$

Particle number density (*pnd*) is proportional to the fluid density and it is given by:

$$pnd = \sum_{i \neq j} w(\left| \vec{r}_j - \vec{r}_i \right|_i) \tag{7}$$

and pnd^0 is the initial value of *pnd*. As will be shown later, in every time step, the incompressibility of the flow is imposed by maintaining pnd of the fluid particles equal to pnd^0.

For the present study two-dimensional analysis r_e was set to 2.1 l_0, where l_0 is the initial distance between particles, to calculate pressure gradient and the particle number density, r_e is set to be 4.0 l_0 for cases involving the Laplacian operator.

2.3 Boundary Conditions

As shown by the green particles of Figure 1, when pnd of a particle is smaller than $\beta \cdot pnd^0$, it is considered to be on the free surface. As pressure variation due to the air entrapped inside the pipes are neglected, the dynamic boundary condition of free surface is imposed by setting the pressure on all free surface particles to atmosphere pressure. According to Koshizuka and Oka [3], β may vary between 0.80 and 0.99.

In MPS method, a simple approach to model the boundary of a solid wall is replacing it by wall particles, as shown in Figure 1 by the grey particles. For fixed walls, the velocity of the wall particles are set to zero and the pressure are computed in these particles. In order to assure correct calculation of the *pnd* of the particles, two additional layers of dummy particles are used (white particles of Figure 1).

In order to model the incoming waste water in the drainage pipe, inflow boundary condition is applied in the upstream section of pipe. From outside of the upstream section, a wall is displaced across the section with a velocity defined by the instantaneous flow rate. When a wall particle crosses completely the upstream section, it is converted to a fluid particle. At the same time, the dummy particle beneath the last one is converted to wall particle, and a new dummy particle is added in the upstream side of the wall to assure that there are always two layers of dummy particles beside the wall particle.

2. 4 Algorithm

The MPS method adopts a semi-implicit algorithm. Except the pressure gradient term, the terms in the right side of Navier-Stokes equation are calculated explicitly to estimate velocity and position. After that, the Poisson's equation of pressure is solved implicitly at ($t+\Delta t$). The Poisson's equation is given by:

$$\left\langle \nabla^2 P \right\rangle_i^{t+\Delta t} = -\frac{\rho}{\Delta t^2}\frac{pnd_i^* - pnd^0}{pnd^0} \tag{8}$$

Where, pnd^* is the particle number density obtained from the particle position estimated explicitly. The value of pnd^* is kept as pnd^0 to ensure the condition of incompressibility. The term of the left hand side of equation (8) can be discretized using the Laplacian model, leading to a system of linear equations. Figure 2 shows the flowchart of MPS algorithm.

The validation of the simulation code based on MPS method adopted in the present study was carried out in several previous studies performed by the author, and more details about the study can be found in [4], [5], [6].

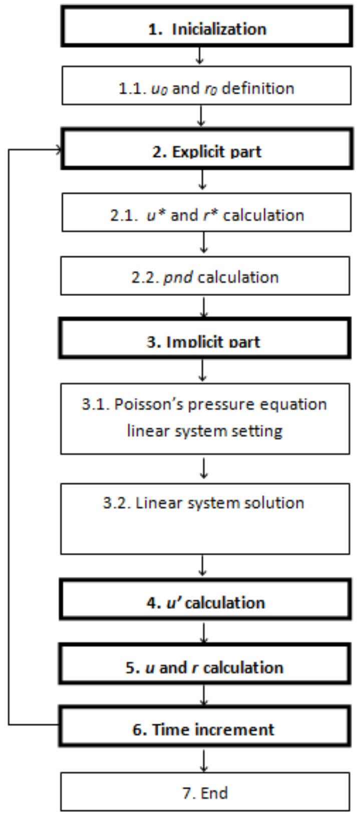

Figure 2 – Flowchart of the algorithm of MPS method

3 The modeling of the drain pipes

In the present study horizontal drain pipes of water closet with diameters of 100 mm and 75 mm are modeled considering slopes of 0.5%, 2% and 4%. As shown in Figure 3, there is a vertical elbow (single 90° join) connecting water closet to the left end of horizontal pipe. To simplify the modeling, the total length of the horizontal pipes is 6 m with an open downstream end located at the right end. Furthermore, the air pressure transient in the system in not considered. In order to monitor the transient flow rate and the wave height, flow rate and water level were computed at five section, with section located at 1 m from the starting point of the horizontal pipe, section located at 2 m from the point, and so on.

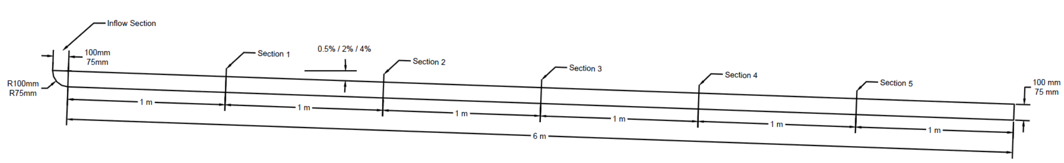

Figure 3 – Sections of the w.c. drain studied

As input data for the numerical simulation, a flush profile of a 6 liters w.c. cistern was used. Figure 4 shows the simplified modeling of the flush profile generated by regression analysis of the discharge of a w.c., obtained experimentally. The transient flow rate was applied to the inflow boundary condition imposed on the upstream section of the elbow (single 90^o) connecting w.c. to the drain.

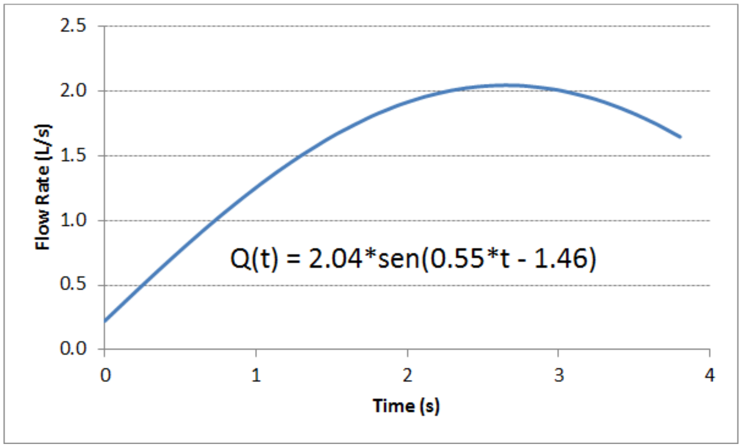

Figure 4 – Water closet flush profile

4 Results and discussions

Figure 5 shows the snapshots of the unsteady flow obtained by the numerical simulation. The results shown in Figure 5 are regarding the w.c. drain pipe with diameter of 100 mm and slope of 2%. Despite the total length of 6 meters, Figure 5 shows only the flow pattern in the first 2 m located at the upstream end of the horizontal drain pipe. In other words, the right end of the pipe shown in Figure 5 is the section 2 of the w.c. drain pipe.

The color scale in Figure 5 shows the magnitude of the velocity module. Starting from the initial instant t = 0.0 second (initial condition), the flow rate increases quickly until it reaches 2.1 L/s at time t = 2.7 seconds and begins declining until it stops at t = 3.8 seconds. Then, a wave front that advances and reaches the section 2 of the pipe, located at 2 m from the starting point of the horizontal pipe, around 3.3 seconds. At t = 5.0 seconds, the crest of the wave also reaches the section 2, leaving the left end, connected to the single 90^o join, almost dry. The simulation in this case lasted until t = 40 seconds, when only residual water remains in the drain pipe.

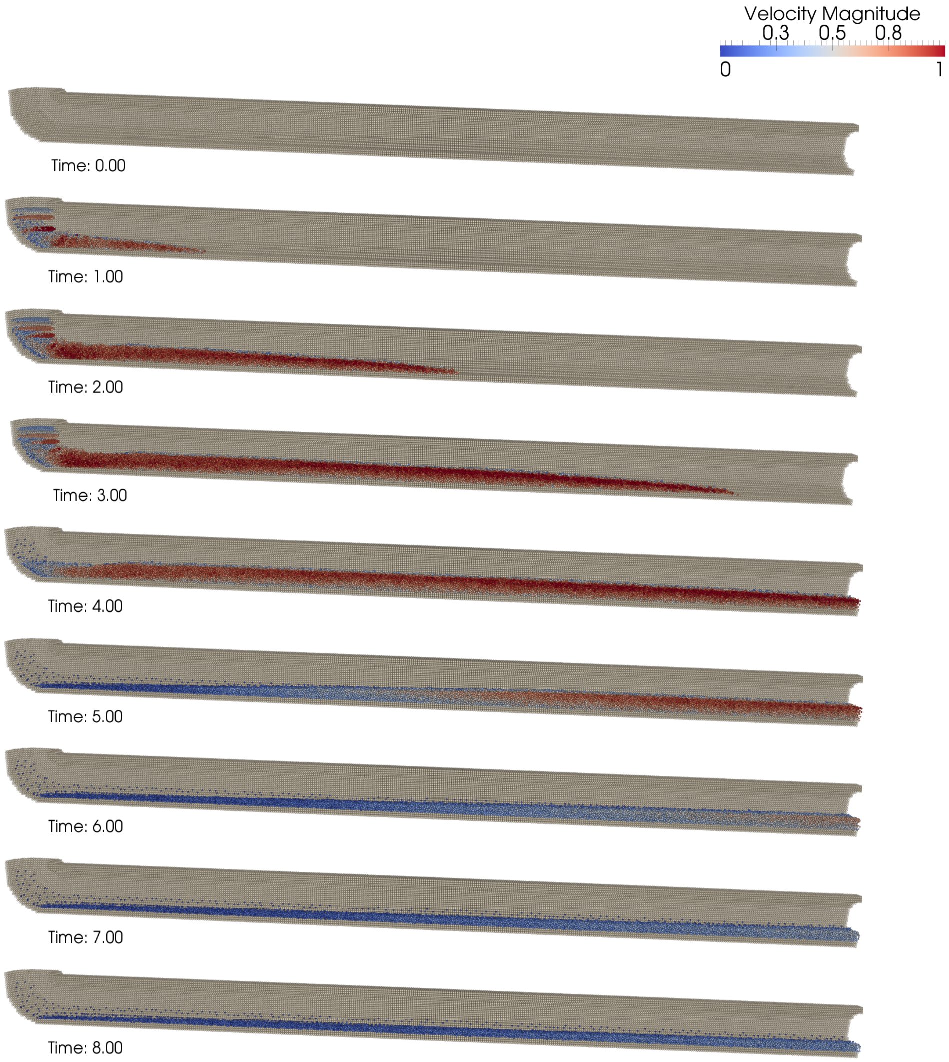

Figure 5 – Snapshots obtained from the simulation showing the flow pattern of a w.c. drain pipe with diameter of 100 mm and slope of 2%

4.1 The effects of the diameter

Figure 6 (a) presents the flow rate profiles of one discharge flush in the five sections of the w.c. drain with slope of 2%. The time histories of the water level computed in the five sections are shown in Figure 6 (b).

From Figure 6 (a) it can be observed that in the section 1, located in 1 m downstream from the 90^{o} elbow, the flow rate increases abruptly and after reaching the peak value about 1.9 l/s, the flow rate drops quickly. Due to the decrease of the inertial force, the peak flow rate decreases in the downstream sections, as well as the peak values of the water level. Also, the decay of the flow rate becomes more and more smooth in the downstream sections.

From the horizontal pipe with 75 mm diameter, the flow rate profiles and the time histories of the water level computed in the five sections are shown in Figure 7 (a) and Figure 7 (b), respectively. Despite the reduction of the diameter in relation to the previous case, as the section area in the measuring points are not fully filled, the flow rate profiles for 75 mm diameter are identical to that obtained for 100 mm. On the other hand, due to the reduction of the diameter, it can be observed that the peak values of the water level are higher in the pipe with 75 mm diameter.

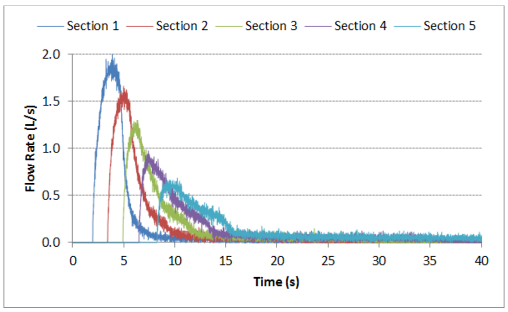

Figure 6 (a) – Flow rate profile (100 mm diameter and slope of 2%)

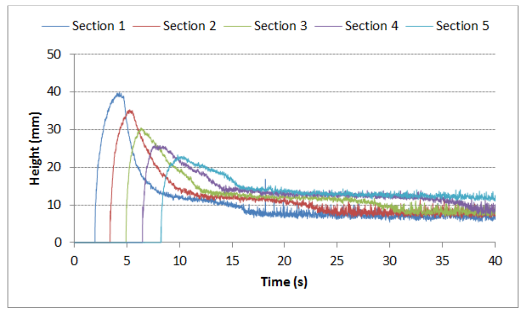

Figure 6 (b) – Height 100 mm (diameter and slope of 2%)

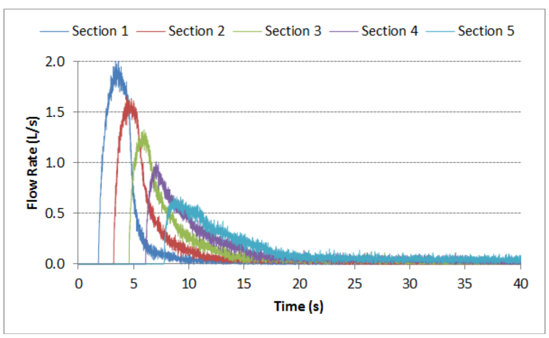

Figure 7 (a) – Flow rate profile (75 mm diameter and slope of 2%)

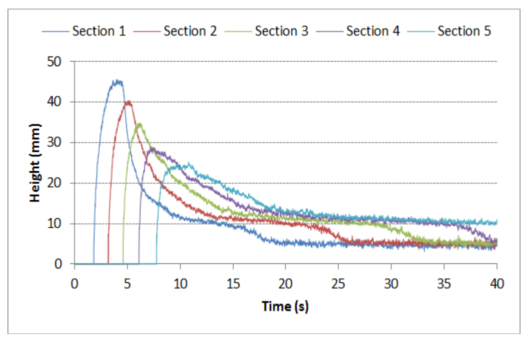

Figure 7 (b) – Height (75 mm diameter and slope of 2%

From Figure 6 (b) and 7 (b), after 10 s, the water levels reduce gradually to 10 mm and then shifts to converge to a residual water level of 5 mm. Considering the spatial discretization adopted in the present study with distance between particles of 5 mm, it is clear that the residual height and the shift of water level from 10 mm to 5 mm are errors due to the numerical modeling.

4.2 The effects of the slope

Figure 8 (a) and 8 (b) show respectively the flow rate profiles and time histories of water level in the section 3 for the pipes with diameter of 100 mm and slope of 0.5%, 2% and 5%. The corresponding computed results for the pipe with 75 mm diameter are shown in Figure 9 (a) and 9 (b). Similar to the fact already pointed out above, as the flow rate w.c. discharge is not so large to full fill the cross section area in all of the three slopes considered in the present study, the computed flow rate profiles are independent to the diameter. The peak flow rate increases with the increase of the slope.

Regarding the timing, there is a small delay for the timing of the rise up and peak value as the slope decreases. On the other hand, as expected, the pipe with larger slope is emptied more quickly. In the case with slope of 0.5%, a residual slope of 20 mm is computed for diameter of 75 mm, and this value reduces slightly in case of diameter equals to 100 mm.

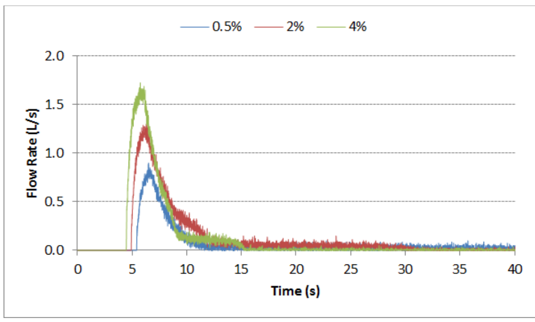

Figure 8 (a) – Flow rate profile (100 mm diameter, section 3 and slope of 0.5%, 2% and 4%)

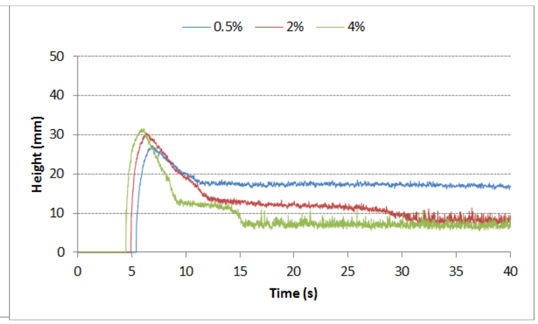

Figure 8 (b) – Height (100 mm diameter, section 3 and slope of 0.5%, 2% and 4%)

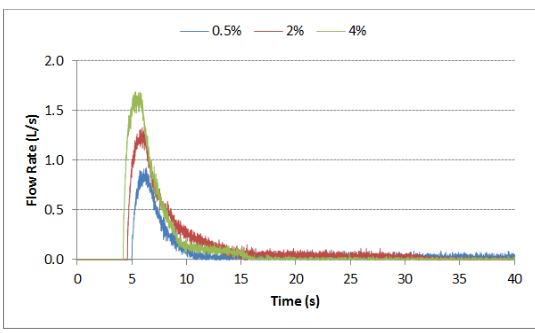

Figure 9 (a) – Flow rate profile (75 mm diameter, section 3 and slope of 0.5%, 2% and 4%)

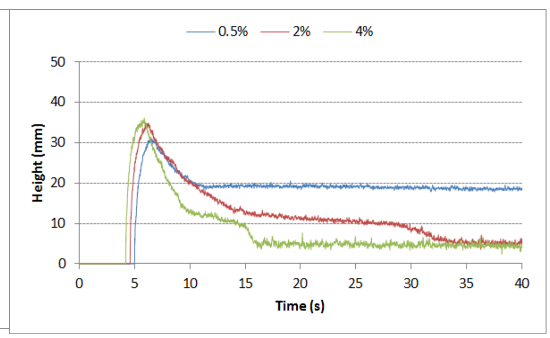

Figure 9 (b) – Height (75 mm diameter, section 3 and slope of 0.5%, 2% and 4%)

5 Final considerations

The present work carried out out numerical simulations of flow patterns inside building drainage system. In order to model the complex free surface flow inside the pipes, a fully Lagrangian particle numerical approach based on Moving Particle Semi-Implicit (MPS) method was adopted. As cases of the study, horizontal w.c. drain pipe with an elbow was considered. Transient flow rate representing a flush of w.c. was utilized. Both the effects of the variation of the diameter and the slope were investigated.

For the flow rate of a w.c. flush discharge, as the section area in all the measuring points are not fully filled, the flow rate profiles computed in the sections are independent to the diameter. The most remarkable effect of the reduction of the diameter is the increase of the peak value of the water level. In the upstream sections, the flow rate increases abruptly and after reaching the peak value and then drops quickly. However, due to the decrease of the inertial force, the peak flow rate decreases in the downstream sections, as well as the peak value of the water level.

Regarding the effects of the slope, the peak flow rate increases with the increase of the slope. Also, there is a small delay for the timing of the rise up and peak value as the slope decreases. On the other hand, as expected, the pipe with larger slope is emptied more quickly.

Despite the effects of the air entrapped inside the piping system and solid transport are neglected in the present study, the results show the feasible to study the behavior of the complex free-surface flow in the drainage systems of buildings by using the particle-based method. As future work, the simultaneous discharge of a water closet and a shower in a drainage piping with junction will be considered.

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7 Presentation of Authors

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Measurement of the noise production in drainage pipes

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Abstract

In the Netherlands new regulations for housing have come into force that require a reduction in noise levels in domestic buildings caused by installations. The maximum allowed noise level is 30 dB(A). This low level has consequences for how the installations are designed and installed. The new regulations have also initiated new methods in constructing buildings.

TVVL and Uneto-VNI have initiated a study with the aim to develop new guidelines and a calculation model. These new guidelines will be used to update the current guidelines which enables consultants and installers to select the correct materials and sound insulation measures to meet the required noise level in rooms.

The scope of the study covers:

- Measuring the noise production caused by different flow velocities in various drainage pipe materials.
- Measuring the noise reduction by using several sound insulation measures.

Keywords

Noise reduction, sound insulation, drainage pipes

1. Introduction

Noise caused by sanitary installations both in the same house or from the adjacent house plays an important role. With regard to tougher regulations on the quality of residential buildings in general, the reduction on the noise levels in residential buildings has comes about. The requirements in relation to noise levels caused by (sanitary) installations are set out in public (Bouwbesluit) and private regulations (GIW): the maximum allowed noise level is now 30 dB(A). This is quite a stringent maximum level. In residential buildings noise is generated in piping systems, which also transmit the noise through contact with the structure. Solutions to this problem are usually not simple because of the many sources at which the noise may originate and because of the complex mechanism by which noise travels and is eventually radiated to the room.

Designers and technicians need practical information how to design and install pipe systems in buildings in order to avoid high noise levels in buildings. Guidelines are available, but it is unknown if the existing guidelines meets the new very strict permitted maximum value of 30 dB(A).

In the study a total of 550 measurements were carried out in the field of sanitary installations. The study covers the following: (1) literature research, (2a) measurements on the noise production of water pipes, (2b) measurements on the noise production of drainage pipes and (3) publication of the report.

This paper is a summary of stage 2b of the study report and covers the measurements on drainage pipes and describes:
1. The methodology used to measure the noise production in drainage pipes.
2. A summary of the results of the measurements

2. Measurements

To get information on the noise emitted by horizontal drainage pipes, measurements were conducted in an acoustical laboratory. The purpose of these measurements is to get insight in the expected noise level in a room caused by a toilet discharging in a horizontal drainage pipe.

The main items of the study are:
1. measuring the sound production of a bare drainage pipe.
2. measuring the influence of external acoustical insulation of a drainage pipe.
3. measuring the influence of a enclosure around the drainage pipe.
4. measuring the influence of different types false of ceiling.
5. measuring the influence of a combination of the items mentioned above

The measurements were made in collaboration with TVVL, Uneto-VNI and several manufactures who provided products and materials such as pipe material, acoustic insulation, suspended ceiling systems and lighting fittings.

3. Methodology used to measure the noise production

The variables as mentioned below have been examined:
- The constructive situation.
- Material of the drainage pipes.
- A variable flow in the drainage pipe.
- Different sound insulation materials and sound insulation measurements.
- Different types and qualities of false ceilings.

The measurements were carried out in the acoustical laboratory of Peutz bv in Mook in the Netherlands according:
- NEN-EN 14366:2004 Laboratory measurement of noise from waste water installations.

- NEN-EN-ISO 140-3:1995 Acoustics – measurement of sound insulation in buildings and of building elements – Part 3: Laboratory measurements of airborne sound insulation of building elements.

3.1 Calculations

To compare the measured noise levels with other situations the measured values are recalculated to a standard reference sound pressure level L_n in dB(A). By measuring the reverberation time of the measure room the equivalent absorber area is calculated with:

$$A = 0{,}163\frac{V}{T} \quad (1)$$

Where:
A = equivalent absorption area (m^2 area of opening)
V = Volume of the test room (m^3)
T = Reverberation time of the test room (s)

The measured sound pressured levels L_p for the various constructions are corrected for the actual absorber area A and recalculated to a standard reference sound pressure level L_n with a reference absorber area of 10 m^2 open window:

$$L_n = L_p + 10\log\frac{A}{A_o} \quad (2)$$

Where:
L_n = sound pressure level (dB)
L_p = measured sound pressure level caused by the flow in the water pipe (dB)
A = according (1) determined absorption area (m^2 area of opening)
A_o = reference absorption area (10 m^2 area of opening)

3.2 Measurement set up

The drainage pipes were installed in a special acoustical laboratory. A pump with a variable speed was installed. From the pump water runs in a vertical pipe to a horizontal pipe connected to a vertical waste stack. The water makes a free fall trough the vertical waste stack along a T-junction and two 45° bends, then it flows into the investigated horizontal pipe. Outside the measurement room the water returns to the reservoir. See figure 1, 2 and 3 for the experimental set-up. The pipes were installed by a certified plumber. In the drainage pipe the falling water generates noise and vibrations. The sound radiated by the drainage pipe was measured in the measurement room with a moving microphone. The measurements were done with various flows: 0.5, 1.0, 2.0, 3.0 and 4.0 l/s.

Depending on the kind of measurement a drainage pipe was installed, a casing around a drainage pipe was constructed or a suspended ceiling system was constructed. The background noise in the reverberation chamber in which the pipes were installed was monitored to ensure it was always 10 dB below the noise radiated by unenclosed pipes for frequencies above 125 Hz.

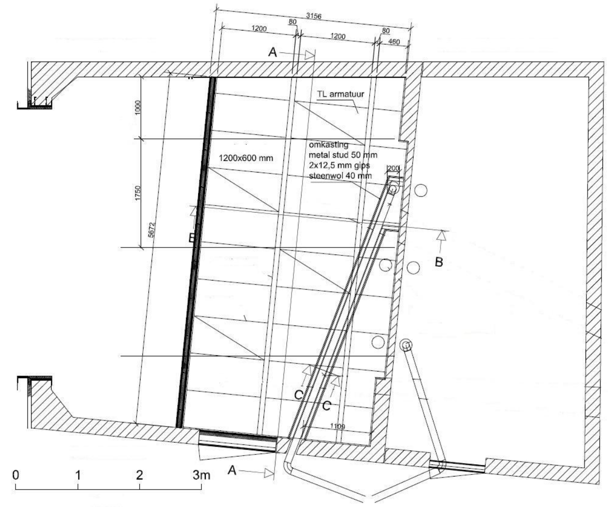


Figure 1 - Plan measurement room

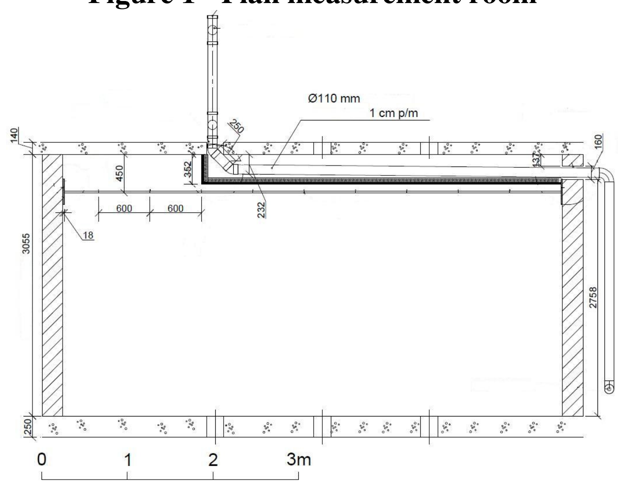


Figure 2 – Cross section A-A of the measurement setup with a horizontal drainage pipe

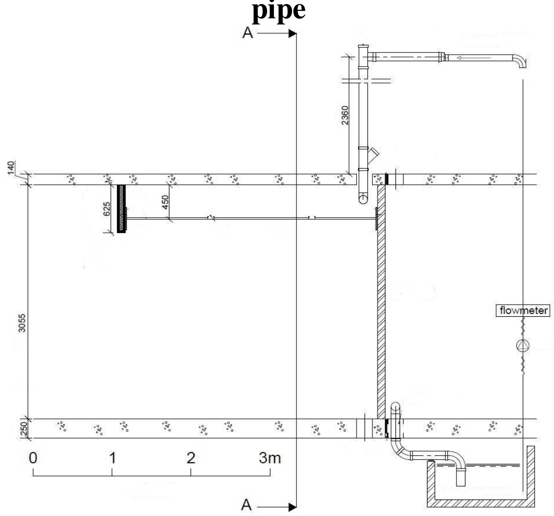


Figure 3 – Cross section B-B of the measurement setup with pump

4. Materials and constructions

The noise production of the drainage pipes as mentioned in table 1 were measured.

Table 1 – Measured types of drainage pipes

Drainage pipe		Picture
Type Mass Inside diameter Outside diameter	PVC U-Ultra 3 $1.3\ kg/m^1$ 103 mm 110 mm	
Type Mass Inside diameter Outside diameter	Wavin AS $3.5\ kg/m^1$ 98 mm 110 mm	
Type Mass Inside diameter Outside diameter	PAM Global (SML) $8.5\ kg/m^1$ 103 mm 110 mm	
Type Mass Inside diameter Outside diameter	Polyethylene $1.23\ kg/m^1$ 103 mm 110 mm	
Type Mass Inside diameter Outside diameter	Geberit Silent-db20 $3.5\ kg/m^1$ 93 mm 110 mm	
Type Mass Inside diameter Outside diameter	DykaStil $1.88\ kg/m^1$ 107 mm 110 mm	

Table 2 gives examples of the used clamps to fix the drainage pipe. Standard clamps and clamps with a rubber inlayer were used.

Table 2 – Examples of used clamps

Type of clamp		Picture
Manufacturer Type Standard	Walraven BIS 4000	
Manufacturer Type With rubber inlayer	Walraven BIS 5000	
Manufacturer Type With rubber inlayer	Saint Gobain Tyrodur 128	

Table 3 shows the acoustical insulation.

Table 3 – Outside acoustical insulation

Acoustical insulation		Picture
Manufacturer Type Corn Outer layer	Insulation Solutions Sonorex Easy Tube 23 10 mm glass wool Thickness 2 mm, mass 4 kg/m^2	

Table 4 describes an enclosure of gypsum board with internal insulation.

Table 4 – Enclosure of gypsum board with insulation

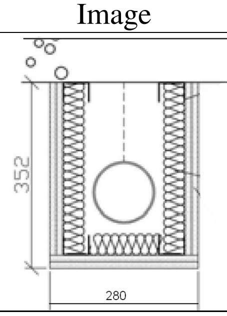
Composition	Image
Stud wall, profiles 50 mm Double gypsum board, 12.5 mm, mass 8.6 kg/m^2 Glass wool, 40 mm, mass 14.6 kg/m^3	

Table 5 – Ceiling tiles

Description ceiling tiles		Picture
Ceiling variant A1		
Material	Glass wool	
Manufacturer	Saint-Gobain Ecophon	
Type	Ecophon focus A	
Thickness	20 mm	
Mass	≈ 1.6 kg/m^2	
Ceiling variant C1		
Material	Rock wool	
Manufacturer	Rockwool-Rockfon	
Type	Sonar 44	
Thickness	50 mm	
Mass	≈ 8.4 kg/m^2	
Ceiling variant C2		
Material	Glass wool, 12.3 mm plaster	
Manufacturer	Saint-Gobain Ecophon	
Type	Combison Uno A	
Thickness	34 mm	
Mass	≈ 10.7 kg/m^2	

5. Comparison with a toilet

The noise measurements on the drainage pipes were executed with a continuous steady flow of 0.5, 1.0, 2.0, 3.0 and 4.0 l/s. In practice the noise generated by a toilet discharging into a drainage pipe is governing.

Most sounds that need to be measured fluctuate in level. To measure the sound properly we want to be able to measure these variations as accurately as possible. However, if the sound level fluctuates to rapidly, displays change so erratically that it is impossible to get a meaningful reading. For this reason, two detector response characteristics were standardized. These are kwon as “F” (Fast) and “S” (Slow). “F” has a time constant of 125 milliseconds and provides a fast reacting display response enabling us to follow and measure not too rapidly fluctuating sound levels. “S” with a time constant of 1 second gives a slower response which helps average-out the display fluctuations on a meter, which would otherwise be impossible to read using the “F” time constant. According the standard the maximum sound pressure level of a source has to be measured with a response characteristic “S” (slow).

To determine the relation between the sound pressure level of a continuous steady flow in a drainage pipe and the various flow of a toilet discharging in a drainage pipe measurements were done with a real toilet situated above the measurement room and connected to the vertical stack and drainage pipe. See figure 4.

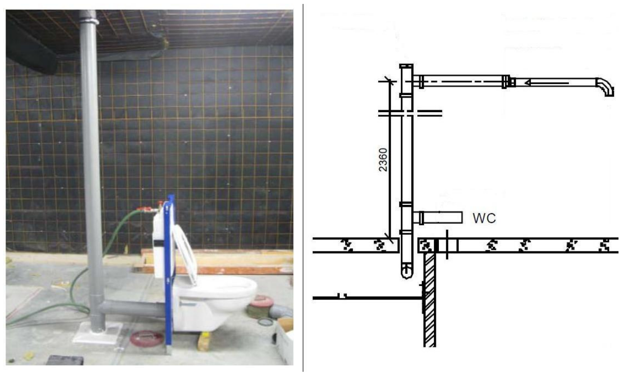


Figure 4 – Measurement set up with a toilet above the measurement room

The sound pressure level caused by a flushing toilet was measured and analysed in eleven compositions with different pipe material, clamps and false ceilings. For each flush the maximum sound pressure level with a response characteristic “F” (Fast) and “S” (slow) is determined. For each composition three flushes were measured and afterwards the average value was calculated. This approach leads to the conclusion that the sound pressure level measured in the setting “F” (Fast) with a continuous flow of 3.0 m/s in a drainage pipe , is comparable with the sound pressure level of a flushing toilet.

6. Three basic setups

Figure 5 shows three setups for basic pipes; (A) an offset vertical with two 45° bends, (B) a straight pipe and (C) a horizontal pipe. Table 6 shows the measured sound pressure levels of these three variants and pipe materials for a flow of 3.0 l/s.

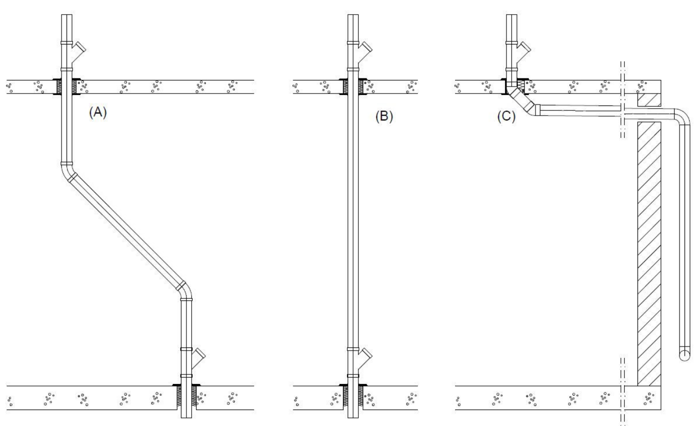


Figure 5 – (A) Offset vertical, (B) straight vertical and (C) a horizontal pipe installed in the measurement room

Table 6: Sound pressure level L_n in dB(A) for three variants and pipe materials, flow 3.0 l/s

Pipe material	L_n in dB(A)		
	Offset vertical (A)	Straight Vertical (B)	Horizontal pipe (C)
PE-SDR 26	n.m.	58.0	n.m.
PE-SDR 32	67.5	61.0	64.5
PP	66.5	55.5	61.0
PVC	64.5	57.5	61.0
AquaSilent	62.5	54.0	56.5
DykaSono	58.5	53.5	55.5
DykaStil	61.0	54.5	56.0
Geberit Silent 20 dB	62.0	53.0	57.0
Wavin AS	58.0	52.0	53.5
SML cast iron	n.m.	51.0	50.5
n.m. = not measured			

It turns out to be that the sound pressure level of a offset vertical with two 45° bends is higher than a vertical and horizontal pipe. The same conclusion applies for the horizontal pipe compared with the vertical pipe. The cast iron pipe has the lowest noise production. For the cast iron pipe the sound pressure levels are similar for the straight vertical pipe and the horizontal pipe.

7. Influence of acoustic insulation used on the drainage pipe

7.1 External acoustic insulation reduces the noise production

The noise production of a drainage pipe reduces of the drainage pipe is insulated with external acoustic insulation. The level of the reduction depends on the pipe material and acoustic insulation. The acoustic insulation material was fixed around three pipe materials: PVC, Wavin AS and SML cast iron. Figure 6 graphically illustrates the measurement results as reduction of the noise level in dB per frequency band and dB(A) in relation with a bare drainage pipe.

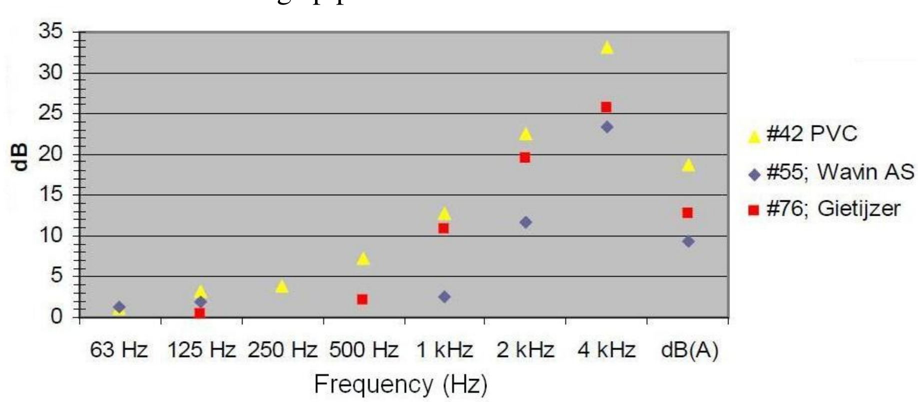


Figure 6 - Noise reduction in dB and dB(A) of acoustic insulation for PVC, Wavin AS and SML cast iron, flow 3.0 l/s

7.2 Partial insulation of the horizontal drainage pipe

It's also possible to insulate a part of the horizontal drainage pipe. Therefore pieces acoustic insulation material were removed in steps of 0.5 metre, and for every step the noise reduction is determined. At the first step the first 45° bend is insulated and at the second step the two 45° bends are insulated. Subsequently the length of the acoustic insulation increases with steps of 0.5 metre. At 4.5 metre the drainage pipe is insulated over the full length. Figure 7 shows the measurement set up and figure 8 graphically illustrates the noise reduction for PVC, Wavin AS and SML cast iron drainage pipes.

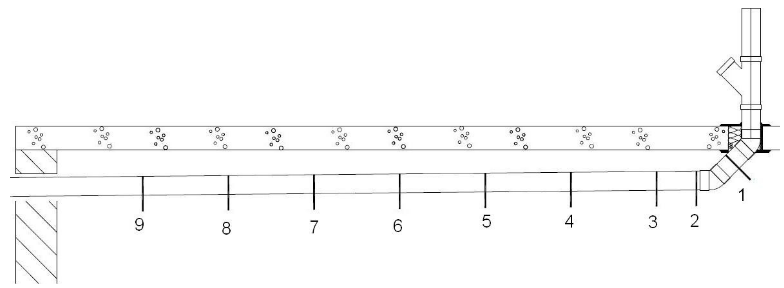


Figure 7 – Set up to measure the influence of acoustic insulation in steps of 0.5 metre

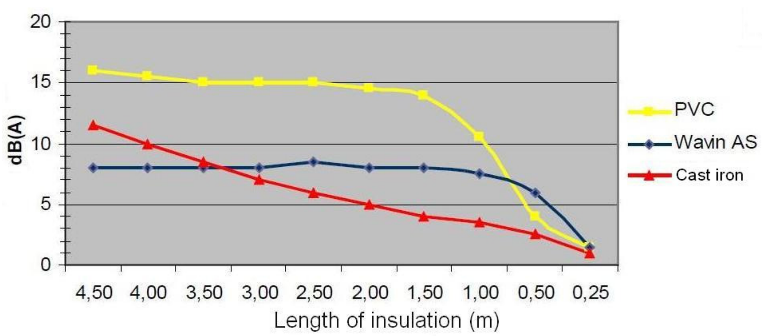


Figure 8 – Noise reduction of acoustic insulation in steps of 0.5 metre for PVC, Wavin AS and SML cast iron, flow 3.0 l/s

7.3 Conclusions acoustic insulation

The noise reduction of a drainage pipe depends on the material of that particular pipe. The influence of the external acoustic insulation increases when the sound pressure level of the bare pipe is high and when the mass of the pipe material is low.

The material of a drainage pipe has influence on the required length of the acoustical insulation and on the effect of the acoustical insulation. So it isn't necessary to insulate the full length of the PVC drainage pipe. There is no significant reduction of the noise level if the pipe is insulated over a longer distance than 1.5 metre.

However, for the cast iron pipe it is. This has to do with the attenuation and stiffness of the cast iron. The generation of noise takes place in the bends and the more the distance from the bends increases, the more the vibrations and sound level decreases.

8. Influence of an enclosure around the pipe

8.1 Measurements

An other way to reduce the sound radiation of a drainage pipe is to add an enclosure around the pipe. The enclosure is described in table 4. Figure 9 shows the construction and dimensions in detail. For absorption and isolation 40 mm glass wool is fixed on the inside. The noise reduction is measured for three pipe materials: PVC, Wavin AS and SML cast iron. Figure 10 graphically illustrates the noise reduction in dB per frequency band and dB(A).

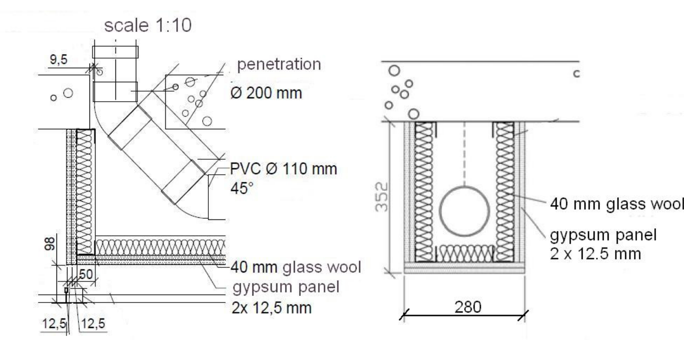


Figure 9 – Construction of the enclosure with acoustic insulation inside

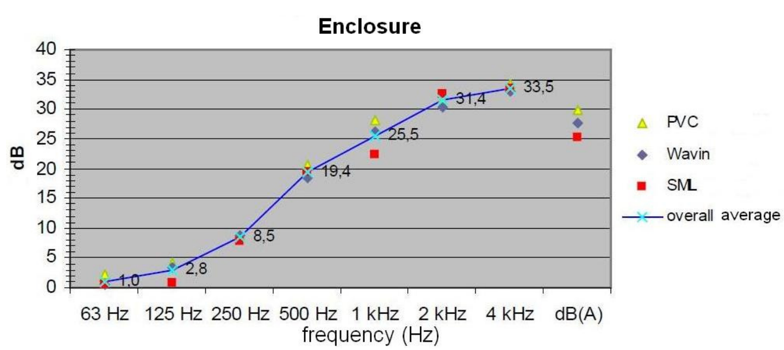


Figure 10 – Noise reduction of an enclosure with acoustic insulation inside for PVC, Wavin AS and SML cast iron

8.2 Conclusions of an enclosure around the pipe

An enclosure around the drainage pipe reduces the noise very effectively. It this case the pipe material has almost no influence on the effect of the noise reduction. This creates the possibility to determine an average value for noise reduction of an enclosure and to use this value in a calculation model.

9. Influence of a suspended ceiling system

9.1 Measurement setup

To determine the influence of a false ceiling on the noise radiation the noise reduction was measured and calculated. The noise reduction was measured for three pipe materials: PVC, Wavin AS and SML cast iron, with a height of 460 mm above the false ceiling.

9.2 Suspended ceiling with Ecophon Focus A tiles

The Ecophon Focus A ceiling tile is a light glass wool panel with a high absorption properties but has limited isolation properties. See table 5 for the description of the material. This ceiling tile is measured in combination with four lighting fittings without noise silencers. Figure 11 graphically illustrates the noise reduction in dB per frequency band and dB(A) of the Ecophon Focus A ceiling tile.

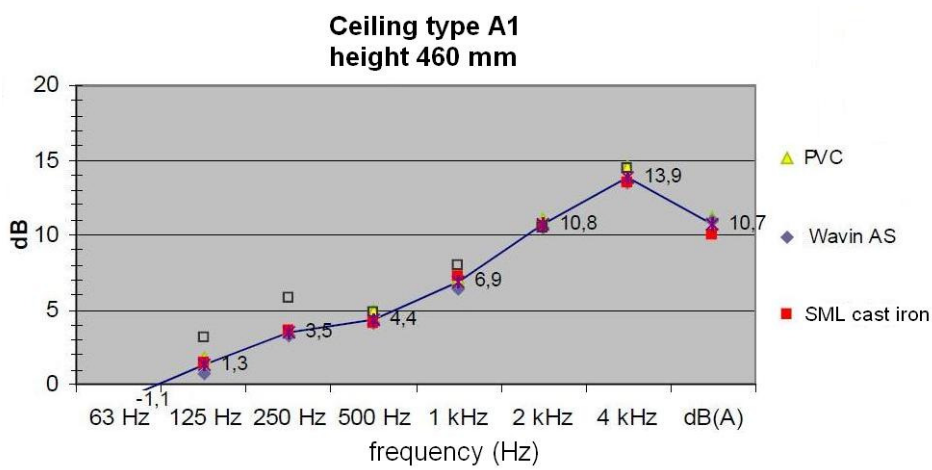


Figure 11 – Noise reduction of a false ceiling with Ecophon Focus A ceiling tiles, height 460 mm

9.3 Suspended ceiling with Rockfon Sonar 44 tiles

For the description of the Rockfon Sonar 44 ceiling tile see table 5. The ceiling panel is a sandwich composition with an absorption layer on the under site, a heavy corn and a absorption layer on the back. The lighting fittings are equipped with sound silencers on the top. Figure 12 graphically illustrates the noise reduction in dB per frequency band and dB(A) of this ceiling construction.

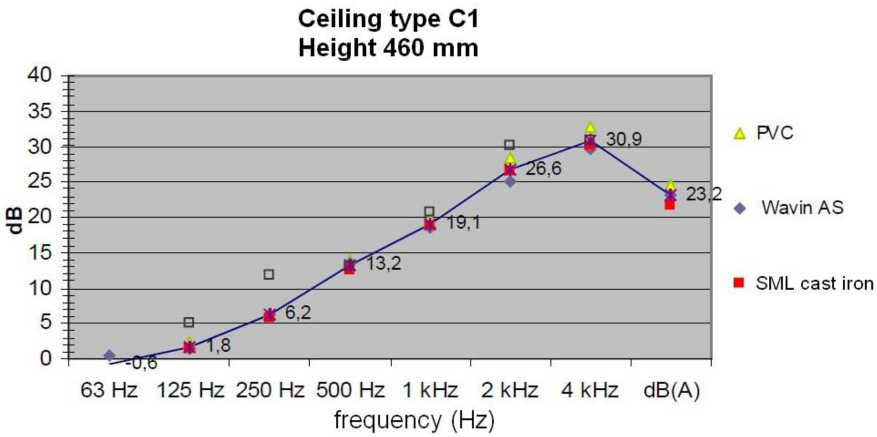


Figure 12 – Noise reduction of a false ceiling with Rockfon Sonar 44 ceiling tiles, height 460 mm, and lighting fittings equipped with sound silencers

9.4 Suspended ceiling with a Ecophon Combison Uno A tiles

For the description of the Ecophon Combison Uno A ceiling in detail see table 5. The composition of this ceiling panel consist of a sandwich construction with an absorption layer on the under site and a 12.3 mm gypsum layer on the back.

The lighting fittings are equipped with sound silencers on the top. Figure 13 graphically illustrates the noise reduction of this ceiling construction in dB per frequency band and dB(A).

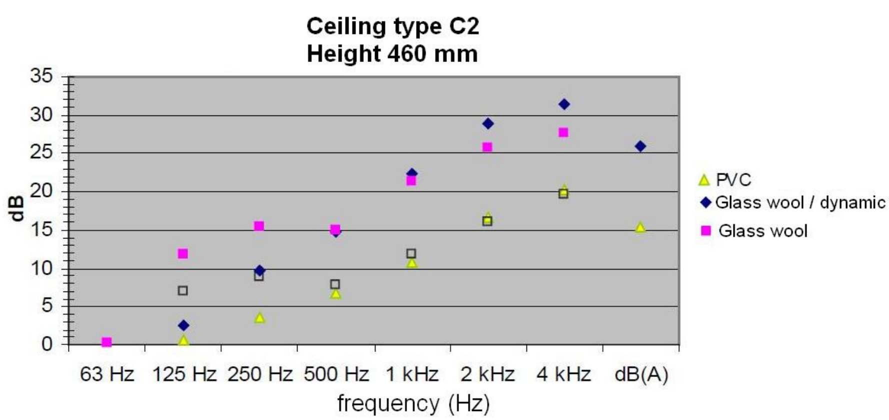


Figure 13 – Noise reduction of a false ceiling with Ecophon Combison Uno A tiles, height 460 mm, and lighting fittings equipped with sound silencers

9.5 Conclusions suspended ceiling systems

The noise reduction of the suspended ceiling systems varies between about 10 dB(A) for light types of ceiling and about 15 dB(A) for type C1 and about 25 dB(A) for the best attenuation.

10. Conclusions

Based on the measurements in the laboratory a continuous flow of 3.0 l/s is applicable as acoustic equivalent for the maximum sound pressure level caused by a flushing toilet. The measured sound pressure levels for a horizontal pipe varies between 61 dB(A) for a standard PVC drainage pipe until 53 dB(A) for a silent type of drainage pipe. The sound pressure level caused by a horizontal offset is higher then for a vertical drainage pipe. The sound pressure level caused by a offset vertical is higher then for a horizontal drainage pipe. A cast iron drainage pipe has the lowest sound pressure level. With the investigated acoustic pipe insulation (outer layer 2 mm and 10 mm glass wool) a noise reduction between 8 and 18 dB(A) is measured. The noise reduction depends on the pipe material .The higher the sound radiation of the pipe the higher the effect of the acoustic insulation.

As enclosure of a double gypsum board with absorption material inside, fixed free from the drainage pipe leads to a reduction of the noise level between 25 and 30 dB(A). The reduction is independent of the pipe material.

For the suspended ceiling systems three different qualities of ceiling panels were measured:

- The most simple version is a light glass wool panel with high absorption properties but with low insulation properties. With this type of ceiling the noise level caused by a horizontal pipe reduces in average with 10 dB(A).
- The second investigated ceiling panel is a pressed mineral fibre with a mass of about 4 kg/m^2. This ceiling system reduces the noise level in average with 23 dB(A).
- The suspended ceiling system with the best performance is a ceiling with a multi layer construction of glass wool and gypsum, and lighting fittings equipped with sound silencers. This type of ceiling reduces the noise level in average with 25 dB(A).

The outcome of the measurements offers the possibility to develop a calculation model to predict the sound pressure level caused by a flushing toilet in a room. The calculation model will provide to choose the right measures to meet a defined noise limit in a room.

11. References

Measurements on the noise production of horizontal drainage pipes; August 2011; Peutz; in the Netherlands.

Presentation of author

Walter van der Schee is a member of the Dutch Technical Association for Building Installations (TVVL). He is a member of the board of the department Sanitary Technologies (ST). The objective of the association is to promote research and technology in the field of building services. This is done by networking; giving courses; lectures; organising symposia; research and co-financing university-chairs. For further information see www.tvvl.nl

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Research and exploration concerning full scale simulated experiment of housing building water supply and drainage in China

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Abstract

In this paper it is introduced concerning construction background of a Chinese experimental tower for housing buildings, some domestic issues urgently needed to solve via the experimental tower and specific Situation about Chinese super-high-rise experimental tower for Housing Buildings which will be put into use soon. The tower is the first installation in China in which full scale simulated experimental research can be done for housing sewerage system. The examination height of the tower is the highest one in the world at present and the performance of the examination devices has met international standard. It will be operated and managed by CNERCHS and will be an experimental base with the widest coverage of performance examination for housing buildings in China. The tower will provide the service of performance experiment in order to regulate overseas and domestic housing building sewerage system and relevant products which plan to enter Chinese market, in the meanwhile it will set up a long term and stable cooperation with overseas and domestic institutes in the field of water supply and drainage and build an international technological platform.

Keywords

Experimental tower；full scale simulated experiment；super-high-rise；CNERCHS

1 Background

Along with constant expanding of construction market of high-rise residential buildings in China, new technical products and devices emerge endlessly. The issues concerning the device system of high-rise residential buildings, however, cannot be solved for a long term owing to the restriction of the low level concerning experiment and research installation, which causes that adaptable codes and rules are lagged and material selection lacks in scientific basis. In this case some institutes of science and research have no alternative but hiring foreign experimental installation to work in order to improve the reliability of their research achievements. In the mean while the research and development of domestic drainage productions is in the state of simple copy and difficult to make innovation. No doubt, it is a real restriction to the development of Chinese housing industry. So, it is necessary to build a super-high-rise building experimental tower with international standard and also it is needed for the market.

At present a project of super high-rise housing experimental tower has been completed in Dongguan, Guandong Province, which is in the charge of China National Engineering Research Center for Human Settlements (CNERCHS) and has been passed the examination on design and checking requirements by relevant department of the state and experts.

2 Operating units - CNERCHS

China National Engineering Research Center for Human Settlements (CNERCHS) is a research and development center of industry technology authorized to establish by the National Science Ministry and the Ministry of Construction and has been listed and put in running in 1990. The support unit of it is China Institute of Architectural Design and Research.

CNERCHS is main brainstorm unit of science and research on the field of housing and residential environment relied on by the state. Main task of it is taking on main national science and research projects, organizing, integrating and popularizing foreign and domestic advanced products and promoting the transformation the achievement of science and research by means of demonstrated projects.

CNERCHS possesses a housing performance laboratory authorized by National Authorization Committee on Qualification Evaluation and authenticated on measure by

National Authentication and Supervision Committee in 2000. It is the first one of housing laboratory in China, which is engaged in standardized evaluation and authentication for housing building as a final product.

3 Some issues urgent to be solved via experimental tower

3.1 Maximum capability of drainage permitted in building drainage system

3.1.1 To establish testing method of drainage capability consistent with China

The capacity of DN110 vertical pipe of stack vent, for example, is 4.0 L/s permitted by Chinese code and it is suitable to multiply a coefficient 0.9 in case the building has more than 15 of drainage levels. When the test is done with Japanese installation borrowed, the result is that the drainage capacity of the system is 2.5L/s in case the building has six drainage levels; 2.0L/s for ten levels and 1.5L/s for 17 levels. It is evident that the data gained by foreign test method is very different from that in Chinese code. Therefore it is needed to utilize housing drainage experimental tower to measure data according to the custom of using water of Chinese residents and re-establish a new test method, which will be consist with China and close to actual working condition.

3.1.2 To ensure the drainage capacity of cast-iron pipe and plastic pipe

Owing to the reason of frugalness plastic pipe is recommended to use in China. However, there are two different view points now concerning the drainage capability between two kinds of pipes. One view point is that under the same condition the drainage capability of plastic pipe is 20% more than cast-iron pipe because the inner wall of the former is very smooth and its roughness coefficient is low. Another view point is that the drainage capacity of plastic pipe is only 77% of that of cast-iron pipe because the inner wall of plastic pipe is smooth, so its velocity of flow is fast and it will cause big fluctuation of air pressure. It is clear that no other than reasonably ensuring drainage capability can guide how to correctly select pipes in design.

3.2 To ensure the method for judging drainage capability

When defining drainage capability of vertical pipes the fluctuation value of maximum pressure permitted should be regulated. This is the precondition of protecting water seal safe. In case measuring the max drainage capability it cannot only test its flow but its corresponding max pressure value. The flow tested will be adoptable when max pressure value is in the permitted range. Other wise it cannot be adopted. It is a pity that a quantitative regulation concerning max pressure value for vertical drainage pipe has not been ensured in Chinese code, yet.

It is recommended to adopt permitted losing value of the water seal or minimum odd quantity of water seal to calculate flow and select diameter of the pipe. In draining process the fluctuation of the air pressure in vertical pipe is inevitable and its exquisite change of the air pressure will cause water seal fluctuating and being damaged. So, it is an intuitive method to adopt minimum odd quantity of the water seal and also it is a method convenient to test.

The characteristic of building drainage is that the flow is unsymmetrical and not constant and the flowing time is short. Besides, the process is a complicated moving mixed with water, air and dirt, so it is difficult to gain flow by a theoretical formula. It should have a maximum of critical flow to keep 25mm of odd quantity of the water seal for all kinds of drainage systems, for which it is needed to do a lot of basic experiments and research.

3.3 The comparison of drainage capacity among all kinds of drainage systems

With the same height the comparison of the drainage capacity has to be done among stack vent system, specific vent system and drainage system with specific joints and then the drainage capacity with different height of each drainage system will be ensured. Finally some drainage systems consist with the characteristics of Chinese buildings and Chinese situation can be chosen out.

3.4 The applicability of air admittance valve

The profession of the drainage opposes to use air admittance valve to replace ventilation system. There are two reasons. 1. The role of it is limited. It can only decrease negative pressure inside the pipe but not increase positive pressure, which means only inhaling and not exhausting. 2. It needs maintenance and cannot be kept good quality. We think, however, it still has some of advantage. For example, it may ease the fluctuation of the water seal, so it is still useful for some special building structures, on which stack vent system cannot be done. Therefore, a seat should be given to qualified air admittance valve.

Some scholars in Japan, Germany and UK have done a lot of test concerning the performance of air admittance valve, drainage capacity and drainage mode of the systems, in which mainly air admittance valves are used. Based on the testing data they have established forecast chart pf the whole drainage process on academic research and also its accuracy has been validated by testing data.

It is in dire need to develop specific technical research of air admittance valve used in buildings and draw up technical application specification in order to normalize design, installation and acceptance.

3.5 Noise test of all kinds of drainage pipes

Good sound environment inside housing is one of the key factors to ensure high quality of neighborhood environment and good health on body and mind of the residents. The noise from drainage pipe system is the main source of building noise, which directly affects normal life and work of the people. Especially in high-rise and super high-rise housing buildings, the residents have made strong reaction about the noise from drainage system. In China a series of research concerning sound insulation has been doing all along and a big quantity of standard and code has been worked out. The research, however, concerning the noise of drainage system is very less. Only in 2010 referring to the testing method of France a first standard of testing method of drainage noise was worked out. Reducing noise of drainage system in the building is a systemic project, which is related to the construction form of the pipes and its material and also related to the layout of drainage system, the performance of sanitary wares, interior design and decoration materials selected. It is in dire need to test the noise from different drainage systems under the situation of simulating actual work, especially under the living condition of living in high-rise housing buildings and based on the situation of actual drainage process as well as their surrounding environment. At the same time of accumulating original data, the appraisal about reducing noise devices and reducing noise methods and optimum seeking in a variety of drainage systems will be done. Finally a good testing method consist with China will be formed and low noise drainage products will be developed.

3.6 The layout of horizontal pipes in changeable space where water is provided and used

Long life housing is an advocated concept in the development of modern architecture and also an important direction of the development of Chinese housing industry in future. In order to meet the needs of a family unit that family structure and the need of the life will be changed constantly, the layout inside housing unit has to be innovated accordingly. So, changeability of interior spaces has been the development trend in the future and the changeability of the water environment is more important and complicated. The research in future will focus on how to arrange horizontal pipes inside the unit to adapt the change. It needs a systemic research such as the connection mode between horizontal pipes and drainage wares, flowing distance and flowing capability in horizontal pipes and the impact of the horizontal pipe on drainage capability of the vertical pipe. As the support of this research project, however, there is still no clear test mode and experimental data on cubic testing in high-rise buildings.

3.7 The research on vacuum drain system

Vacuum drain system adopts vacuum toilet, vacuum control technology, vacuum pump and vacuum tank, collect life sewage to the airtight tank via vacuum pipe and finally pump it to drainage pipe network outside by sewage pump. The advantage of it is that the diameter of the pipe is small, the laying of the pipe is flexible and the effect of water saving is better. The shortcoming of it is that initial investment is higher, some of key devices must be imported and relevant software and engineering standard have to be provided from other countries. More, the adaptability and reliability of this system adopted in the housing building have to be validated through a lot of experiment.

4 Housing experimental tower

4.1 General introduction

The housing performance full-scale experimental tower is co-constructed by CNERCHS and VANKE Company, Ltd. At present its pre-debugging about test system has completed and it will put into use in November, 2012. The tower is the first one in China and also the highest one of full-scale simulated test installation in the world with the best advanced test technology for drainage performance. The total investment is more than 30 million of RMB. The total height is 123m with 37 stories (3m high for each room) on the ground and one story under ground (4.5m high for each room). All of test devices and other accessorial devices meet international standard.

Figure 1 - full scale experimental tower of housing performance`

4.2 The composition of the tower system

Whole of the system can be divided into control system, test system, data colleting system, data analysis system, monitor and control system and network system.

4.2.1 Control system

Via PAC it will realize PID adjustment of constant flow solenoid valve, control in variety of switches and electric valves and complete the test of constant flow drainage and experiment of ware drainage test. By means of controlling water supply pump it will realize auto supplement of water to low and high tanks. Three meteorological stations will detect atmospheric wind speed, temperature, humidity and solar radiation parameters and via Modbus link to PAC controller on every level in the system.

4.2.2 Testing system

4.2.2.1 Experiment of drainage system with constant flow

Range of pressing sensor: -10000Pa-+10000Pa; Resolution: 5Pa; Response cycle: 20Hz; Wave filtration: 3Hz.

Test items: pressure of horizontal pipes, ventilation speed of stack vent system, liquid surface level in floor drain and liquid surface level in horizontal pipe.

Judge condition: ±400Pa within pressure range of the system

Control measure: According to the feedback of flow meter to control constant flow solenoid valve and realize constant flow output.

Process: Testing pressure value inside horizontal pipes on every level and comparing with judge condition. Adding flow of 2.5L/s starting from the highest level; arbitrarily select drainage levels no more than eight and adding flow of 2.5L/s before close to judge condition turn and turn about; when close to the condition adding flow of 0.11L/s turn and turn about as far as reaching the condition.

4.2.2.2 Experiment of ware drainage

Range of pressing sensor: -10000Pa-+10000Pa; Resolution: 5Pa; Response cycle: 20Hz; Wave filtration: 3Hz.

Test items: Testing pressure of horizontal pipes; testing liquid surface level in water seal of toilet, wash bowl and bathtub.

Control measure : To control the switch of standard ware which is custom-made according to the character of the ware and realize ware drainage controlled by output module of the controller.

Judge condition: ±400Pa within pressure range of the system.

Process: Testing pressure value inside horizontal pipes on every level and comparing with judge condition. Controlling drainage of bathtub and close-tool from the highest level; arbitrarily select drainage levels no more than eight and realize ware drainage turn and turn about as far as reaching the condition.

4.2.3 Data collecting system

Access layer: Floor switcher: 100M industrial Ethernet exchanger KIEN1005 with five electric ports. Ethernet access equipment: floor RX3I controller 1, noise meter 1 and network camera 1.

Convergence layer: floor exchangers at 1st -15th floors will access to the two-layer network cabinet of gigabit convergence layer exchanger WS-C2918-24TT-C; floor exchanger at 16th-33rd floor s will access to the sixteen-layer gigabit exchanger WS-C2918-24TT-C.

Core layer: Super six categories: two sets of WS-C2918-24TT-C will access to the three-layer exchanger 3560-24TS-S. Optical fiber access: the three-layer gigabit exchanger 3560G-24TS-S will provide 24 electric ports and two SEP gigabit fiber port available for WLAN or other inward accesses.

Data collecting on site: there are shielding categories DCS signal cables between the data-colleting controllers and sensors on site. Multi-parameters Meteorological station will use Modbus linkage to access the nearby floors` Rx3i controllers. The air-conditioning set and water bumps will be controlled by the single layer PAC controlling cabinet.

There will be 802.11g/802.11n WIFI access at meeting room and office area, the 3560G-24TS-S will provide more than 12 extra 100/1000M electric ports for other accesses.

4.2.4 Data analysis system

4.2.4.1 Purview control module

It may realize that personnel on different level will gain different operation instruction and function on the man-machine interactive interface by setting up purview levels, code and password input.

4.2.4.2 Data dispel module

Its colorful, intuitive and dynamic figure interface in Chinese is easy to use and understand for users and it can realize multi-windows display of working situation.

4.2.4.3 Output control module

It may set up output and some parameters needed to adjust in manual.

4.2.5 Monitor and control system

The system of central work station is made up of data-base server，PC station, color large screen display and printer. It is the core of BAS system directly connected with Ethernet. All of mechanical and electric devices monitored and controlled in the tower will be managed and displayed here. Built-in interactive interface may provide drop-down menu, man-machine dialog and dynamic figure display, which is very easy to learn and operate. The operators can manage the whole control system only by mouse, keyboard and touch screen without any professional software knowledge. The system can connect one or two stations used as assistant control stations or backup. There are 33 sets of Sony network HD cameras (SNC-CH140-720P) with moveable brackets for video assistant monitor on every level connected with KIEN1005 electric port of 100M switches in the control boxes on every level. Network hardware VCR supports 33 lines of 720P video kept for 6*24 hours with expandable storage space.

4.3 Main technical indicators of performance

(1) The cycle of data collecting and storing is 20Hz or 50ms each time; the highest one is 20ms. 5M record storage space can be used for single controller users. Record time for 100 point simulation can be more than 10 minutes.

(2) Synchronous time for collecting different data is <10ms.

(3)All data may start to record on the jumping-off point at the same time and stored in the controller of its own level. After being tested they will go back to general control room for analysis.

(4)There should be two interfaces of curve and numeral value for test personnel to make initial qualitative estimation.

(5)During the process of the test the data can be transmitted to general control room, too.

(6)The adjustment time for determining flow should be within a minute.

(7)Interior network of the system adopts Ethernet transmission medium.

(8) Open data interface and agreement are adopted.

(9) The system has to keep a certain capacity for the need of increment test.

(10)The test process will be set up on the man-machine interactive interface including start-up, finish time, test content, etc.

(11)The host computer will output test instruction to output touch PAC controller, which will carry out output, touch off input of all PAC collecting controllers and realize benchmark synchronous on record time.

(12)The work station may retrieval data from data-base for software filtration and treatment, which will be used for analysis, statistics or printing out.

(13)The system may keep the capacity of long-distance transmission.

4.4 The direction about research and development

(1)Performance of drainage system in the building including two experimental methods: drainage with constant flow and ware drainage.

(2)Product test related to water supply, drainage and ventilation of air-conditioning

(3)Noise from drainage system

(4)Exhaust system and fumes exhaust system of the housing building

(5)Hot pressing ventilation

(6)Technology concerning saving energy and water

(7)Components putting on the outside of the building

(8) Water and hot water supply system of the housing building
(9) Gas supply system
(10) Air–condition system
(11) Rain water system
(12) Experiment of object falling from high place of the building

5.Summing-up

Based on the housing experimental tower, a research and intercourse platform will be established concerning foreign and domestic housing new products and technology, thus reducing the difference between China and developed countries step by step. A uniform experiment and test standard for housing performance will be formed relied on experiment and research. Complete test devices will strictly examine housing products in the market and the existing situation concerning the performance of engineering products that the good and the bad are intermingled and no way to assess will be broken.

At present the tower is the only one of experimental institute in China to test technical function of high-rise and super high-rise buildings, which will play active role for the development of Chinese housing industry.

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Modelling solid transport in shallow gradient pipe installations: application to simplified sewerage in an international development context.

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Abstract

More than 2.6 billion people still live without adequate sanitation globally. 'Simplified sewerage' is one possible solution, offering the possibility of an appropriate scale for urban sanitation. Adoption of such systems requires the range of engineering and advocacy tools erstwhile only available in developed countries: modelling, design codes and codes of practice would all lead to a widening acceptance of the technology and a far greater uptake amongst communities and local authorities. This paper describes the fundamental solid transport mechanisms which allow simplified sewerage systems to be modelled. The application of small bore solid transport system models are wholly appropriate for simplified sewerage, however modifications are required to account for the shallow gradients and the likely accumulation of solids due to low water usage. The importance of local water flow depth on drain self- cleansing, where large accumulated solids are present, has been identified and the solid movement threshold has been quantified for a range of expected gross accumulated solids. These modifications, together with improved solid deposition predictions, have contributed to the development of a robust model suitable for application to simplified sewerage systems which when applied to real systems can improve efficiency.

Keywords

Solid Transport, Ultra low flow modelling, development, simplified sewerage.

1 Introduction

The basic purpose of a sanitation system is to isolate people from potentially harmful waste material. Transporting waste material in a contained drainage/sewerage system offers users the highest possible protection against disease. The most recent WHO Global annual Assessment of Sanitation and Drinking-Water[1] estimates that there are some 2.6 billion people without access to adequate sanitation globally. The situation has been exacerbated by the rapid urbanisation of the late 20th century; for the first time in recorded history there are now more urban than rural dwellers Of the 3 billion urban dwellers, as many as 1 billion people live in unplanned peri-urban shanty towns, 'favelas' or slums. Living on the margins of cities, most of these dwellers do not have access to adequate sanitation provision, leading to inevitable health and quality of life issues.

The challenges set by the Millennium Development Goals (MDG) are therefore immense. The task of halving the number of people without access to improved sanitation by 2015 is a monumental one, and one which cannot ignore the urban aspect to the problem. Despite best efforts, the goal seems more elusive than ever. There is hope that the recently announced 'boost' to the impetus for attaining the MDG for sanitation with a 'five year drive to 2015'[2] will help, but clearly the issue is a real problem. The close correlation between access to adequate sanitation and poverty predetermines that any credible solution must be both 'low cost' and 'cost effective'. Solutions must also be capable of dealing with the growing numbers of people needing provision. There are many potential technological solutions to the problem of providing improved sanitation; ventilated improved pit (VIP) latrines and on-site sanitation in general are important elements of the strategy and provide on-site solutions appropriate to many rural areas with favourable ground water conditions; however, space is at a premium in the peri-urban setting and therefore these options are not always possible or appropriate. Conventional sewerage systems are obviously desirable, but cost and access for deep excavations preclude their use in both low income and unplanned high-density settlements.

Simplified sewerage systems, with their characteristic shallow gradients, and therefore shallow excavation requirements, provide a real alternative for the many peri-urban dwellers on the fringes of large cities. The cost savings relative to conventional sewerage systems are considerable: recent analyses in India, for example, show the cost of simplified sewerage to be approximately one third that of conventional sewerage systems[3,4,5]. This reduced cost and ease of construction are appropriate to the socio-economic background of the peri-urban community that, in many cases, self-manage both the installation and the on-going operation and maintenance of the system.

The design methodology for simplified sewerage is based on steady-state hydraulics and the favoured method is to specify the pipe diameter and gradient to achieve a minimum tractive tension in the system[6,7,8].The design is based on rational changes in the design standards defining conventional sewerage that makes simplified sewerage cost-effective without sacrificing quality (Ibid). The changes from conventional sewerage design result in small bore pipe configurations and systems that are more similar in their characteristics to Building Drainage Systems (BDS) than conventional sewerage systems. Many of the time-dependent numerical predictive techniques used to model and improve BDS are therefore applicable to simplified sewerage designs and offer real advantages in the simulation of waste solids transport.

This research seeks to extend an existing solid transport / building drainage predictive model and apply it to the shallow gradients and large 'accumulated' solids characteristic of simplified sewerage systems. The benefits of predictive modelling have been enjoyed by engineers, designers and stakeholders in the developed world for many years. For community managed simplified sewerage systems the stakes are high; predictive models can increase confidence that the limited resources available are contributing to the construction of an efficient, optimized system, suitable for purpose with a low risk of failure.

2 Solid transport modelling

Two conceptual models currently exist for the transportation of discrete solids in near horizontal pipes; these are:

- The velocity decrement model
- Mach number model

These conceptual models focus on the distance to deposition for solids since this is a useful measure of system performance. The main difference between these two models is that the velocity decrement model contains boundary condition equations which operate alongside the water flow calculations; solid transport is therefore calculated in a virtual sense. The models associated with Swaffield, McDougall and Butler[9,10,11] fall into this category. The second category of transportation model is due to Gormley and Campbell differs from the virtual model in that the presence of the solid modifies the surrounding water which in turn modifies solid transportation, a capability that becomes essential close to deposition[12.13].This model is based on the solid Mach number in the flow and is therefore deterministic. This Mach model is particularly appropriate when solids are close to deposition, a situation characteristic of the transport of solids in pipes of shallow gradients or driven by very low intermittent flow regimes. It is considered essential to develop specific boundary equations for solids in simplified sewerage networks and to locate these boundary equations in a deterministic model where the solid itself influences the water flow and *vice versa*.

Another issue affecting modelling solid transport is the impact of 'flow anomalies' on solid movement. These anomalies are usually slow moving deeper areas of flow, such as those found behind a hydraulic jump, upstream of a junction, or the water 'pooling' behind a solid which has come to rest. For these scenarios Gormley and Campbell proposed a 'modified mach model' to cope with the changing nature of the transport mechanisms when a solid meets an area of non – uniform flow, again providing an advance on existing velocity decrement approaches[12,13].

While these models can accurately predict solid transport in building drainage systems in modern, 'developed world' installations where ample piped water is generally available, it is only on long horizontal pipe runs that the accumulation of solids become a real issue.

This phenomenon, usually associated with toilet tissue paper occurs when the paper has been transported to a maximum distance and deposited, however this process occurs along the way so solids can vary in size, shape and weight with distance. This maximum distance is due to the attenuation of the transporting surge wave, the leak flow past the solid and other contributing factors such as solid specific gravity, pipe slope and diameter and the presence or absence of joining flows from other branches.

The result of this can be a settling, and partial drying out of the waste (both paper and faeces). Subsequent surge waves may carry a similar waste load which may settle on the previous, partially dried load. In this way the solid mass accumulates in the pipe and can potentially lead to blockage of the pipe leading to the requirement for expensive remedial work. By predicting the minimum flows available at any point in the pipe under real system simulation conditions, an assessment of blockage risk can be made by minimizing the risk of blockages the system can be optimized for minimum maintenance intervention.

2.1 Model Basis

The method of characteristics technique is appropriate for the simulation of free surface flows in partially filled drainage pipes. Based on the solution of The St Venant equations for continuity and momentum, this modelling technique represents the fundamental equations as two first order finite difference equations, known respectively as C^+ and C^- characteristic slopes in the method of characteristics grid, linking known conditions at time *t* to conditions at *P* at one time step in the future.
With reference to Figure 1 it can be shown that;

$$\frac{dV}{dt} \pm \frac{g}{c}\frac{dh}{dt} + g(S - S_o) = 0 \qquad 1$$

provided that the calculation time step conforms to the Courant criterion, defined as

$$\frac{dx}{dt} = V \pm c \qquad 2$$

where, the wave propagation speed *c* is defined as $c = (gA/T)^{0.5}$, S and S_o are the friction and pipe slopes respectively, and *A* and *T* are the flow cross sectional area and the surface width. The form of equation 1 requires a small base flow in the pipe in order that the calculations can commence[9,14].

From Figure 1 it can also be seen that only one characteristic is available at system entry or exit. Thus it is necessary to define boundary equations that may be solved with the appropriate C^+ and C^- characteristic at these nodes. Previous research in this area (Ibid) has yielded boundary equations for many conditions including;

- W.c. discharge
- Pipe junctions
- Displaced upstream hydraulic jumps
- Flow at the base of a vertical stack.

The grid used to represent the progress of a calculation in the method of characteristics scheme of the type most relevant to the partially filled pipe, unsteady flow regimes experienced in building drainage systems is also shown in Figure 1. This is a specified grid system in that the nodal distances along the x axis are pre-defined while the time step may vary depending on the flow conditions and subject to the courant criterion outlined above.

The transport of a solid in a near horizontal drainage pipe under steady flow conditions is characterised by a number of significant changes in the flow depth profile. The water depth behind the solid reduces gradually to a point where the water depth is normal for the particular flow regime due to the inflow and the water immediately in front of the solid is below normal water depth and increases downstream. This bow wave is due to the effects of water tumbling over the solid at a higher than normal velocity.

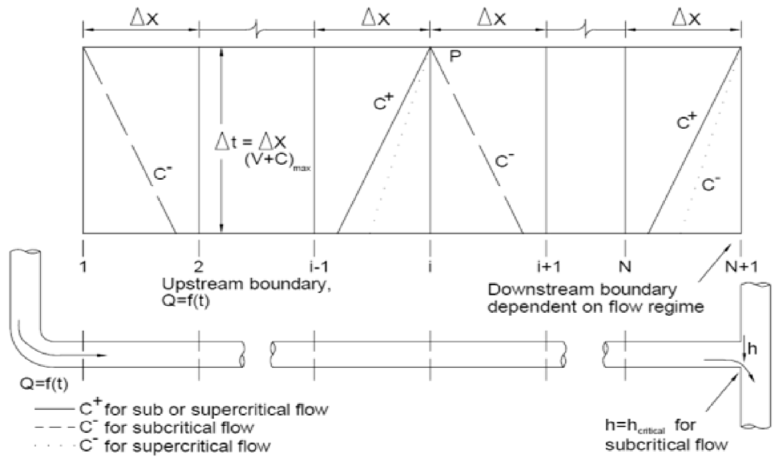

Figure 1. Application of method of characteristics specified time interval grid to partially filled pipe flow.

2.2 Solid boundary condition

The presence of the solid in a flow requires a simple modification to the water depth profile at the solid's location along the pipe at a given time. The water depth is therefore given by

$$h_i = h_i + dH_S \qquad 3$$

Where h_i is the water depth at node i if no solid is present and the flow can be either supercritical or subcritical, and dH_S is the water depth difference across the solid which is a function of the velocity of the solid, V_S .

2.3 Extending the existing model for pipes at shallow gradient

The laboratory test rig to be used to establish these boundary conditions is shown in Figure 2 and consists of three pipes (of diameters 75mm, 100mm and 150mm) laid at a gradient of 1:166, a typical simplified sewerage gradient. A representative plastic cylindrical solid of 36mm diameter and 75 mm length with variable specific gravity were inserted a steady flow rate. These solids were first developed by the National Bureau of Standards in the U.S.A. in the 1980s and formed the basis for much of the

work carried out to date on solid transport mechanisms in drainage systems[9]. As the solid travelled along the pipe two water depths were recorded
1) The water depth behind the solid (upstream waves speed Cus)
2) The water depth in front of the solid. (downstream wave speed Cds)

From these two variables a graph similar to that shown in Figure 3 can be produced, where the relationship between the upstream and the downstream wave speeds are plotted under conditions set by their relationship to the wave speed of the steady flow rate normal depth (cn). This methodology was repeated for a range of solids in the three different pipe diameters.

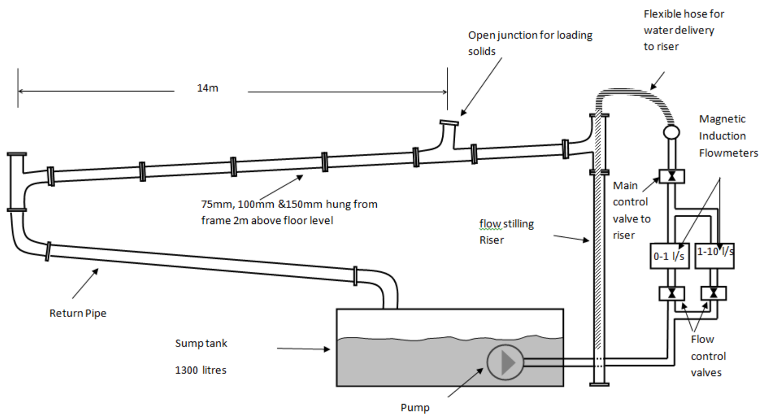

Figure 2. Laboratory Test Rig

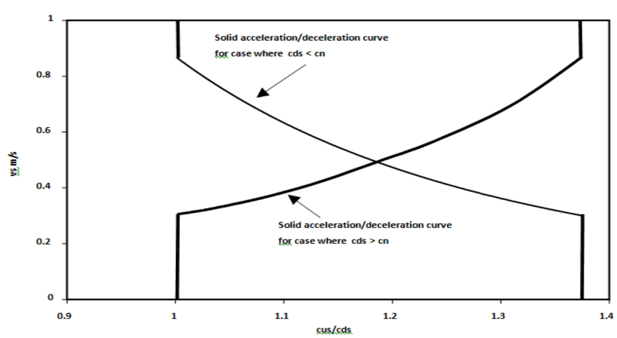

Figure 3. General Form of the wave speed model

2.4 Results and discussion

Previous research by Gormley & Campbell [13] established the importance of the ratio of upstream to downstream wavespeed in determining the velocity of a solid in a flow it also predicts the deceleration and acceleration of interacting solids as they travel along a pipe. It is therefore a useful way to describe solids in a flow. Figure 4 depicts the changing nature of this relationship with changing pipe diameter for the shallow pipe gradient of 1:166 used in the experiments.

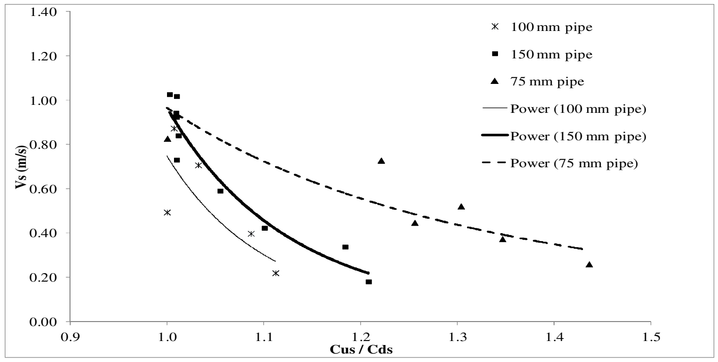

Figure 4. Cus/Cds for pipe slope of 1:166

In addition to the work carried out by Gormley and Campbell, previous research on solid transport in pipes set to gradients as shallow as 1:140 was carried out by Goulding[15]. Goulding's methodology was to determine the water depth behind a solid when it was towed at different velocities, thus giving a range of water depths over a range of flow conditions. The data from all previous investigations, including Gormley and Campbell[12] and Goulding[15] together with the data from this research are presented in Figure 5. The progressive steepening of the power curve trendlines with decreasing pipe gradient confirms that the results from the current work complies with the general form of the model developed by Gormley and shown in Figure 4 above. It is also of interest to note that as the pipe gradient decreases the maximum solid velocity decreases and the range of flow rates cus/cds decreases also. This confirms that as the gradient decreases the effect of flow velocity is diminished and that hydrostatic forces are in the main responsible for solid movement and transport. This phenomenon was observed in the laboratory as a 'stop – start' movement of the solid along the pipe. The mechanism involves the solid coming to rest; water building up behind it initiating movement, the solid is carried on by inertia until it comes to rest again where the process repeats until the hydrostatic force can no longer initiate movement.

This phenomenon is of more significance in pipes set to shallow gradients as demonstrated above. The 'stop-start' process raises an additional concern in practice; that solid waste accumulates and solids become large and difficult to move.

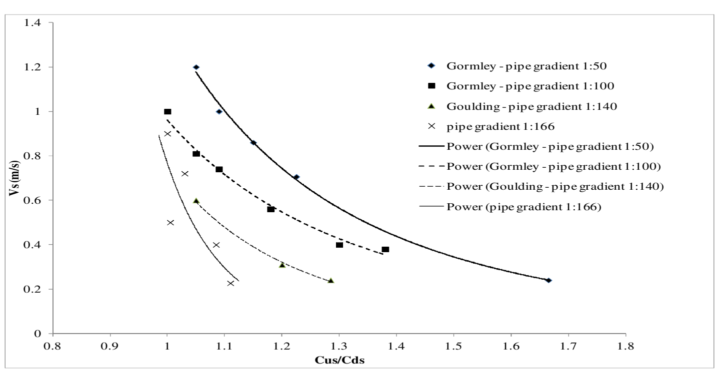

Figure 5. Comparison of curves for all data

3. Determination of the movement threshold of large, accumulated solids.

To address the specific issue of the accumulation of large solids in simplified sewerage systems set to shallow slopes an additional set of experiments were carried out to establish the movement thresholds for various large solids chosen to represent near blockages of the pipe. This in effect establishes the resilience of the system under ultra low water usage criteria.

While the movement threshold is important for solid transport it is also a useful indicator of the risk of blockage, since slow moving solids tend to accumulate and create bigger solids which are all the more difficult to move. This issue is of significant importance to simplified sewage since the pipes are set to shallower gradients and the flows available are very low in the first instance. Any predictive model dealing with solid transport under these conditions needs to be able to cope with the movement threshold of large solids and blockages.

3.1 Methodology

Figure 6 shows the solids used to simulate the large accumulated waste which can be found in a system. The methodology used was to place the mass in the pipe and subjected it to a steady flow. A steady flow was used since the flows found in such systems are, in the main, quasi-steady, particularly at the point in the system where accumulation is considered a risk. Figure 9 shows an illustration of the transport mechanism near deposition where the surge wave from the appliance has abated. This phenomenon occurs at a considerable distance from the closest source and the predominant transport mechanism is hydrostatic, as water builds up behind the solids and carries them further along. The dimensions of the solids used in the test are shown in Table 1. For each solid the flow rate was increased slowly (to avoid creating a shockwave) and the solid movement flow rate was recorded.

Figure 6. Test pieces used to simulate large blockages

Table 1. Dimensions of large solids used

% Blockage	75mm	100mm	150mm
20	45mm x20mm	45mm x 30mm	11mm x 30mm
30	45mm x 30mm	55mm x 60mm	90mm x 55mm
50	55mm x 60mm	55mm x 70mm	94mm x94mm

3.2 Conceptual model

Figure 7 illustrates the range of flow rate required to initiate movement for all the cases tested. It can be seen that, in general again, as the pipe diameter increases and the solid specific gravity increases then the flow rate to initiate movement increases also. It is also interesting to note that at larger pipe diameters the range of flow rates required to initiate movement is much greater for the range of solid sizes and specific gravity tested. In general then, it can be said that as solid specific gravity, percentage blockage and pipe diameter increases, so does the flow rate required to initiate movement. This confirms that solid transport is generally better, and more consistent, in small bore pipes.

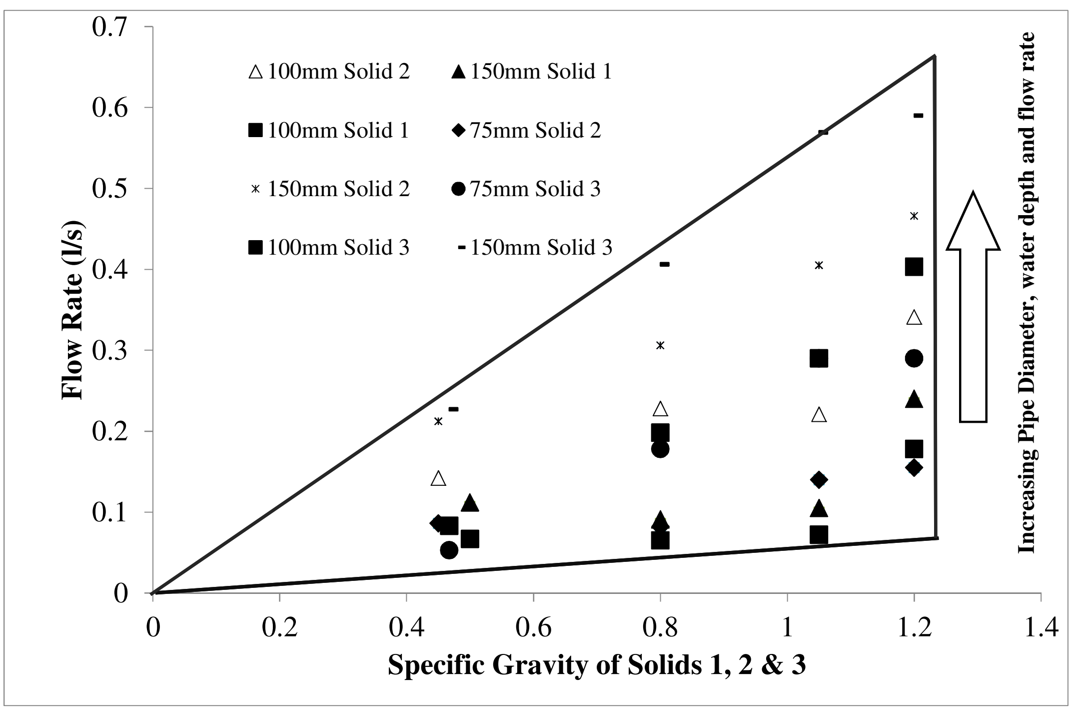

Figure 7. Range of flow rates required to initiate solid movement

3.3 Mathematical model

The data shown above was conflated in Microsoft Excel using a solver algorithm developed for the purpose. A sensitivity analysis using regressive techniques was carried out on the data and it was concluded that the 'best fit' for the equations occurred when the normal depth of the flow rate required to initiate movement was used. It was found that the normal depth (H_n) of the flow required to initiate movement of solids can be calculated from;

$$H_n = \left((2.643 \ x \ 10^{-7} * B^{0.78} - 9.064x10^{-8}) * D^{3.784} + \ 8.384\right) * S + 4.72 \qquad 4$$

Figure 8 shows the actual depth recorded for each blockage threshold movement and the model predicted water depth. The R^2 value is considered reasonable given the variability experienced in the experimental investigation. Static friction between the solid and the pipe wall, difficulty in setting very low flow rates and small movements in the solids as the water engulfed them were among the factors most responsible for the discrepancies observed.

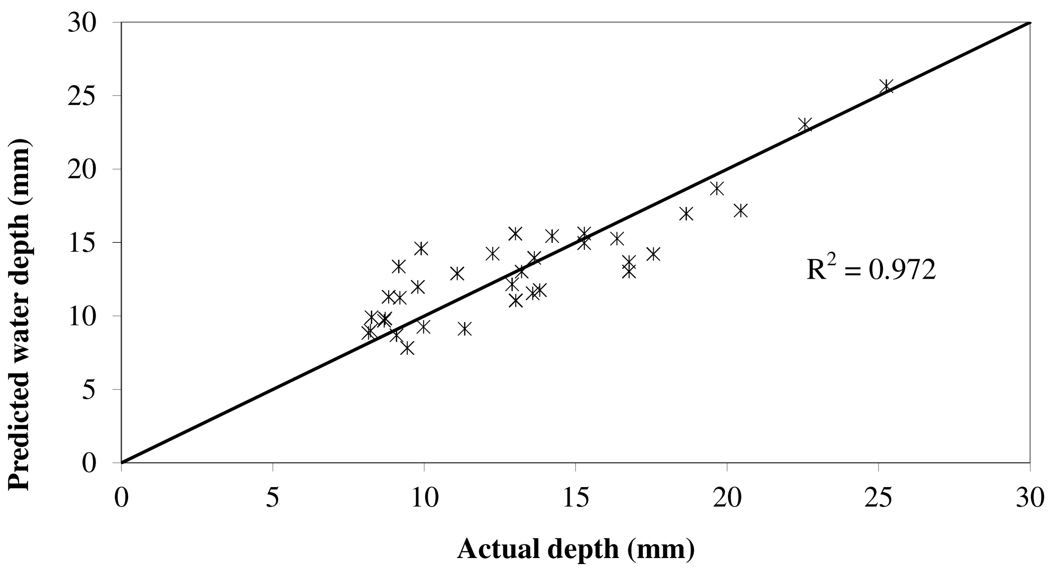

Figure 8. Predicted against actual depth for the model

3.4 Discussion

The ability of a system to self-cleanse is essential for trouble free operation. The conceptual model developed for the threshold movement for large accumulated solids suggests that maintaining a sufficient water depth along the pipe is crucial if total blockages are to be avoided. The process is aided however by the creation of the partial blockage created by the accumulation of solids itself, in that it allows a build-up of water and this increase in hydrostatic force contributes significantly to the robust nature of simplified sewerage. This may seem counter –intuitive, however the shallow slopes facilitate a significant hydrostatic effect which is lost in systems with steeper gradients as the fast flowing water leaks past solids at a far greater rate. This phenomenon means that simplified sewerage systems make more efficient use of the water used and so contributes significantly to water conservation and water efficiency strategies.

4. Conclusions

The rapid urbanisation of the late 20th Century has provided sanitation provision challenges to policy makers, planners and engineers alike. The scale of the problem is immense and the options of either low cost on-site solutions or expensive conventional systems are both inappropriate in many cases. Simplified Sewerage can play a significant part in addressing the problem, however, despite significant successes in Brazil and India uptake is still slow. Modelling and investigating systems has led to continuous sanitation improvements in developed countries over the past two Centuries and it is concluded here that this success could be replicated in developing countries. Models act as an excellent advocate for a technology, as well as a forensic tool, building confidence in the technology through dissemination of results and initiating debate.

The laboratory investigations described in this paper go a considerable way in adapting a method of characteristics based building drainage system numerical model for the specific application to Simplified Sewerage Systems. The investigations also define some important solid transport mechanisms relevant to such systems and confirm some long held beliefs amongst practitioners in the field; that smaller bore pipes are less prone to blockage, that local water depth and minimum tractive tension are just as important, if not more, than drain self- cleansing velocity and finally, almost counter intuitively, that under low water usage shallow gradients promote solid transport and hence minimize blockages and help conserve water. The fundamental principles and the empirically derived equations described in this paper form the basis for an engineering led approach to 'scale up' potential solutions to widespread sanitation neglect of a large proportion of the world's population. To make this model more effective there is a need for further research to refine, calibrate and validate the model using real installation and usage data from the field. This will form the basis for the next phase of this work.

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A Study on the Evaluation of a Super Water-Saving Toilet in Regard to the Drainage Performance thereof in the House Drain Section

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Abstract
Toilet efficiency in conjunction with water conservation has been promoted worldwide, but this unfortunately often diminishes the drainage performance in the large-diameter house drain section of drainage systems, causing waste materials, toilet paper, etc. to block the house drain, as reported at the International Symposium of CIB W062. In Japan, 6-litre flush toilets which were mainstream a few years ago have been gradually taken over by super water-saving toilets which use much less water and are becoming more available on the market.

This paper examines, through experiments, how the drainage performance of the house drain is affected by employing different types of super water-saving toilets, including those using less than 6 liters of water, in consideration of various factors, such as the type of waste material (substitute), the toilet drain height, and the condition of drainage flow.

Keywords
Super water-saving toilets, House Drain,

1 Background of the study
Toilet water conservation has been promoted worldwide, and 4.8-litre toilets are available in the West Coast of America. However, toilets using less water can diminish the carrying performance of the house drain of drainage systems, as pointed out at the International Symposium of CIB W062. Fig. 1 shows the trend of toilet water conservation in Japan in relation to standards and specifications. In Japan, 6-litre toilets have been used since 1999, and in 2011, 4-litre toilets became available in the market.

At present, even more efficient, 3.8-liter toilets are commercially available. Water-saving toilets in Japan are currently classified into type I and type II, depending on the type of flushing system and the amount of water used for flushing (see Table 1), in accordance with Japan Industrial Standards (JIS). At the International Symposium of CIB W062, it was reported that in Taiwan, the application of water-saving toilets diminished the carrying performance of the house drain of drainage systems[1)2)]. Subsequently, this report evaluates the carrying performance of the house drain when waste substitutes are drained from different heights through a drainage stack system which is equipped with a 4-litre super water-saving toilet. Furthermore, based on the assumption that the downward flow of drainage water and waste in the drainage stack affects the carrying performance of the house drain, this report clarifies the relationship between the carrying performance of the house drain and the drainage characteristics at the base of the drainage stack.

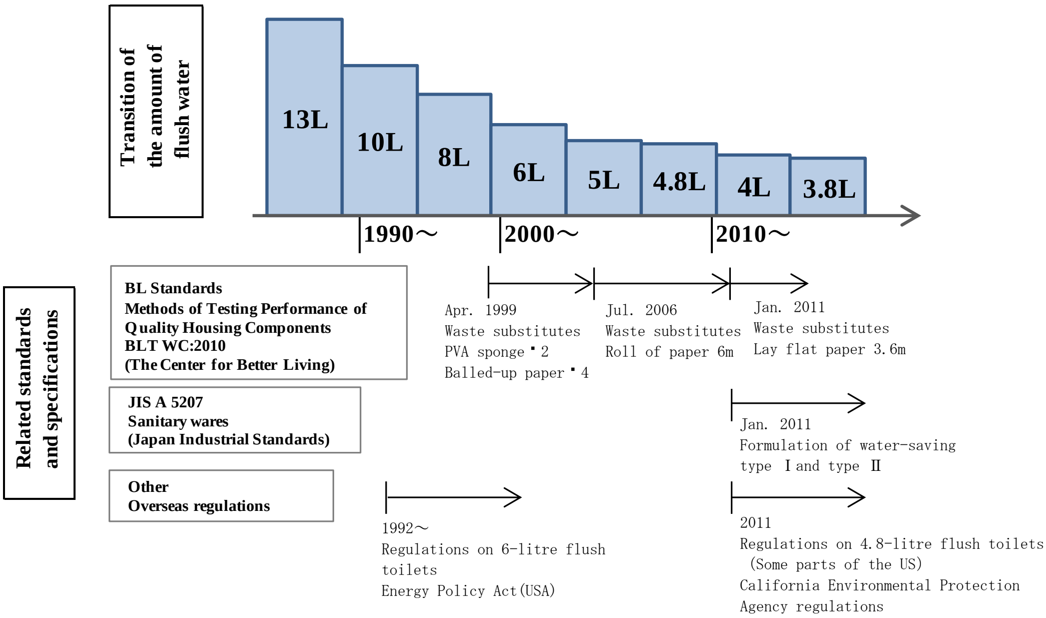


Fig. 1 Trend of toilet water conservation and related standards and specifications

Table 1 JIS classification of water-saving toilets

Classification	Cistern	Flush valve
Type I	8.5[L] or less	8.6[L] or less
Type II	6.5[L] or less	8.5[L] or less*)
*)Type II/flush valve: limited to specific-type toilets with a flush valve		

2 Objective of the study

Using an experimental tower which simulates a typical drainage system for high-rise buildings, this study discusses the following points about the carrying performance of the house drain:

(1) Clarify the relationship between the toilet drain height and the distance waste substitutes are transported in the house drain.

(2) Examine the toilet drain height and the variation of the drainage characteristics measured in the base part of the drainage stack

3 Outline of the experiment

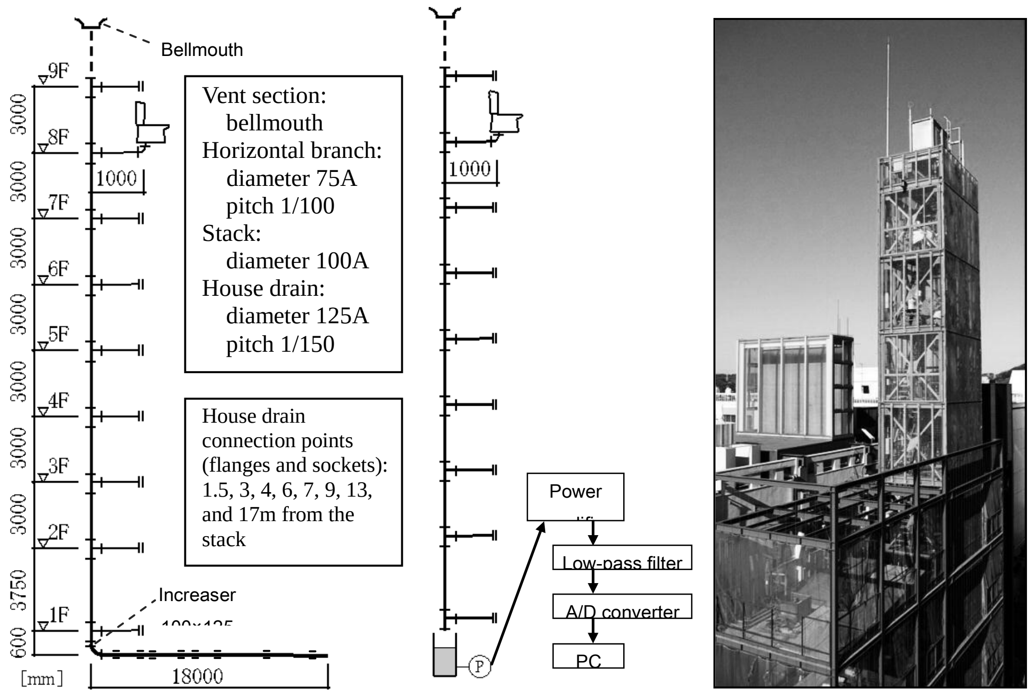
(1) Experimental systems

(A) House drain carrying performance experiment

This experiment employs a high-rise simulation tower of Kanto Gakuin University, which has nine storeys and a height of 25m. Fig. 2(a) shows the stack system used for this experiment. The stack system is of a vent type and comprises a drainage stack with a diameter of 100A (with JIS-DT fittings attached thereto), and horizontal fixture branches with a diameter of 75A (pitch 1/100). The diameter of the house drain is 125A (pitch 1/150), and the length thereof is 18m with reference to the previous report[2] presented at CIBW62 in 2011. In (a) the house drain carrying performance experiment, a super water-saving, 4-litre toilet is used, and a drainage load is applied from the 1st to 8th floors respectively. Incidentally, there are two types of drainage loading: a large amount of flush water for draining solids (full flush) and a small amount of flush water for draining urine (partial flush). As waste substitutes are drained from each floor, the distance they are transported in the house drain is measured.

(B) Stack drainage characteristics experiment

This experiment uses a stack comprising a large inlet installed at the base of the stack, and the characteristics of a downward flow in the stack are measured. Fig. 2(b) shows the stack system used for this experiment. In (b) the stack drainage characteristics experiment is implemented from the 1st, 3rd, 6th and 9th floors which provide typical drainage loading conditions.



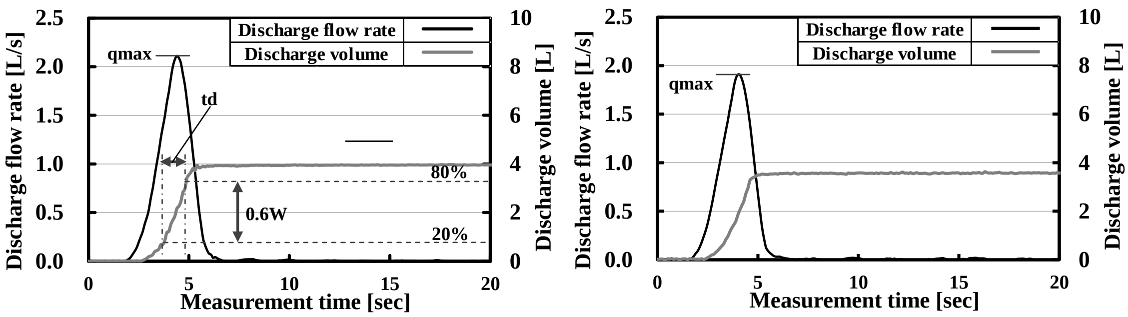
(a) House drain carrying performance experiment

(b) Stack drainage characteristics experiment

Fig. 2 Experimental stack systems

(2) Discharge Characteristics of Toilets

Fig. 3 shows curves representing the discharge characteristics of the toilet used in the experiments. The curves are of discharge volumes, discharge flow rates, etc. which were recorded when the full flush and the partial flush were used. Meanwhile, Table 1 lists the values of the discharge characteristics of the toilet. Incidentally, a 4[L] toilet was used in the experiments, and the discharge characteristics thereof were measured in accordance with SHASE-S 220_{-2010}, “Testing Method of Discharge Characteristics for Plumbing Fixtures”. The average discharge flow rate, qd, is one of the indices representing the discharge characteristics of plumbing fixtures, and a qd value is obtained by measuring a discharge flow rate while 20-80% of flush water is discharged from a toilet and dividing the discharge flow rate by the discharge time. Table 1 also lists the discharge characteristics of a 6-litre water-saving toilet for comparison. Table 2 indicates that although the 4-litre toilet used in the experiments uses less flush water, the average discharge flow rate, qd, and instantaneous maximum discharge flow rate thereof are greater than those of the 6-litre toilet. This suggests that a high discharge flow rate compensates for a small amount of flush water so that the discharge performance of a toilet does not have to be compromised.



(1) Full flush **(2) Partial flush**

Fig. 3 Discharge flow rate curves and discharge volume curves

Table 2 Discharge characteristic values

	Discharge flow rate	Discharge time	Avg. discharge flow rate	Instantaneous max. discharge flow rate	Avg. discharge flow rate with the drain pipe connected
Type of flush	W[L]	td[s]	qd[L/s]	qmax[L/s]	qd'[L/s]
Full flush	4.2	1.2	2.23	2.39	2.01
Partial flush	3.7	1.2	1.88	1.91	-
6L(Full flush)	6.0	1.9	1.93	2.11	-

* The length of the horizontal branch with the drain pipe connected: 1m

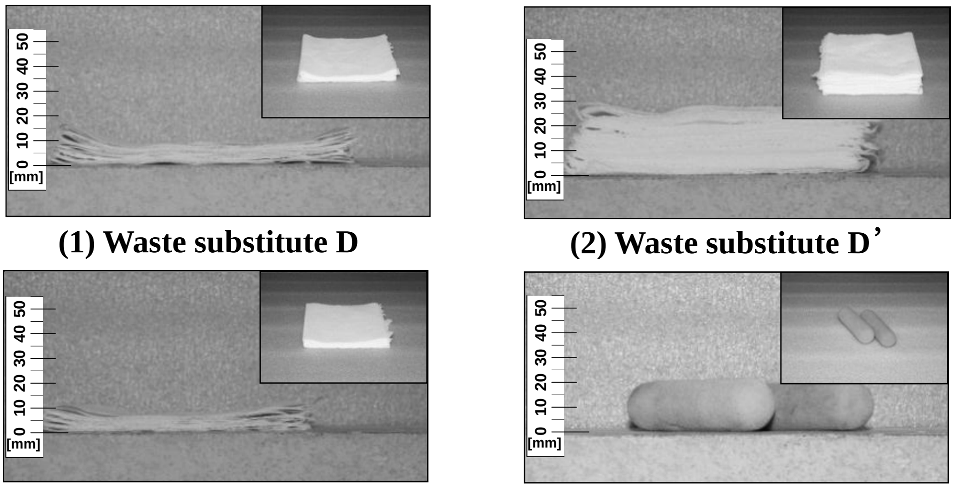
(3) Waste substitutes for the experiments

Table 3 and Fig. 4 show the waste substitutes used in the house drain carrying performance experiment. Waste substitute D is a 1m-long piece of paper (1 ply) which is folded into six layers, and waste substitute D' is a 1m-long piece of paper (2 ply) which is also folded into six layers. Furthermore, new waste substitute BL is a 0.9m-long piece of paper (1 ply) which is folded into four layers, and this is in accordance with a BL (Better Living) standard, "Methods of Testing Performance of Quality Housing Components" which was formulated in 2011 by the Center of Better Living. In addition, in order to compare with the outcome obtained from the study in Taiwan, two pieces of PVA sponge were also used in the experiments for reference.

Table 3 Waste substitutes for the experiments

Waste substitute	Description
D	Lay-flat toilet paper, 6m (1 ply)
D'	Lay-flat toilet paper, 6m (2 ply)
NewBL	Lay-flat toilet paper, 3.6m (1 ply)
PVA sponge	PVA sponge, 2 pieces

* New BL: "Methods of Testing Performance of Quality Housing Components" BLT WC:2010 by the Center of Better Living



(1) Waste substitute D **(2) Waste substitute D'**

(3) Waste substitute New BL **(4) Waste substitute PVA sponge**

Fig.4 Waste substitutes for the experiments

(4) Transport Distance in the House Drain

As shown in Fig. 5, the transport distance in the house drain is from the core of the stack to the very last waste substitute which is held up in the transport direction in the house drain. The transport distance was measured five times using waste substitute D, and twice with the other types of waste substitutes respectively. The average transport distance in relation to each type of waste substitute will be described later.

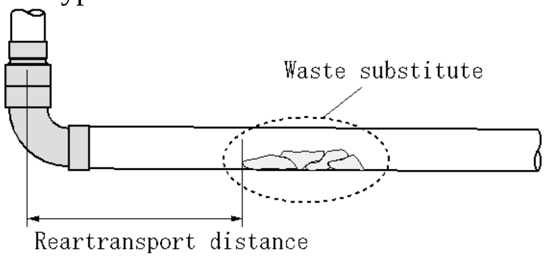


Fig. 5 Transport distance in the house drain

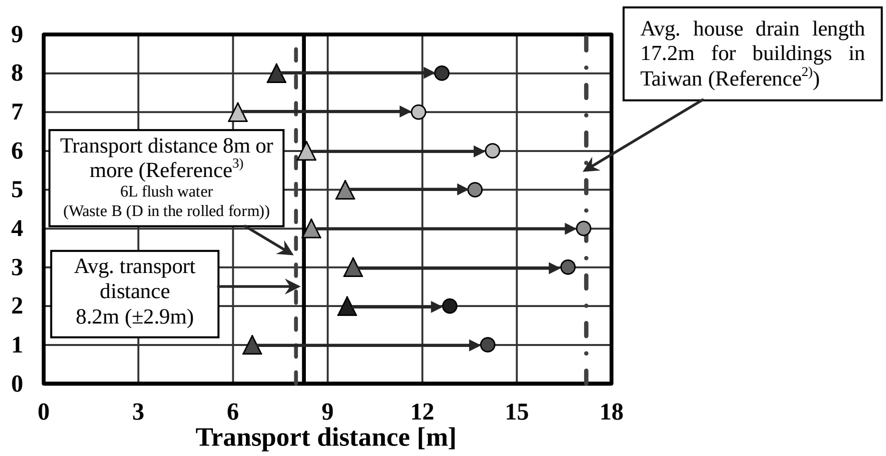
4 Results and Consideration

4.1 House drain carrying performance experiment

(1) Comparison of transport distances by full flush and partial flush

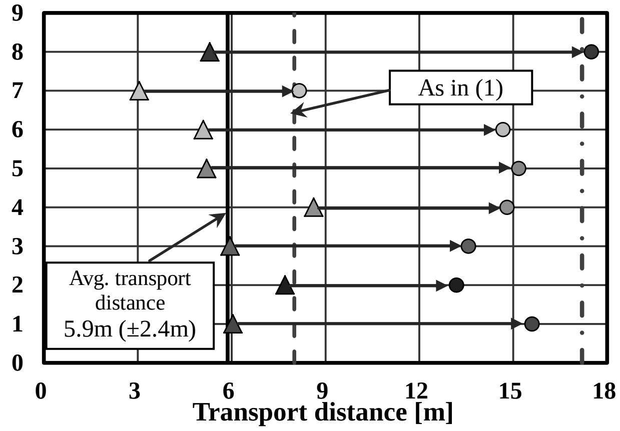
Fig. 6 shows the relationship between the floor height from which draining is performed and the transport distance measured in the house drain. Fig. 6 first shows respective transport distances after the first full flush, and then shows respective transport distances after the subsequent, partial flush. The change of each transport distance is indicated by an arrow. Fig. 6 also shows, for reference, the values obtained from a drainage experiment, which used a 6-litre toilet and which was carried out from the 15th floor of an experimental tower of the Urban Renaissance Agency, and the average length of the house drain applied to actual buildings in Taiwan. In relation to waste substitutes D, D' and New BL, the transport distance becomes longer as the drainage load becomes smaller, i.e. New BL (smallest load), D, and D' (largest load). As for the transport distance with the PVA sponge, when comparing to the transport distance measured in the experiment described in the previous document[1], which employed a drainage system similar to the one in this experiment, a decrease of approx. 50% in the transport distance was obtained from this experiment using a smaller volume of flush water and a larger house drain diameter. In addition, the transport distances of waste substitutes D, D' and New BL all became shorter when draining was performed from upper floors (the 6th, 7th and 8th floors) and lower floors (the 1st and 2nd floors) than from intermediate floors (the 3rd and 4th floors).

Table 4 summarises the differences in the transport distances between when measured using a full flush and when measured using a partial flush subsequently, as shown in Fig. 6. When paper waste substitutes were used, the average transport distance was longer than 10m. When waste substitute D' was applied with a partial flush, the transport distance was longer than the transport distance when waste substitute D was applied. This suggests that a large volume of waste holds back a large amount of water.

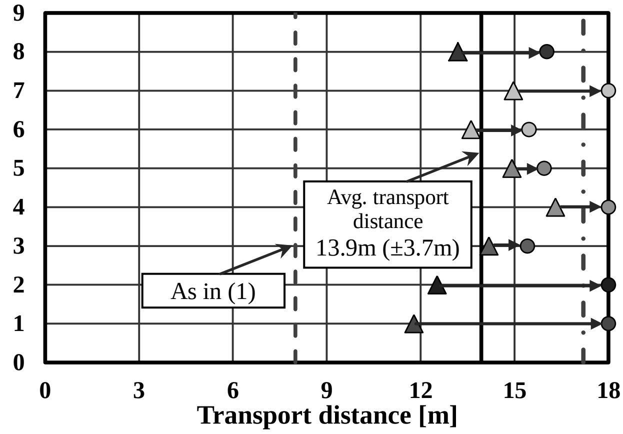


(1) Waste substitute D

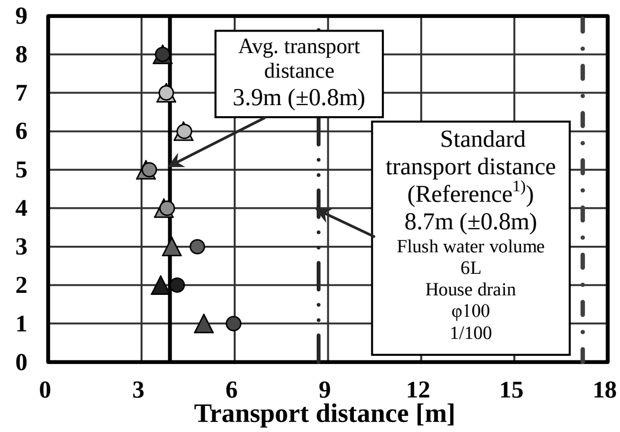
Fig. 6 Drain heights and transport distances of different waste substitutes



(2) Waste substitute D'



(3) Waste substitute New BL



(4) Waste substitute PVA sponge

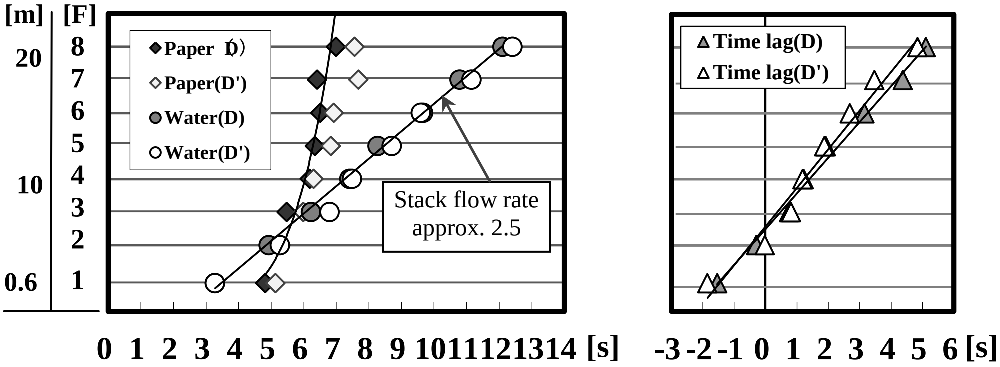
Fig. 6 Drain heights and transport distances of different waste substitutes

Table 4 Transport distances of different waste substitutes (full flush ⇒ partial flush)

Waste substitutes	Avg. distance ± standard deviation [m]		
	Full flash	⇒	Partial flush
D	8.2 (±2.9)	⇒	14.1 (±3.9)
D'	5.9 (±2.4)	⇒	14.2 (±4.0)
New BL	13.9 (±3.7)	⇒	16.9 (±2.7)
PVA sponge	3.9 (±0.8)	⇒	4.2 (±1.1)

(2) Waste substitutes and the flow characteristics of drainage in the stack

The transport distances of waste substitutes D, D' and new BL were respectively shorter when draining was performed with a full flush from upper floors and lower floors than from intermediate floors. The cause was considered to be related to how paper and clean water was mixed together. Fig. 7 (1) shows different time durations from draining is started, using a mixture of clean water (D or D') and paper (D or D'), until the drainage flow first reaches the base part of the stack. Fig. 7 (2) shows the time lags calculated from the time durations in (1). Fig. 7 (1) indicates that when draining is performed from the 3rd floor upwards, the waste substitute contained in the drainage reaches the base part of the stack before the clean water, and when draining is performed from floors below the 3rd floor, the order of the drainage contents reaching the base part of the stack reverses. When draining is performed from the upper floors, the paper and the water in the drainage become separated while flowing down in the stack. Furthermore, the flow rate of the drainage from the upper floors decreases gradually as the drainage flows down the stack. As for the drainage from the lower floors, because the water flows down ahead of the paper, the amount of water for pushing the paper decreases. These findings suggest that the drainage from the upper floors and the lower floors resulted in creating shorter transport distances than from the intermediate floors, as shown in Fig. 6.



(1) Free-fall time of water/waste substitute-containing drainage

(2) Time lags

Fig. 7 Water/waste substitute-containing drainage in relation to the free-fall time thereof

(3) Reality involving drainage conditions and drainage systems

Here, Fig. 8 shows a typical drainage system for apartment houses in Japan. In Japan, the drainage piping branches out to connect to different plumbing fixtures, and therefore, the drainage from all the fixtures all goes into one house drain. Such being the case, when accommodating super water-saving toilets, as shown in Fig. 8, the transport distance of the drainage received in the house drain from the toilets is an important factor.

Furthermore, the previous document[3)] describes a questionnaire survey about the recent awareness among people about the use of toilets and how they actually use their toilets, and on the basis of the survey results, Fig. 9 shows a daily drainage pattern. According to Fig. 8, full flushes are intensively used during morning hours, and partial flushes are used averagely during the day. Obtained from all the results are: the average number of toilet events per person per day is excrement 1.1 times and urination 5.2 times. The average number of washing is 0.4 times.

These findings support that the transport distance of paper in the house drain exceeds 10m when a full flush is operated followed by a partial flush, as explained earlier, and it would be possible to transport drainage in the house drain adequately even by using a 4-litre toilet.

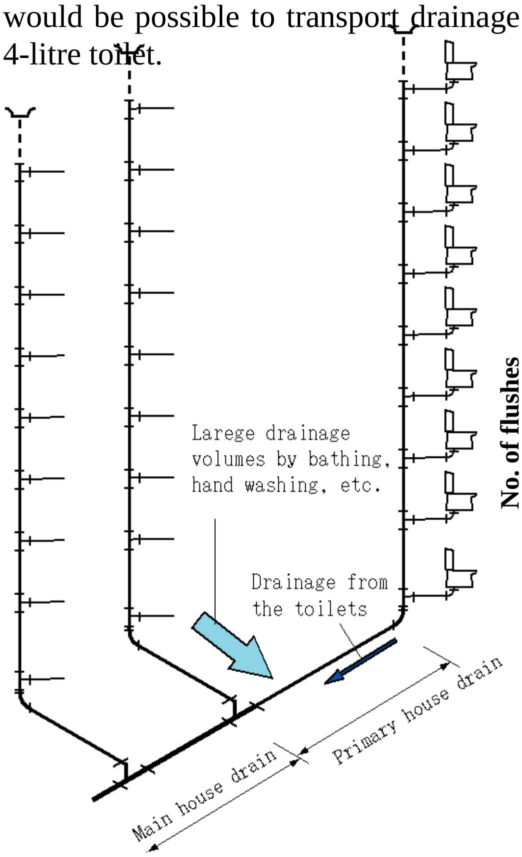


Fig. 8 Typical drainage system for apartment houses in Japan

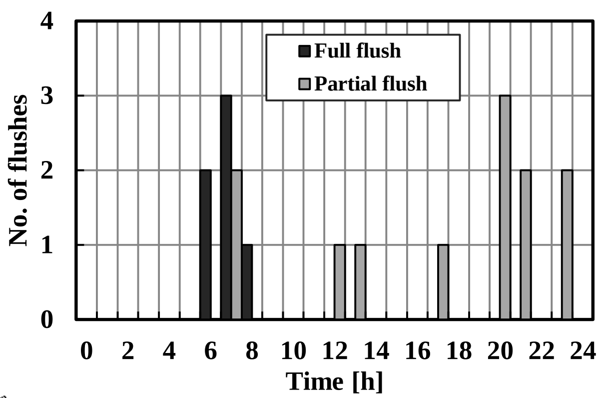


Fig. 9 Daily drainage pattern obtained from the previous document

4.2 Understanding the characteristics of drainage flowing in the stack

As described in 5.1 (2), it is considered that the transport distance of waste substitutes in the house drain is affected by the variation of the flow rate and volume of drainage flowing down in the stack. Fig. 10 shows how the characteristics of drainage, which is from the 1^{st} to 8^{th} floors, vary when measured at the base part of the stack. On the basis of this and in accordance with SHASE-S220, the variation of the flow rate of fixture drainage, qd_s', per floor was measured, when connected to the stack, which is shown in Fig. 11 also shows the drain height in relation to the qd_s' value, indicating that the higher the floor level, the smaller the qd_s' value, and that the qd_s' value of the drainage from the 8^{th} floor is significantly smaller than that of the drainage from the 1^{st} floor. Incidentally, the flow rate of clean water from a height of approx. 20m was approx. 0.1[L/s].

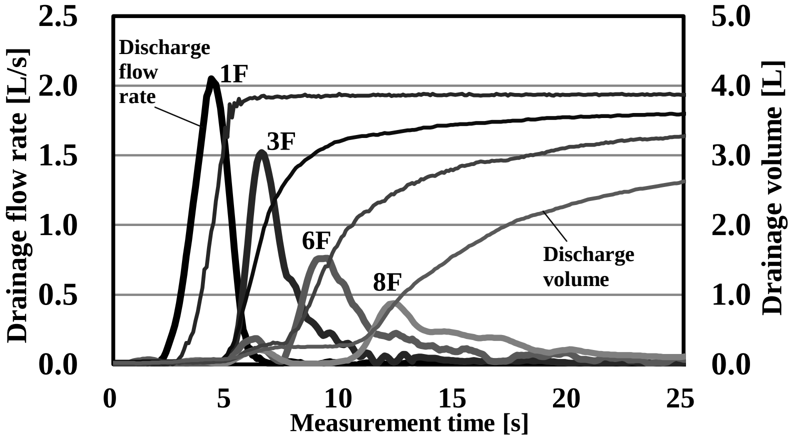


Fig. 10 Volume and flow rate of drainage

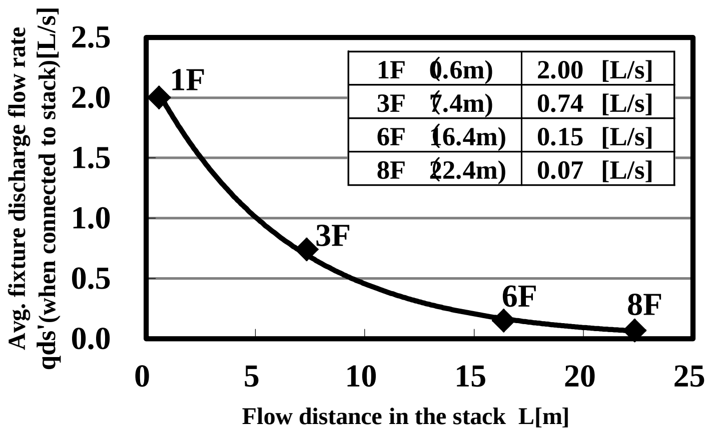


Fig. 11 Average fixture discharge flow rate qds' when connected to the stack

5 Summary and Conclusions

Subsequent to the experiments using the drainage stack system of a 9-storey high-rise building, which is equipped with a 4-litre super water-saving toilet and JIS-DT fitting, the following knowledge has been acquired:

1) The relationship between the drain height and the transport distance of waste in the house drain has been understood through the house drain carrying performance experiment. The average transport distance of waste substitute D was approx. 8m with drainage loading from all the selected floors.

2) Assuming a real usage situation, when a full lush was applied followed by a partial flush, the average transport distance of paper (waste substitute) was longer than 10m.

3) By draining clean water from the floors, the characteristics of drainage in the base part of the stack were understood; as the drain height increases, the flow rate of the drainage in the base part of the stack decreases. The flow rate of clean water applied from a height of approx. 20m was approx. 0.1[L/s].

Acknowledgement

This study is partially supported by "A Study on a Drainage System that Enables Free-plan Housing Technology (Masayuki OTSUKA et al.)", Ministry of Education, Culture, Sports, Science and Technology, 2009 Grants-in-Aid for Scientific Research (c), Research Number 21560621.

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6） SHASE-S 206-2009: Plumbing Code by the Society of Heating, Air Conditioning and Sanitary Engineers of Japan

Presentations of Authors

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Research of Optimal Design for Lavatory Number in Factory

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Abstract

Taiwan industry has been transformed a couple times since 1953. Especially the innovation of Taiwan's Hi-Tech industries rapidly developed from 1970s, the original Building Technical Regulation is not applicable to modern industries. Thus, the issue of modifying the original Building Technical Regulation to implement the factory operation mode nowadays should be reconsidered. Excessive lavatories set up in factories and warehouses would be an unnecessary waste of resources and water. In order to explore this issue and find the optimum solution, this research investigated the current situation and analyzed the number of lavatories in factories and warehouses. Herein, we built up a reasonable assessment model for optimum number of lavatories to achieve the target of efficient use of resources. In result, this research found out that most of the operation mode in factory nowadays is between traditional manufacturing industries and business-oriented light industries. Consequently, this paper proposed that Building Code of the number of lavatories in factories should be modified as the number between office building and manufacturing building.

Keywords

Optimum design, factory, lavatory, building code, assessment model

1 Introduction

Taiwan has abundant of rainfall every year, however, water shortage is still a serious problem, Now, Taiwan is the top 18th countries facing water scarcity in the world. Taiwan government still needs to promote water conservation policy more on industrial department. Additionally, Taiwan industry has been transformed a couple of times since 1953. Especially the innovation of Taiwan's Hi-Tech industries rapidly developed from 1970s, the original Building Technical Regulation is not applicable to modern industries. Redundant lavatories set up in factories and warehouses would be an unnecessary waste of resources and water. In order to explore this issue and find the optimum solution, this research investigated the current situation and analyzed the number of lavatories in factories and warehouses and the issue of modifying the original Building Technical Regulation to implement the factory operation mode nowadays. Consequently, the current mode should be reconsidered to prevent unnecessary waste of resources and save the energy.

To achieve the target of modifying Building Code of the number of lavatories in factory and build up a reasonable assessment model for optimum number of lavatories, this paper goes through the following research steps: first of all is technical review of the research paper related to this issue and building code collection from different countries. Secondly, the investigation on the paper survey research range setting, and design of questionnaire. For the paper survey it demonstrates the statistics of water usage profile and changes of industry in Taiwan. And for questionnaire design, it would explain why it set up the target group for the survey. Then it comes to analysis part, which illustrates the trend types of factory, the practical circumstances of traditional types of factory and the realistic situation of new types of factory. As a result, this paper proposed that Building Code of the appropriate number of lavatories in factory and warehouse should be modified as the number between office building and manufacturing building.

2 Technical Reviews

2.1 Past Related Research

According to the past research, papers related to the quantity of sanitary appliances such as lavatories, water closets, urinals, bathtubs, and showers is not as much as the design for these appliances. *Revised scales for sanitary accommodation in offices* [7] (2003, P.J. Davidson, R.G. Courtney), *Research of public toilet equipment quantity in MRT Station* [8] (2011, Wan-Ju Liao, Cheng-Li Cheng).

2.2 Building Code

2.2.1 Taiwan Building Technical Regulations

Taiwan Building Technical Regulations (**Table 1**) is the main basis regulation for Taiwan on the area of construction management and architectural design. It is written according to the Building Code, which includes 3 parts and 32 chapters: 'Building Design and Construction Code', 'Architectural Construction Code', and 'Building Equipment Code'. To adjust the transforming of engineering technology updates and the problems occuring from time to time, it modifies frequently. Taiwan Building Technical Regulations was formulated from article 97 of the Building Code, which is the statute law.

< Taiwan Building Technical Regulations > Chapter II of water supply and drainage systems- Part II. sanitary facilities section of sanitary facilities: on the building type of factories and warehouses, the quantity of lavatories should be 1 per 10 when less than 100 people, 1 per 15 when over 100 people. The area of factory and warehouse are based on 0.1 person per square meter or employees number from invest and set up plan.

Table 1 Number of sanitary equipment installation in buildings [3]

Type of Building or Occupancy	**Water Closet**			**Urinals**	**Lavatories**	**Bathtub or Shower**
Factory Warehouse	Number of Person	Male	Female	Number	1 to 100 Employees: 1 per 10 Over 100 employees: 1 additional for each additional 15 employees	At High Temperature and poisoned factory: 1 per 15
	1-24 25-49 50-100	1 1 1	1 2 3	1 1 2		
	Over 100 employees 1 additional for each additional 120 male employees, 1 additional for each additional 30 female employees			Over 100 employees 1 additional for each additional 60 male employees		

2.2.2 California Plumbing Code 2007

The Plumbing Code in California (**Table 2**): on Industrial building type, such as factories, warehouses, loft buildings, and similar establishments. 1 to 100 Employees 1 lavatory per 10 people, over 100 employees, 1 additional lavatory for each additional 15 employees or fraction thereof. On the other word, it means that when there are 1000 employees working together in one factory, it needs 28 male toilets and 28 female toilets, which totally needs to apply 70 lavatories. To clarify, it means that when we put one lavatory in every toilet, there are 14 lavatories surplus.

Table 2 Minimum required fixtures for the number of persons [4]

Type of Building or Occupancy	**Water Closet (Fixture per Person)**		**Lavatories (Fixtures per Person)**
	Male	Female	
Industrial-factories, warehouse, loft buildings and similar establishments	1 1-15 2 16-35 3 36-55 4 56-80 5 81-110 6 111-150	1 1-15 2 16-35 3 36-55 4 56-80 5 81-110 6 111-150	1 to 100 employees 1 per 10 Over 100 employees 1 additional for each additional 15 employees or fraction thereof
	1 additional for each additional 40 employees or fraction thereof		

2.2.3 National Plumbing Code Handbook

National Plumbing Code published by USA (**Table 3**): on the building type of manufacturing, warehouse, workshops, loft building, foundries and similar establishments- 1 to 100 persons 1 fixture for each 10 persons; over 100, 1 for each 15 persons. The figures shown are based upon one fixture being the minimum required for the number of persons indicated or any fraction thereof. On the other word, it shows that when there are 1000 employees working together in one factory, and both male toilet and female toilet should be 35, which totally needs to apply 70 lavatories. To clarify, it shows that when we put one lavatory in every toilet, there is no lavatories surplus.

Table 3 Minimum facilities [5]

	Water Closets		**Urinals**	**Lavatories**
Manufacturing, warehouse, Workshops, loft buildings, foundries and similar establishments	Number of persons	Number of fixtures	Same substitution as above	1 to 100 persons, 1 fixture for each 10 persons over 100. 1 for each 15 persons
	1-9 10-24 25-29 50-74 75-100	1 2 3 4 5		
	1 fixture for each additional 30 employees			

2.2.4 Building Code of different countries

Making comparison of different countries' building code, it is not difficult to find out the similarity of lavatory quantity regulation in different countries (**Table 4**). All of the building codes regulated: on the industrial department such as factories, warehouses and similar establishment, 1 to 100 employees, 1 lavatory per 10 people, over 100 employees, 1 additional lavatory for each additional 15 employees or fraction thereof.

Table 4 Building code of different countries (3) (4) (5)

Building Code	Publish Party /Year	Chapter	Regulation	
			Type of building	Lavatories
National Plumbing Code (NPC)	USA 1957	Chapter 7 Plumbing Fixtures 7.21	Industrial-factories, warehouse, loft buildings and similar establishments	1 to 100 employees, 1 per 10 Over 100 employees 1 additional for each additional 15 employees or fraction thereof
California Plumbing Code	California, USA 2007	Chapter 4 Plumbing Fixtures and fixture fittings P74	Manufacturing, warehouse, Workshops, loft buildings, foundries and similar establishments	1 to 100 persons, 1 fixture for each 10 persons over 100. 1 for each 15 persons
Taiwan Building Technical Regulations	Taiwan 2011	Building Equipment Code No. 37	Factory Warehouse	Less than 100 people, 1 per10 Over 100 people, 1 per 15

3 Investigations

3.1 Paper Survey

Taiwan is a narrow and long island, which is about 600 kilometers north, and south and 150 km wide. The Central Mountain Range goes through from north to south causes the flow of the river is short and current is swift. Though Taiwan has an average rainfall of up to 2,510 mm (2.5 times the world average), the unique geographical conditions and uneven rainfall allocation makes the average annual amount of rain is only about 1/7 of the world average. Actually, Taiwan is an abundant rainfall water-scarce country. Hence, any activities to improve water efficiency and reduce overall water consumption are important issues for sustainable use of water resources in Taiwan.

According to 2010 statistics of Taiwan Water Resources Agency (**Fig. 1**), the annual water consumption is around 17.064 billion cubic meters. For domestic water is 3.256 billion cubic meters, which accounts for 18.23% of the overall water use. Agricultural water consumption takes the first place, which is 12.205 billion cubic meters water (accounts for 71.53%). The industrial water consumption accounts for 8.98% of total water consumption (1.603 billion cubic meters of water).

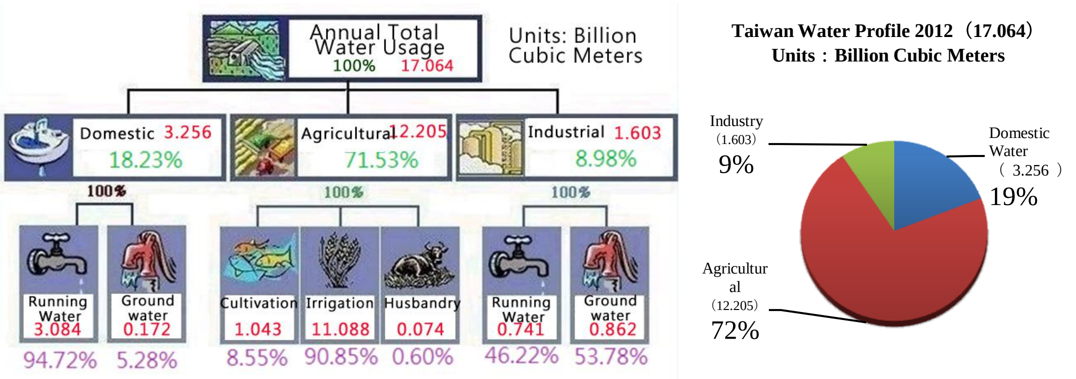

Fig. 1. Taiwan Water Profile 2010 [(1)]

The following table illustrates factory operating number from 1979 to 2009 (**Fig. 2**) and the industrial department population from 1998 to 2012 in Taiwan (**Fig. 3**). Take a look of decades change of factory operating number from 1979 to 2009, on 1979 has 40,102 factories; 1989 has 76,826 factories; 1999 has 82,937 factories; 2009 has 77,331 factories. The factory number has soaring increase from 1979 to 1989 since the economic development in Taiwan. However, the factory number has slightly decreased from 1999 to 2009 since Asian financial crisis. The industrial department population from 1998 to 2012 in Taiwan shows a more delicate response to Asian financial crisis, the population working on industrial department from 1998 to 2012 dropped down from 758.4 thousands of people to 696.6 thousands of people. As the financial situation grows back from 2003 to 2008, population working on industrial department grows from 696.6 thousands of people to 736.8 thousands of people. The people working on industrial department on 2010 accounts 3.2% of total Taiwan population, which means that the issue related of industrial department is important and concerned with huge groups of people.

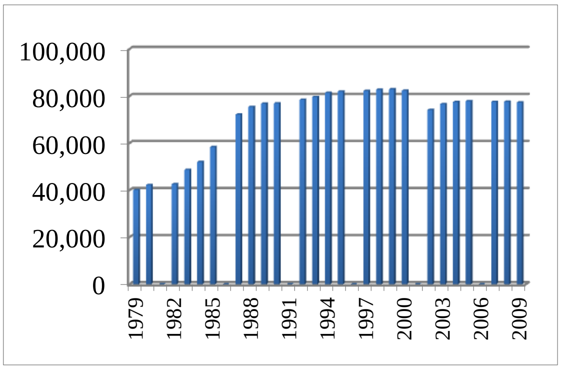

Fig. 2. Factory operating number from 1979 to 2009 (2)

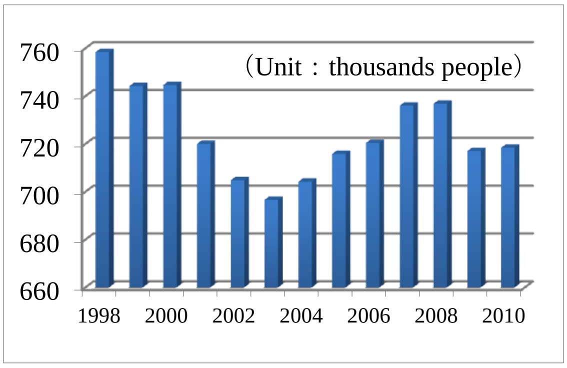

Fig. 3. Industrial department population from 1998 to 2012 in Taiwan (2)

Fig.4 illustrates the population ratio in various industries, which include agriculture, forestry, fishery, mining and quarrying, manufacturing, electricity & gas, construction industry, wholesales and retailing, transportation and warehousing, finance, insurance, real estate business services, community service, and public administration. The percentage of manufacturing has steadily increased from 1978 (accounts 31%) to 1986 (accounts 34%). From 1986 to 1994, manufacturing keeps on 34% on industries. Then from 1994 to 2001 the ratio of manufacturing slides down from 34% to 28%.

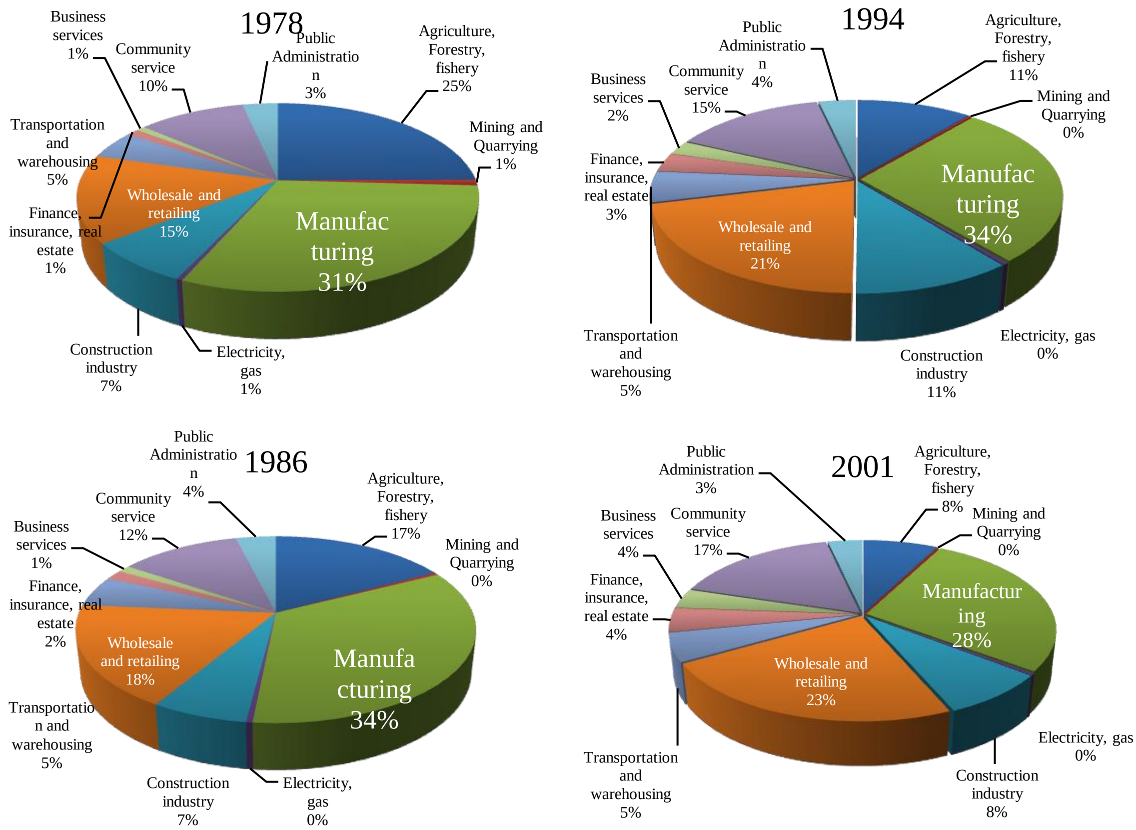

Fig. 4. Population ratio in various industries from 1978 to 2001 (2)

There is totally 92,131,009 square meters in Taiwan industrial area. The top 5 types of industry are chemical materials industry, basic metal industry, metal products industry, food industry, and textile industry. Chemical materials industry accounts for 26.39% (24,311,369 square meters) , basic metal accounts for 12.98% industry (11,958,002 square meters), metal products industry accounts for 8.15% (7,507,883 square meters), food industry accounts for 5.20% (4,793,943 ㎡) , final one is textile industry which accounts for 4.80% (4,424,316 square meters). Make a comparison with top five sectors last year, non-metal industry has been replaced by textile industry, and the remaining four are fluctuated on the rank of the order. These five sectors set up factories in the total area of 52,995,513 square meters, accounting for 57.52% of the total area among Taiwan factories.

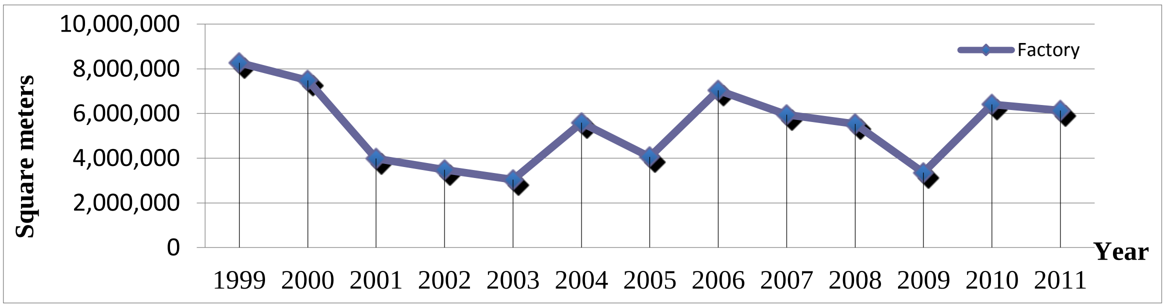

Fig. 5. Construction permit by use from 1999 to 2011 [(6)]

Fig. 6 shows the ratio of industrial warehouses accounts for 38% of all license area among different building types, which means the issue concerned of factory should be concerned.

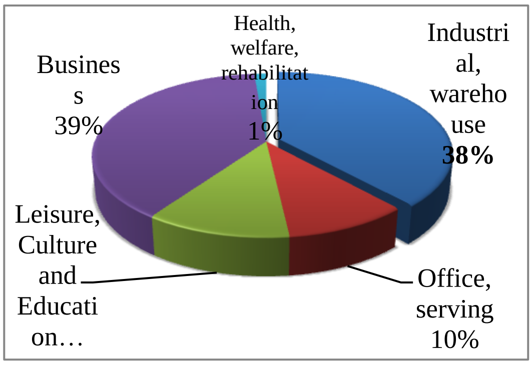

Fig. 6. Different building types of construction license area ratio 1999 [(6)]

3.2 Research range, percentage of different types of factory

Fig. 7 demonstrates operating factories from 1979 to 2009 and the trend of increasing or decreasing from 1979, 1989, 1999 to 2009. The top 3 industries are plastic product industry, fabricated product industry, and machinery and equipment industry.

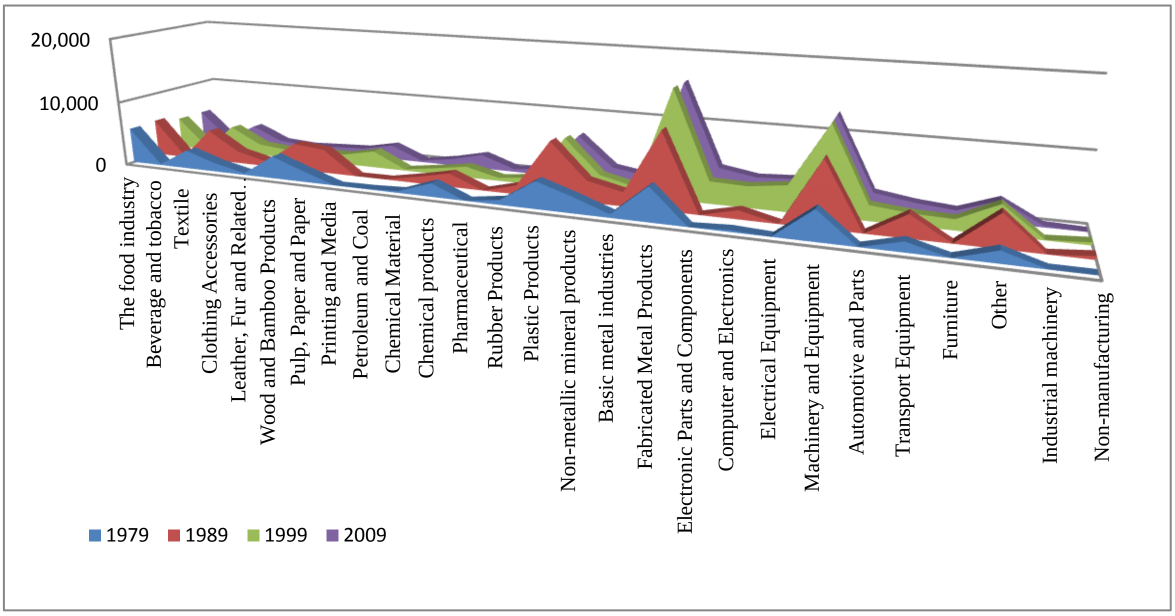

Fig. 7. Operating factories from 1979 to 2009 (2)

3.3 Questionnaire, real statues, photos, how to do the investigate

To realize the practical issue of lavatory in factories, the best way is site survey. This paper chooses 12 factories as samples for the research. The question content includes 2 main parts, the basic information and using efficiency of sanitary appliances. The basic information contains the name of the factory, founded time, employees' number, location of toilets, total quantity of lavatories, factory area, placement system, and whether factory has fixed breaks time or not. The other part is using efficiency of sanitary appliances, which includes types of factories, working operation mode, sanitary appliances using peak time, whether the number of lavatories is sufficient, and recommended lavatories optimize design number.

The process of research for this paper: design the proper questionnaire, and then send it via mail or email to 200 factories. The next step is ask the ability to do a state survey of factories and send an official document to factories and make appointment to do the survey. The following thing to do is taking photos and asking employees' personal experiences when using sanitary appliances on office hour. The final step is analysis and built up a reasonable assessment model

4 Analysis

4.1 Trend and types of the factory

Due to changing of industrial types in Taiwan, the statistics (**Table 5**) shows that non-traditional industry GDP is increasing 60% from 2001 to 2006, and it still has 9.9% increase every year. A high-tech and medium high-tech product becomes the main export goods of Taiwan. The global economy continued expansion on 2006 and export sales expanded reaches up to 1,59.5 billion U.S. dollars. Compared with 2005 has years of growth 13.8%. What's more, from 2001 to 2006 annual average growth rate is 13.4 percent; slightly higher than growth rate of customs export (12.1 %). High-tech and medium high-tech products portion accounts for 71.2% all over the export GDP on 2006.

Table 5 Analysis of high-tech and medium-tech manufacturing from 2001 to 2006 (9)

	2001	2002	2003	2004	2005	2006
High-tech, medium high-tech manufacturing GDP (billion NT dollars)	4310	4762	5289	6247	6442	6899
Ratio of manufacturing	57.9	59	59.4	59.1	59.0	59.1
GDP (%)						
Electric Component	27.5	30.7	32.0	35.2	36.6	39.9
Chemical Material	17.1	16.7	18.6	21.1	21.7	22.0
Computer	26.0	23.7	20.4	15.3	13.5	12.0
Machinery	8.7	8.4	8.6	8.6	8.8	8.5
Transportation	9.0	9.2	9.4	9.3	9.5	7.5
Electric	6.3	6.1	5.7	5.6	5.4	5.7
Chemical Products	4.0	3.8	3.7	3.4	3.3	3.3
Precision Instrument	1.4	1.4	1.4	1.4	1.2	1.1
Export GDP (billion US dollar)	126	135	151	182	198	224
High-tech, medium high-tech product export GDP (billion US dollar)	85.1	92.7	104.5	129.6	140.2	159.5

4.2 Traditional types of factory

Based on the survey, there are 5 over 12 companies (accounts for 42%) has working type similar to traditional manufacturing factories inside factories. The equipment labors need to operate and control is a polluted machine. Concern with the time, employees need to use lavatories longer than white-collar office workers. The traditional manufacturing factories employees take 2 to 3 minutes which is 10 to 15 times compare with average people (12 seconds). Hereby, the building regulation on lavatories in traditional manufacturing factories can keep the original one and doesn't need to be changed: 1 to 100 persons 1 fixture for each 10 persons; over 100, 1 for each 15 persons.

Fig. 8. Traditional industries [10]

4.3 New types of factory

Based on the survey (**Table 6**), there are 7 over 12 companies (accounts for 58%) has office working type inside factories. What's more, the sanitary criteria are very strict on high-tech and medical factories. Most of non-traditional **(Fig. 9)** industries can make more profit than traditional one, thus they need to make good use of the factory. It causes most of the non-traditional factories has placement system every day like 2 rotates or 3 rotates. Therefore, it spread employees to different time; less people will use lavatories together in rush hours. What's means there are excessive lavatories set up in factories and warehouses. Excessive lavatories would be an unnecessary waste of resources and water. However, there is still small portion of the works related to machine washing and high-polluted working mode. The building regulation on lavatories towards non-traditional industries can be modified as the number between office building and original building code for factories. To optimize non-traditional factory lavatories number, the new building regulation code should be: 1 per ten when less than 100 employees; 1 per 30 when above 100 employees.

Fig. 9. Non-traditional industries (10)

Table 6 Analysis of state survey (10)

	A	B	C	D	E	F	G	H	I	J	K	L
Founded Year	1956	1984	1986	1964	1965	1992	1970	2001	1958	1984	1975	1931
Employees	218	503	257	1027	400	90	220	160	60	5590	70	1500
Floor area (m^2)	15000	21625	257	1027	400	90	220	160	60	5590	70	1500
Lavatories survey number	13	74	48	93	62	5	36	19	11	314	20	120
Lavatories regulation number	18	37	21	72	30	9	36	14	6	390	7	104
Working type				Equipment operation and control / clerical or planning / affairs				Equipment operation and control / computer processing / clerical or planning / affairs		Equip-ment operat-ion and control	Equipment operation and control /affairs	

5 Results

Based on currently survey it reveals that the operation mode nowadays is different from past manufacturing industry. The operation mode has turned from labor intensive to mechanic automation industry. What's means that labors' working mode on non-traditional type of industry is similar to office worker, sitting in front of computer to control machines? The only difference is that white-collar office workers or people working in clean room have using peak than traditional workers since it has regular breaks time. Lavatories number in factories regulated by Taiwan Building Technical Regulations is more than practical need. Seeing through the aspect of energy and resource saving the Building Technical Regulations need to have optimal design for lavatory number in factory.

Due to changing of industrial types in Taiwan, the statistics shows that non-traditional industry GDP is increasing 60% from 2001 to 2006, and it still has 9.9% increase every year. Moreover, the factory operator working way is similar as office staff working type. Hereby, a reasonable demand of non-traditional industry should toward the lavatories required number as office building. However, there is still small portion of the works related to machine washing and high-polluted working mode, the optimize number of lavatories for non-traditional industry factory should be between office building and original factory and warehouses regulations. The new building regulation code should be: 1 per ten when less than 100 employees; 1 per 30 when above 100 employees.

Learning from this paper, the good building codes should change from times to time according to different types of building, operating types, and industrial patterns to make the good use of resource. Nowadays, the number of operation scale and change and production shift line is quiet changes a lot as before. The further research can do the survey on different types of building such as domestic buildings, schools, office buildings, dormitories, theaters, train station, airports, and similar establishment. By doing so, we can know the trend of changing all over the world and make optimum design number to sanitary appliances in building code all over the world.

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7 Presentations of Author(s)

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A Study on Drainage Transportability of Dual Flush 4-Liter Toilets

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Abstract

This report presents the results of the experiments on transportability of 4-Liter toilets introduced last year. Focusing on the behavior of a kind of solid wastes discharged from the toilet bowl into the drainage system, we examined the solid waste transportation performance in the horizontal fixture drain and the horizontal main drain of building. According to our research, we have confirmed that, regarding the water saving toilets of up to 6 liters, the transportation distance tends to decrease with a reduction of the flushing volume. And we have confirmed that in dual flush toilets, partial flush after full flush is much more effective for transportability than single full flush. These experimental results show that the dual flush 4-Liter toilets have enough transportability, and give us a new perspective regarding the solid waste transportation based on the actual use of toilets in Japan.

Keywords

4-liter toilet, drainage transportability, solid transportation, drainage flow rate

1 Introduction

In Japan, water saving toilet technology has been progressing for about 20 years at a rate of about 0.34 liters a year, as shown in figure 1. Since 2011, around the 4-Liter toilet has been on the market. Around the same time, the plumbing industry has gradually been interested in the transportability of water saving toilets. Since we introduced two types of 4-Liter toilets last year, we received several concerns regarding their drainage transportability in various conferences.

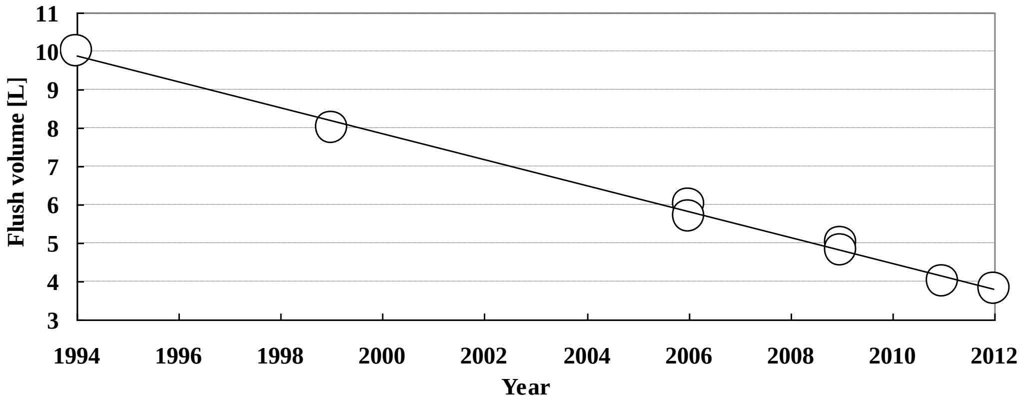


Figure 1 - Evolution of the water consumption for a toilet in Japan

We have concerned about the importance of the transportability of water saving toilets since 2005. In this process, it has become clear what is about more actual transportation of the solid waste, and we explain about that by the following. The first flush transports the solid waste for a certain distance, and then it stops. The following second flush transports the next one in the same way, and then it stops too. However, the second flush water pushes the stagnant water which remains after the first solid waste, then the first solid waste begins to move again before overlapping into each other. This behavior is reproduced every consecutive flush. It is a kind of chain-reaction, or figuratively speaking, it looks like the clash of billiard-balls, as shown in Figure 2. What is important here is that all solid wastes are neither clashed nor overlapped each other.

This attitude is based on the results of numerous repeated experiments, and suggests the more actual index of the transportability than the conventional one which evaluates only single full flush transportation. It brings us a change of perspective. This attitude shows that it is not a problem even if the first flush could not transport the solid waste completely. The next flush could transport it enough.

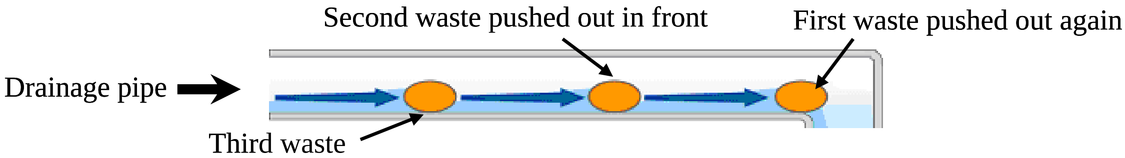


Figure 2 - The behavior of the consecutive flushes with solid wastes

On the other hand, the toilet use patterns based on usual lifestyle patterns of standard Japanese families are also concerned. For example, the full flush with solid waste is used at least 4 times a day and the partial flush with only liquid waste is used at least 12 times a day, per family. Assuming there is no concern about the solid waste transportability in repetition as described above, we think it is important to confirm how long the following partial flush, which is done frequently like above-mentioned example, can transport the resting billiard-ball, the remained solid waste of the previous full flush. If the following partial flush transports the previous solid waste by enough distance, we will not have to worry about pipe clogging.

2 Structures of 4-Liter toilets

2.1 The gravity feed toilet with a non-electrical vacuum aspirator

This system, which is named type A, is similar in outer appearance to the conventional gravity feed toilet. It has a special component in the flush tank. The top of the trap way has a hole that is connected to the cylindrical chamber which is a part of the flush tank. The cylindrical chamber is fixed in the middle of the flush tank. The top of the chamber is connected to the trap way with a check valve, and the bottom of that opens into the flush tank. When flushing the toilet, it produces a siphonic effect with the aspiration of air through the trap way during flushing.

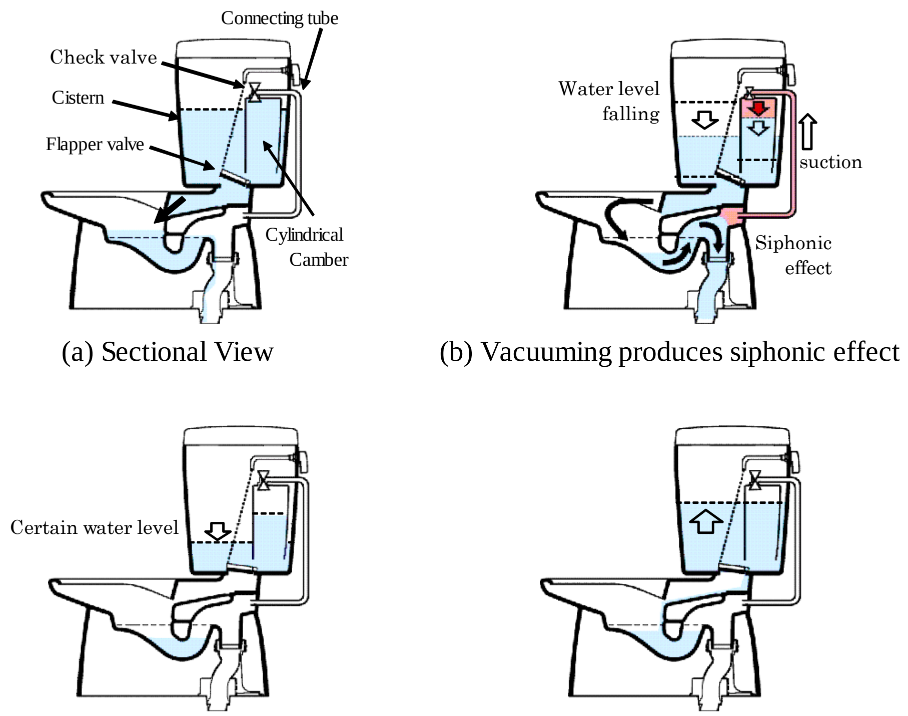
Flushing progresses as follows: (Figure 3)

(a) The flapper valve opens, the water in the cistern (also in the cylindrical chamber) begins to flow into the bowl, and the water level rises in the bowl.

(b) The water level falling in the cylindrical chamber operates like a piston and sucks air into the trap way. Then negative pressure is generated and a siphonic effect is produced. The siphonic effect ejects all of the waste from the bowl completely.

(c) Once the water reaches a certain level, the vacuum effect stops. When the flushing is finished, the flapper valve closes by itself.

(d) The cistern and the bowl are then refilled with water.



(a) Sectional View (b) Vacuuming produces siphonic effect

(c) Vacuuming and Flushing are finished (d) Refilling water

Figure 3 - The flushing sequence for the Gravity Feed Toilet with an aspirator

2.2 The tankless toilet with a non-electrical accumulator

The 4-liter tankless toilet includes the non-electrical accumulator as a standard equipment which has the aim of keeping the flushing performance sufficient even at lower pressures. This system reduces the flushing volume when compared to a conventional one by combining directly connected water-supplies to pressurized water from the accumulator. Figure 4 shows sequence diagrams of this device. This flushing system consists of three operations. In this report, 4-Liter tankless toilet is named type B. The conventional 5-Liter tankless toilet is named type C.

(1) The flushing water is shot into the bowl while generating a vortex, and washes the bowl thoroughly. The spring of the accumulator stays contracted before flushing in this moment because the restitution of the spring is less than the compressive force of the water pressure.
(2) Jet water is discharged from the jet nozzle at the entrance of the trap way and causes a siphonic effect. The expanding force of the spring enlarges beyond the compressing force due to the water pressure reducing. Then the spring discharges the water from the accumulator. So the tankless toilet can temporarily obtain a higher pressure level than the simply supplied water.

(3) The bowl is refilled with water. After the flushing operation, the spring is contracted by the water pressure again.

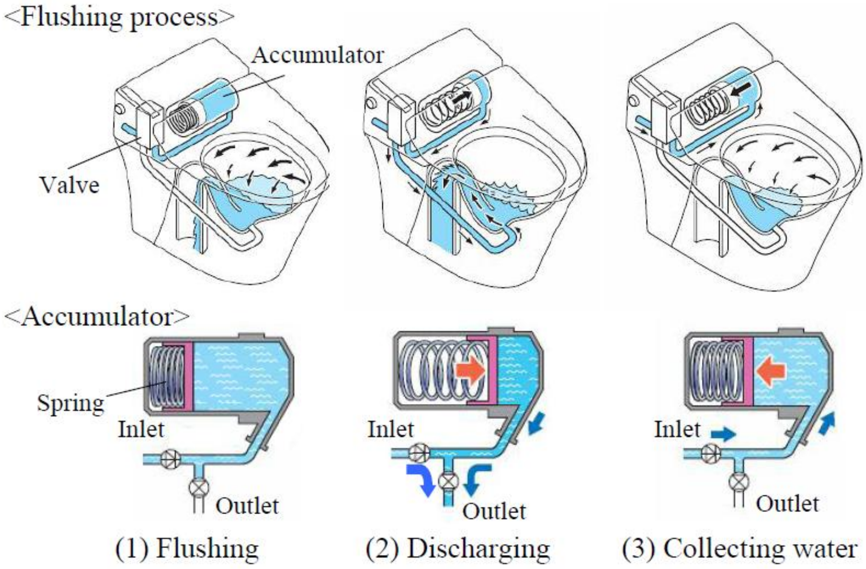


Figure 4 - The system of the tankless toilet with accumulator

3 Summary of the methods of experimentation

In order to evaluate the drainage transportability of two types of 4-Liter toilets, we conducted a measurement of their drainage characteristics and two experiments to confirm the transportability in the horizontal fixture drain and the horizontal main drain pipe of building. We also tried to evaluate how the partial flush contributes to the transportability. The subjects of the experiments were type A and B. For comparison, we quote the results of type C, D, and E described in the literature in the past.

3.1 Measurement of the drainage flow rate

We confirmed the drainage flow rate of the new toilets by installing the measuring equipment shown in Figure 5. Water pressure was measured by using a pressure gauge (P_1), water pressure in the pipe was measured by a pressure transducer (P_2) and the flow rate was measured by an electromagnetic pulse flow-meter (Q_1) every 0.01 seconds. Pressure change of the inflow to the box was measured by a pressure transducer (P_3) and converted into the flow rate change of drainage. This method is based upon SHASE-S220 (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan), a standard that Japanese pluming systems are usually designed in accordance with.

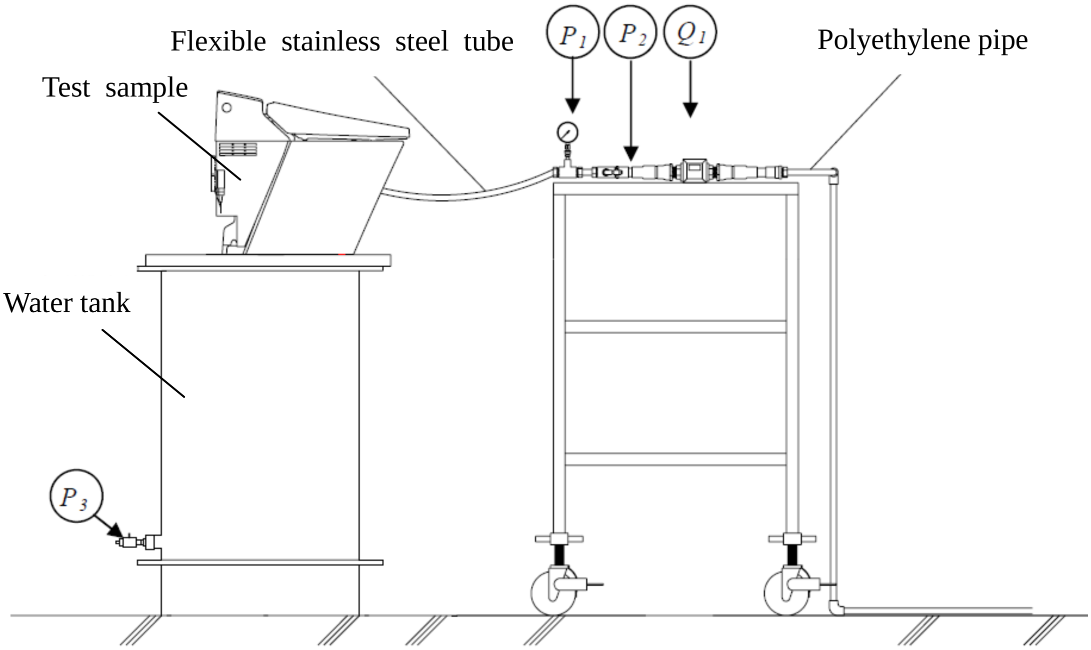


Figure 5 - Equipment to measure flow rate of drainage

3.2 Measurement of the drainage transportability

As test media of transportation experiment, we used 6-ply of JIS P 4501 standard toilet paper (single type). Each ply is 1 meter's worth which was folded 4 times into a sheet of paper with a total length of 125[mm]. The paper was laid on the water surface in a stacked flat as shown in Figure 6, 7. After soaked in water for 15 seconds, drainage was performed. As shown in Figure 8, we have measured the distance between the core of the vertical pipe and the tail of the stagnant test media as the transportation distance. The interval of time between full flush and following partial flush was 700 seconds which is average interval of drainage equipment in housing by SHASE-S206. The dynamic pressure of the toilet was fixed at its possible setting that can be used; that is 0.05[MPa].

Figure 6 - Papers laid in a stacked flat

Figure 7 - Papers laid on a bowl

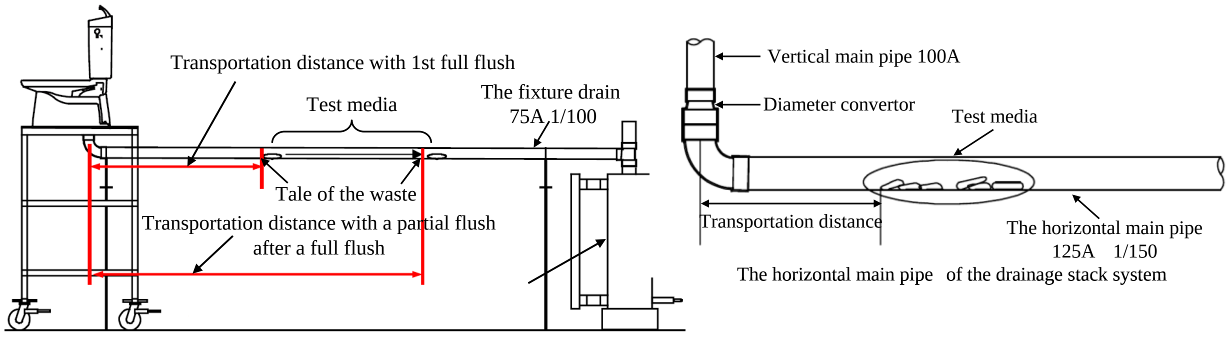


Figure 8 – Method for measuring the transportation distance

3.2.1 Measurement in the horizontal fixture drain

The experimental equipment of the horizontal drainage pipe constructed from rigid PVC pipe which is 75 [mm] in diameters and 1/100 in gradient., the 1m pipes connected each other were placed straight up to 18m in length (system 1). And the pipes connected by 90 ° LL at intervals of 1m, were placed horizontally in a zigzag up to 18m in length (system 2) as shown in Figure 9. As with section **3.1**, the drainage flow rate was measured in each pipe length. We evaluated the drainage transportability of single full flush and the effect of partial flush after full flush for transportability. The transport evaluation was repeated three times each, recording the average, maximum, minimum.

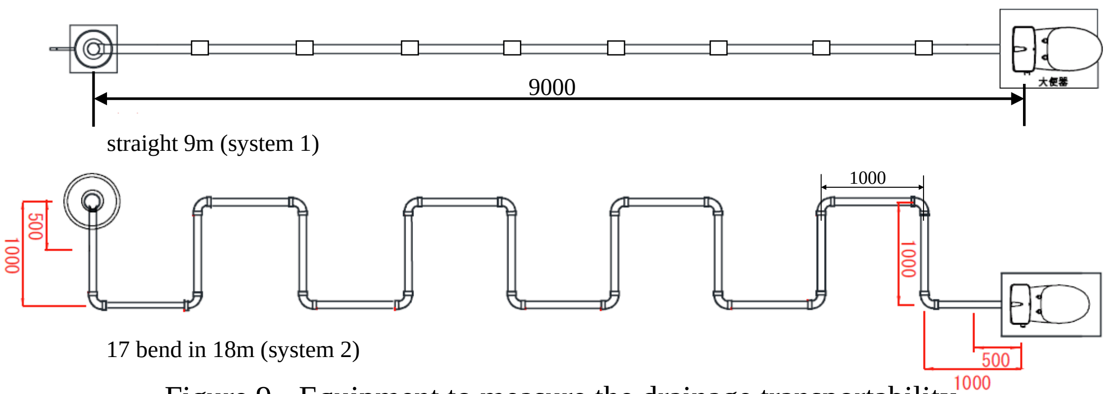


Figure 9 - Equipment to measure the drainage transportability

3.2.2 Measurement in the horizontal main pipe of the drainage stack system

In order to evaluate the drainage transportability in the horizontal main pipe of the drainage stack system, we conducted drainage experiments by using a simulation tower in Kanto-Gakuin University, as shown in Figure 10. The diameter of the vertical pipe was 100[mm], the main horizontal pipe was 125[mm] and the pipe inclination was 1/150. An overhead-venting pipe was installed on top of the vertical pipe. A test sample was installed on the 8th floor in the tower.

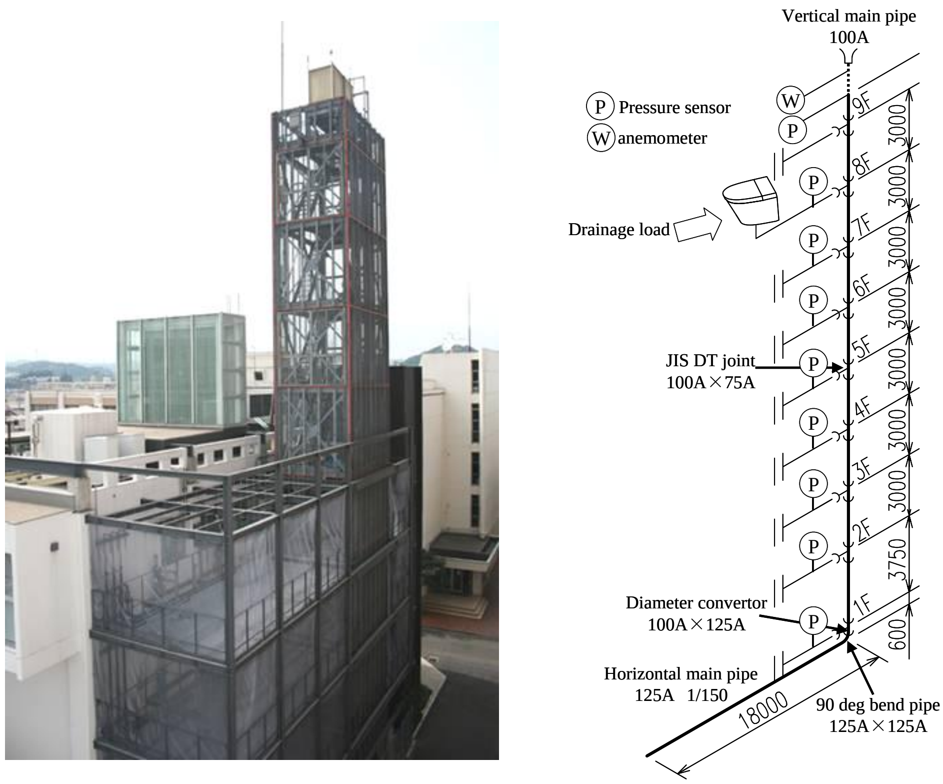


Figure 10 - Picture and drawing of equipment with vertical pipe

4 Results and consideration

4.1 Drainage flow rate

Table 1 - Property of test samples

	Division	Volume W [L]	Drainage Time td [s]	Average flow rate qd [L/s]	Maximum flow rate qmax [L/s]
Type A (4-Liter new GF)	Full	4.3	1.3	2.0	2.1
	Partial	3.8	1.2	1.9	1.9
Type B (4-Liter new tankless)	Full	4.4	2.0	1.3	2.1
	Partial	3.5	1.4	1.5	2.0
Type C (tankless)	Full	5.1	2.4	1.3	2.0
	Partial	4.4	2.1	1.2	1.9
Type D (Wash-down GF)	Full	4.8	―	1.4	1.5
Type E (Siphonic GF)	Full	6.0	―	1.4	2.1

Table 1 shows properties of the test samples. The average drainage flow rate (qd) of type A was slightly higher than the other toilet in both full flush and partial flush. However, in terms of maximum flow rate (qmax), they were similar except type D which is wash-down style. Drainage time (td) of type A, B was shorter than the conventional toilet type C due to the reduction of flushing volume.

4.2 Drainage transportability in the fixture drain

In case of single full flush only, the relation between the transportation distance and the flush volume of each toilet is shown in Figure 11. We also showed the results of conventional toilets (type C, D, E) described in the literature. On the straight piping (system 1), despite the reduced amount of flush volume, their transportability were about to decline slightly. However, on the bend piping (system 2), the rate of decline in the transportability due to the decrease of flush water became higher. Compared with straight piping, transportation distances of type A and B were reduced by about 13% on average per a bend place. Next, Figure 12 shows the distance with a partial flush after a full flush. We also showed the results of conventional toilets (type C) described in the literature. In all toilets, it was confirmed that a partial flush after a full flush encouraged the transportation distance up to about twice. On the straight piping (system 1), it was confirmed to be conducive about +10m.

	Type A	Type B	Type C	Type D	Type E
System 1	△	○	◇	□	×
System 2	▲	●	◆		

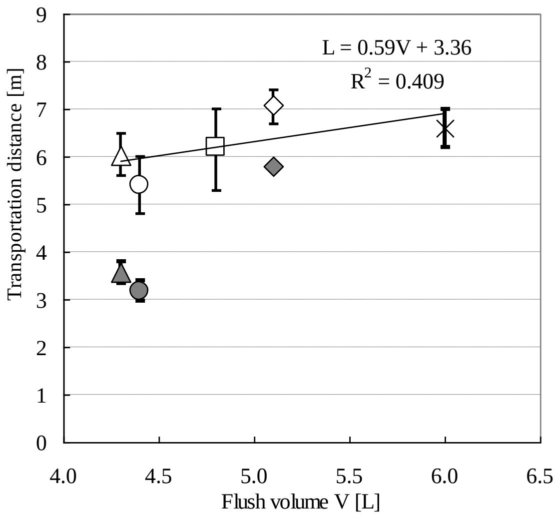


Figure 11 – Distance with a full flush

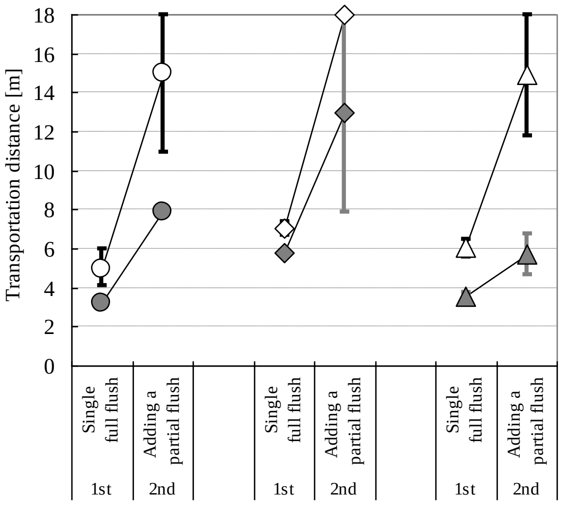


Figure 12 - Distance with a partial flush after a full flush

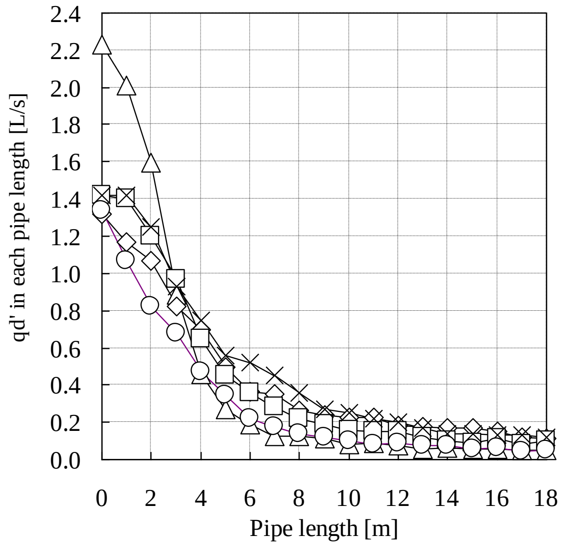


Figure 13 – qd’ in each pipe length

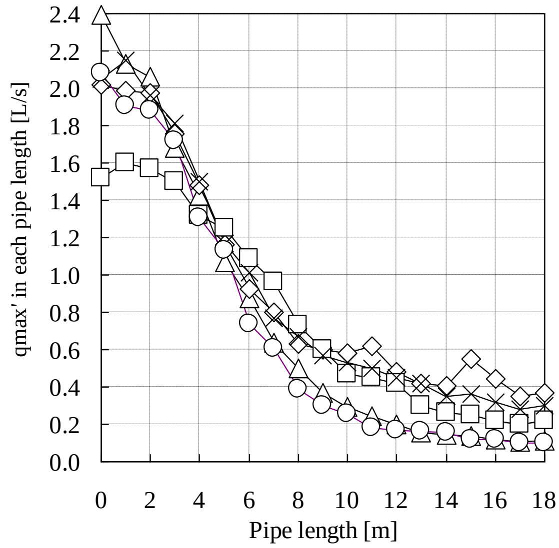


Figure 14 – qmax’ in each pipe length

In addition, on the straight piping (system 1), the drainage flow rate (qd’) and the maximum flow rate (qmax’) were measured in each pipe length as shown in figure 13, 14. We also showed the results of conventional toilets (type C, D, E) described in the literature. With the increase of pipe length, it was confirmed that the qd’ of type A which had a higher initial value decreased rapidly. On the straight piping (system 1), qd’ and qmax’ in the position where test media had been stagnant were shown in Figure 15 on the flush volume of each toilet. Average qmax’ of each toilet was found to be in the range 0.85 ~ 1.06 [L /S] in all toilets, and qd’ was found to be in the range 0.18 ~ 0.48 [L /S].

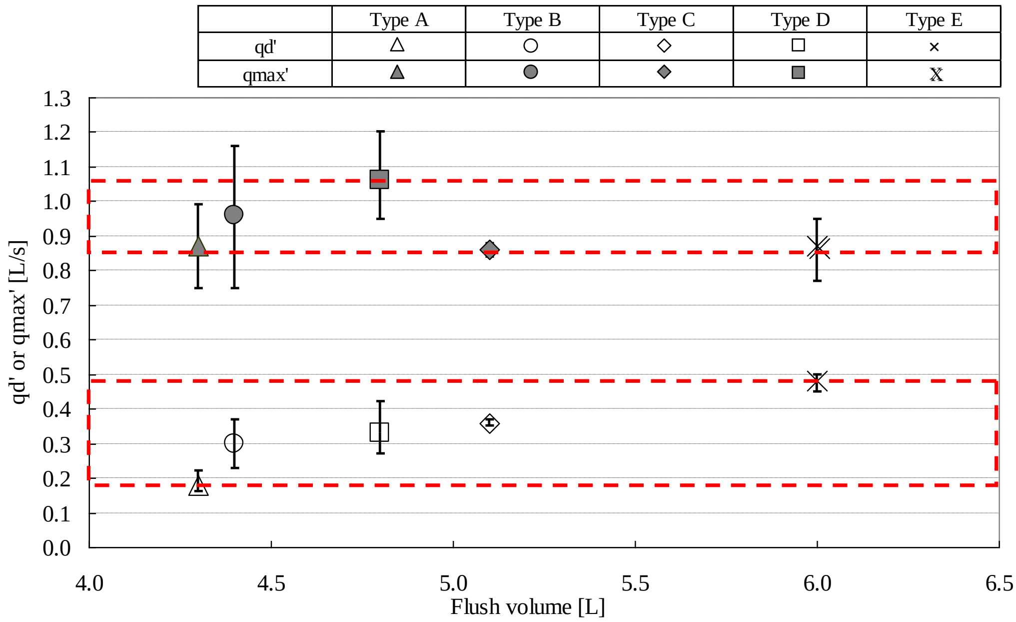


Figure 15 – qd’ or qmax’ on the position where test media had been stagnant

As a result in each side, the major difference among two types of 4-Liter toilets in their transportability could not be confirmed.

4.3 Transportability in the horizontal main pipe of the drainage stack system

Figure 16 shows the distance of single full flush and a partial flush after a full flush on type A and B. In the single full flush, the average transportation distance was more than the one in result of previous literature which refers to 4.7m horizontal distance as criterion for the confluence of other gray water. The major difference among two types of 4-Liter toilets in their transportability could not be confirmed. In both toilets, it was confirmed that a partial flush after a full flush encouraged the transportation distance up to about twice. Also the multi-frequency in the drainage stack system may lead the transportability to more secure side. However, in the future, further consideration is required under more stringent conditions such as the horizontal main pipe having a bend.

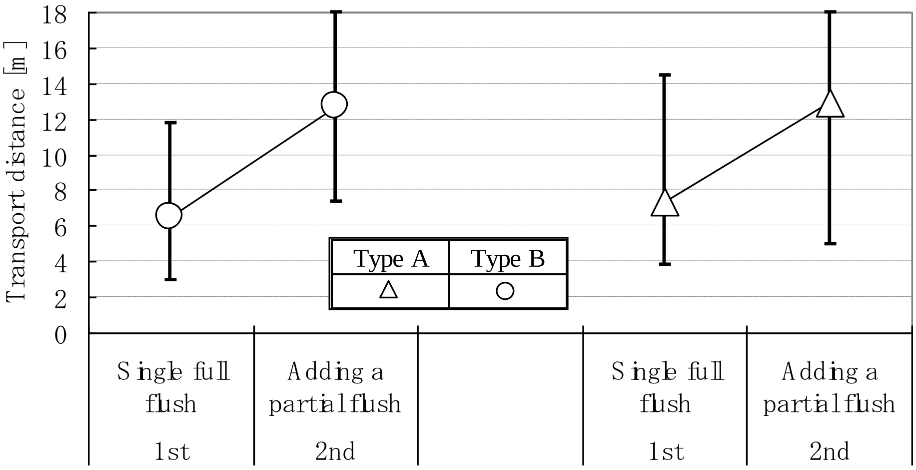


Figure 16 – Distance with a partial flush after a full flush in the horizontal main pipe

5 Conclusions

We confirmed the following results of transportability about 4-Liter toilets.

(1) Average transportation distance of single full flush is about 5.5～6[m] in the straight fixture drain and tends to decrease with a reduction of the flushing volume from 6 liters to 4 liters. While in the bended pipe, average transportation distances are reduced by about 13% per bend.

(2) Average transportation distance of single full flush is about 6～7[m] in the horizontal main pipe of the drainage stack system.
(3) A partial flush after a full flush enhances the transportation distance up to about twice in the both drainage system.
(4) The major difference among two types of 4-Liter toilets in their transportability could not be confirmed.

These results suggest that a partial flush after a full flush makes the adequate transportation of 4-liter toilets possible and support the validity of using dual flush 4-Liter toilets under the general life pattern of Japan.
We would like you to refer to this report for facility designs and planning regarding the use of 4-liter toilets. The transport assessment incorporating partial flush and full flush is considered a valid method for evaluating more realistic conditions of use. Therefore, we will continue such assessments in the future.

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7 Presentation of Authors

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Design assessment of sanitary sewerage systems in a Business Park

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Abstract

Public sanitary sewerage system on a business park aims to ensure the main purposes of municipal use, rather than the industrial-type use.

System performance depends on a number of issues. First of all, it should be taken into account the conditions of drainage, ensuring the proper hydraulic capacity, critical velocity and shear stress for self-cleaning and adequate aeration throughout the network. On the other hand, the selection of materials and equipment should be consistent with reliability considerations and the expected useful life of the project. Secondly, an industrial wastewater treatment plant should be taken into account if necessary. Finally, is crucial for system performance the ability to extend the network in order to meet future demand that may result from the enlargement of the business park.

The main goal of this paper is to present a new simple tool which can assess sanitary sewerage systems performance in the design phase. Five indicators were developed in order to evaluate the system capacity, velocity and shear stress, materials, equipment, industrial wastewater treatment and the possibility of extending the network. These indicators were quantified and combined according to weighting and aggregation procedures, resulting in a synthetic score for the sewerage system design. The assessment tool was applied to a business park located in Viana do Castelo, in Portugal, and the results are discussed.

Keywords
Public Sewerage Systems, Wastewater Drainage, Sewerage Systems Assessment, Sewerage Systems Design.

1 Introduction

Developing a business park is a complex task, demanding integration across many fields of design. In a comprehensive manner, the main issues focus on public utilities, facilities and amenities, as well as on the physical characteristics and layout of the lots available for the location of enterprises and on the area landscape.

A model for assessing the quality of business parks design, called AQPZE, was developed in Portugal by a team from the Polytechnic of Viana do Castelo and the University of Minho [1]. The assessment focuses on twelve dimensions, which reflect different project components, covering the main public utilities, facilities, amenities and other issues that should be considered in business parks design, as follows:

- i) street network;
- ii) water supply;
- iii) sanitary sewerage;
- iv) storm sewerage;
- v) electricity supply;
- vi) gas supply;
- vii) telecommunications;
- viii) street lighting;
- ix) solid waste disposal;
- x) facilities and amenities;
- xi) zoning and lot layout;
- xii) landscape.

The model uses a multicriteria approach based on a hierarchical tree structure, where a set of lower level criteria contributes to the assessment of the next higher level criteria or dimension. The assessment of each bottom lower level criterion is achieved by using an indicator or a set of dependent indicators that reflect the performance of the adopted design solutions in that domain. The assessment model settles a global index, which reflects the quality of business park design as a whole, and also allows the acquisition of partial scores that evaluate the quality of its project components and design solutions.

The next topics will focus in the identification of the main factors to evaluate the sanitary sewerage system design, in order to assess its hydraulic performance, the materials and strength of sewers, the appurtenances, the wastewater treatment and the ability to extend the network.

2 The sanitary sewerage

Business parks may produce different types of sewage. Usually, in these parks, the public sewerage system is designed to ensure the demand due to sanitary wastewater, but not to treat pollutants from industrial facilities. In these cases, the industrial wastewater flows must be subject to pretreatment prior to its release into the sewerage system [2].

The design approach to the sewerage system should, in a broad sense, encompass the conditions of drainage, the sewers materials and structural design and the definition of all appurtenant facilities, also taking into account both the need of industrial wastewater pretreatment and the extension of the network, in order to meet future demand that may result from the enlargement of the business park. Focusing on the hydraulic design of sewers, the main issues are the selection of its gradients and sizes in order to ensure the proper hydraulic capacity, the critical velocity and the shear stress for self-cleaning, as well as the adequate aeration throughout the network. This design approach is reflected on the assessment procedure adopted for the sanitary sewerage system.

3 Formulation

Each dimension is assessed by using one or more associated dependent criteria. On the other hand, each criterion is assessed by using one or more indicators, which can be measured and evaluated. These indicators measure the performance of the design solutions. This measurement is carried out by using a transformation function which gives a score, with a value ranging on a scale of 0 to 1. Subsequently, the score of each criterion is achieved through the combination of the scores from dependent indicator. Similarly, combining the dependent criteria, it will be obtained the score of the dimension.

In all cases, to combine indicators and criteria, procedures for weighting and aggregation are developed. The weights associated with each indicator and each criterion are then set. The aggregation is now set based on the method of Weighted Linear Combination (WLC) [3], according to the Equation 1:

$$S = \sum_{n} w_i \, x_i \tag{1}$$

where:
S is the final score,
wi is the weight of the criterion or indicator i, as follows:

$$\sum_{n} w_i = 1 \tag{2}$$

xi is the score of the criterion or indicator i standardized in a 0-1 range;
n is the number of dependent criterion or indicators of a same hierarchical level.

The assessment of sanitary sewerage results from the weighted linear combination of three normalized criteria: system performance, wastewater treatment and network expansion. The criterion system performance is assessed by using two second level criteria: the criterion flow rate, flow bore section, flow velocity and shear stress, which is evaluated by using the indicator with the same name, and the criterion network components, which is evaluated by using the indicator sewers and a second indicator called manholes and branches. The criterion wastewater treatment is then evaluated by using a single indicator called industrial wastewater pretreatment. Finally, the criterion network extension is evaluated by using a single indicator also called network extension (Figure 1).

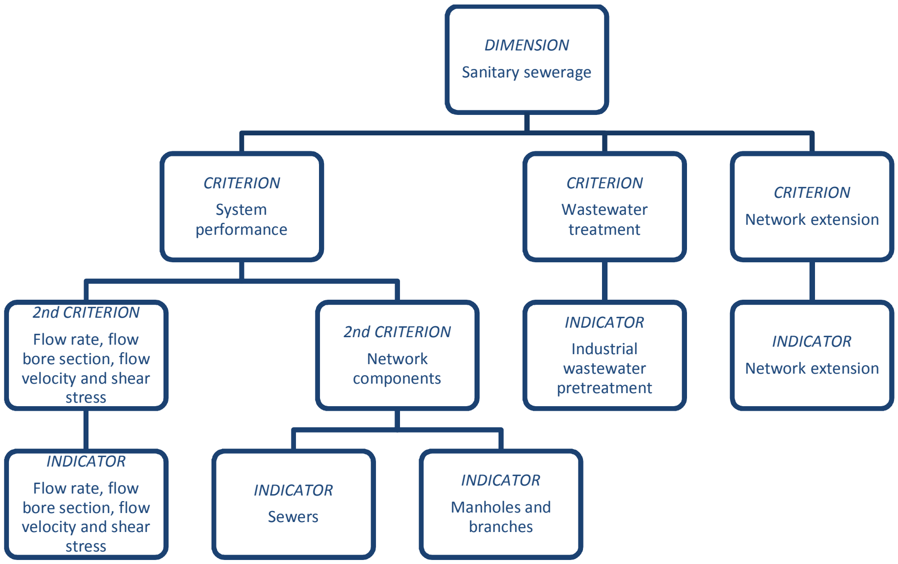

Figure 1 - Sanitary sewerage system assessment criteria and indicators

3.1 System performance

The performance of the system relies on two crucial issues. The first concerns the hydraulic conditions of collection and convey of sewage, such as flow rate, flow bore section, flow velocity and shear stress throughout the network, the latter being important to avoid silting of sewers. The second covers the components of the network, both in terms of materials and appurtenances.

Thus, the criterion *system performance* is assessed by two second level criteria, one being *flow rate, flow bore section, flow velocity and shear stress* and the other *network components*.

3.1.1 Flow rate, flow bore section, flow velocity and shear stress

As stated before, this second level criterion aims to evaluate the conditions of collection and convey of sewage throughout the network. It must be verified that the network guarantees those conditions for the main purposes of domestic and commercial uses, but not for industrial uses.

So, this second level criterion is assessed by using a single indicator called flow rate, flow bore section, flow velocity and shear stress. This indicator checks if the flow rate, the minimum diameter value, the slope, the flow bore section, the flow velocity and the shear stress are within the target range of values. It is understood that if one of them is outside the target range, the proper conditions of drainage are not guaranteed and the score of the indicator equals zero. Instead, if all values are within the ranges, the final score equals one.

The score of this indicator is calculated by verifying, in selected checkpoints, if the design values meet the target values, according to the following steps [4, 5, 6, 7, 8, 9]:
i) It is calculated the target *Flow Rate* Q through the equation 3:

$$Q \geq 0{,}244Sl + 1{,}042Sl^{1/2}$$

where:
Q is the design flow rate [l/s];
Sl is the area of lots to be developed [ha];
assuming that:
Average daily flow: 14080 l/day×developable hectare of lots;
Capacity factor $f_p = 1{,}5+6{,}396\times Sl^{1/2}$. (3)

ii) The minimum *Inside Diameter* of the sewer D is set as follows:

$$D \geq 200 \text{ mm} \quad (4)$$

iii) The *Slope* of the sewer i is set as follows:

$$0{,}3\% \leq i \leq 15\% \quad (5)$$

iv) The target *Wet Flow Bore Section* is set through the *Hydraulic Depth* h, as follows:

$$h \leq 0{,}50\times\text{D} \text{ if } \text{D} \leq 500 \text{ mm}; \; h \leq 0{,}75\times\text{D} \text{ if } \text{D} > 500 \text{ mm}$$

where:
D is the sewer inside diameter [mm];
h is the hydraulic depth [mm]; (6)

v) The target *Flow Velocity* V is set as follows:

$$0{,}6 \text{ m/s} \leq V \leq 3{,}0 \text{ m/s} \quad (7)$$

vi) The target *Shear Stress* τ is set as follows:

$$2 \text{ Pa} \leq \tau \leq 4 \text{ Pa} \quad (8)$$

vii) The final score of the indicator *Flow Rate, Flow Bore Section, Flow Velocity and Shear Stress*, *Sfw*, takes the value 1 if all design values, from i) to vi), meet the target values. Otherwise, the final score of the indicator equals 0.

3.1.2 Network components

The assessment of network components focuses on sewers, manholes and branches. Regarding the sewers, it is important the selection of appropriate materials, taking into account their chemical, physical and mechanical properties. Such characteristics affect the short-term performance of the pipes, but also its reliability and the expected lifetime of the project. The manholes should be assessed with regard to their location and dimensions. Finally, the branches should be assessed with regard to their location and the angle between the main pipe and the branches.

Thus, the second level criterion network components is assessed by using two indicators, one being *sewers* and the other *manholes and branches*.

Sewers
This indicator focuses on the quality of the pipes and results from an evaluation according to two strands - mechanical strength and pipe materials.

The score of the indicator *Sewers Scw* is calculated by using two 2nd level indicators through the Equation 9:

$$Scw = Srmw \times Smtw \tag{9}$$

where:
Srmw is the score of 2nd level indicator *Mechanical Strength* (Table 1);
Smtw is the score of 2nd level indicator *Pipe Materials* (Table 2).

Table 1 - Mechanical strength

Score	Nominal pressure *PN*
1,00	The selected pipe has a nominal pressure class equal or greater than the maximum design load
0,00	The selected pipe has a nominal pressure class lower than the maximum design load, or there is no information about its pressure class

Table 2 – Pipe materials

Score	Material
1,00	Ductile Iron
0,75	Corrugated PVC
0,50	PVC-U or Vitrified Clay
0,00	Cast Iron, Concrete or Asbestos Cement Pipes

Manholes and branches
This indicator focuses on the manholes and branches and results from an evaluation according to two strands – the first concerns manholes location and dimensions, the latter being branches location and angle between the main pipe and the branches.

The score of the indicator *Manholes and Branches Svw* is calculated by using two 2nd level indicators through the Equation 10 [4]:

$$Svw = \frac{Scvw + Sfaw}{2} \tag{10}$$

where:
Scvw is the score of 2nd level indicator *Manholes* (Table 3);
Sfaw is the score of 2nd level indicator *Branches* (Table 4).

Table 3 - Manholes

Score	Location and minimum dimensions
1,00	Provided at all junctions of two or more sewers, whenever diameter or slope of sewer changes, whenever direction of sewer line changes and when sewers of different elevations join together; maximum spacing of 60 m (100 m in case of technical galleries) in straight alignments. Plan diameter or size $\geq$ 1,00 m or 1,25 m, respectively to a depth < 2,50 m and $\geq$2,50 m.
0,00	The design does not meet the above requirements

Table 4 – Branches

Score	Location and angle
1,00	At least one branch between two manholes in sewers serving lots. Angle between the main pipe and the branches $\leq$ 67°30'.
0,00	The design does not meet the above requirements

3.2 Wastewater treatment

This criterion aims to assess the measures established in the design phase leading to the treatment of effluents from industrial facilities. Although the business park regulations usually set the quality parameters of the flows discharged into the sewerage system, it is understood that an industrial wastewater pretreatment plant is an asset to the park.

Thus, the criterion wastewater treatment is assessed by using a single indicator called *Industrial Wastewater Pretreatment*, using the Table 5.

Table 5 - Industrial wastewater pretreatment

Score	Solution
1,00	The design solution addresses the installation of an industrial wastewater pretreatment plant.
0,00	No design solution was addressed to install an industrial wastewater pretreatment plant.

.

3.3 Network extension

The network extension criterion aims to evaluate the ability to extend the sewerage system in order to meet future demand that may result from the enlargement of the business park. Thus, it is important to check how an increase in wastewater flow can be met - whether by extending the existing network, or via a new independent sewerage network.

So, this criterion is assessed by using a single indicator called *Network Extension*, using the Table 6.

Table 6 - Network extension

Score	Solution
1,00	Network extension by one or more interconnection points. The existing network has the ability to withstand the extension, keeping the appropriate hydraulic performance.
1,00	Network extension via a new independent sewerage network
1,00	It is not expected to expand the business park
0,00	It is expected to expand the business park but no design solution was addressed to extend the network.

4. Case study: Business Park of Lanheses

The assessment tool of street lighting energy efficiency was applied to Lanheses Business Park, which is located in Viana do Castelo, in the north of Portugal. This is a new generation business park, whose phase one covers a total area of 150.074 m2, including 56.805 m2 to build 33 lots for industry, storage and facilities (Figure 2).

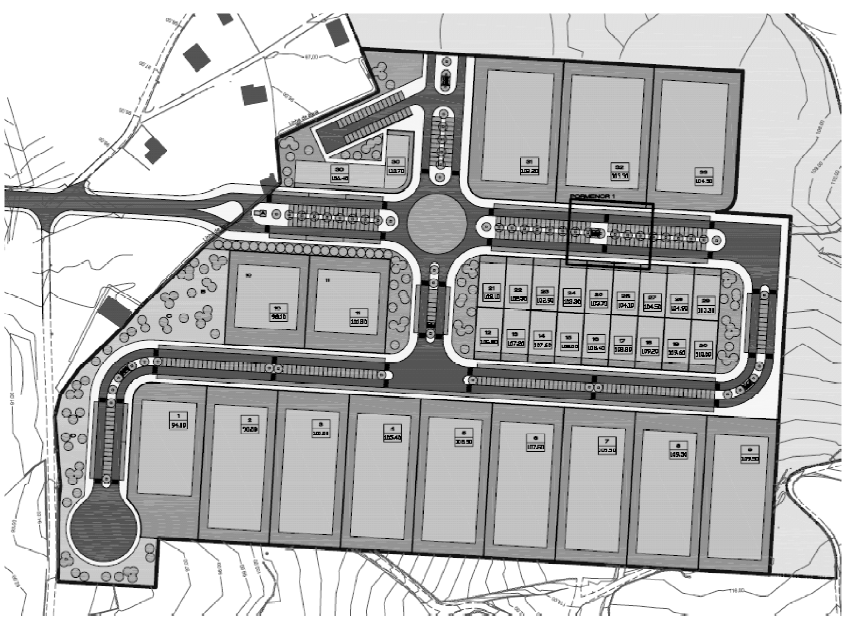

Figure 2 - Plan of Lanheses Business Park

The sewerage network is of radial type. It consists of PN6 corrugated PVC sewers, with a nominal diameter of 200 mm, served by an compact wastewater treatment plant, on the assumption that the park only deals with sanitary wastewater. The design average daily flow was set at 24 m3/hectare of lots, while the design population and the design flow rate are set, respectively, at 150 inhabitants/hectare of lots and 4,76 l/s.

The evaluation for each of the five indicators can be observed in Table 7. For each indicator it is presented the score and relevant comments are made.

Table 8 shows the combination of all the indicators and criteria, which led to a final score of 0.98 for the dimension Sanitary Sewerage. For each indicator and each criterion it is indicated their weights. It is also calculated, according to Equation 1, the partial scores for each criterion, always with values ranging on a scale of 0 to 1.

Table 7 – Sanitary sewerage indicators evaluation

Criterion	2.nd level Criterion	Indicator	Score	Comments
System performance	Flow rate, flow bore section, flow velocity and shear stress	Flow rate, flow bore section, flow velocity and shear stress	1,00	Qdesign=4,76 l/s > Qtarget= =3,09 l/s D=200 mm i min=0.50% i max=6.12% $h \leq 100$ mm $0,6 \text{ m/s} \leq V \leq 3,0 \text{ m/s}$ $2 \text{ Pa} \leq \tau \leq 4 \text{ Pa}$
	Network components	Sewers	0,75	PN 6; Srmw=1,00 Corrugated PVC; Smtw=0,75
		Manholes and branches	1,00	Proper manholes location; spacing=59 m; diameter=1,00 / 1,25 m; Scvw=1,00 Proper branches location; angle< 60º; Sfaw=1,00
Wastwater treatment		Industrial wastewater pretreatment	1,00	Planned to install an compact wastewater plant (definitely the park as no pollutant flows)
Network extension		Network extension	1,00	It is expected to expand the business park and a design solution was addressed to extend the network

Table 8 - Sanitary sewerage: combination of indicators and criteria

Criterion	Score	Weight	2nd level Criterion	Score	Weight	Indicator	Score	Weight
System performance	0,94	0,37	Flow rate, flow bore section, flow velocity and shear stress	1,00	0,50	Flow rate, flow bore section, flow velocity and shear stress	1,00	1,00
			Network components	0,88	0,50	Sewers	0,75	0,50
						Manholes and branches	1,00	0,50
Wastwater treatment	1,00	0,35				Industrial wastewater pretreatment	1,00	1,00
Network extension	1,00	0,28				Network extension	1,00	1,00

5 Analysis and conclusions

The dimension Sanitary Sewerage in Lanheses Business Park has a score of 0,98. This final score is a combination of the partial scores obtained from the system performance, wastewater treatment and network extension criteria, whose values are respectively 0,94, 1,00 and 1,00. So it can be said that the score reached for all the criteria was very good. Indeed, the only weakness that can be found in the sanitary sewerage system of the park is the material of the pipes, which would reach the maximum score if it was adopted ductile iron instead of corrugated PVC. Conversely, it should be stressed that the wastewater criterion reaches the maximum score because it is planned the location of a compact wastewater treatment plant in the park and it is not at all expected to occur production of industrial pollutants in the facilities.

The model assesses the hydraulic performance of the system and its possible extension, taking into account reference values for flow rate, wet flow bore section, sewer inside diameter, sewer slope, flow velocity and shear stress. On the other hand, the network components – manholes and branches- are assessed according to their properties and layout. Finally, the model assesses the measures established in the design phase leading to the treatment of effluents from industrial facilities. The overall assessment of the sanitary sewerage system combines the previous aspects, transforming them into a final index.

The assessment of sanitary sewerage system should be, among others, a central concern in business park design. This will contribute to improve system performance and avoid major design errors. Such assessment can also lead to significant economic benefit.

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7 Presentation of Author

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Energy loss optimization in basic T-shaped water supply piping networks for probabilistic demands

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Abstract

Minimization of pipe friction energy loss of water supply networks is a major concern of pump power reduction for sustainable water systems in buildings. Potable water demands in buildings are unsteady, random and intermittent and survey studies indicated that the end-use water demand probability is generally less than 0.1 even during daily rush hours. Statistical methods for estimating appliance usage patterns and associated instantaneous water demands have been developed to size mains water pipes. However, there are no existing models systematically addressing energy efficiency and interrelated issues with respect to the optimal operation of water supply networks in buildings where the demands are unsteady. This paper presents a mathematical model for energy loss optimization in a common basic T-shaped water supply piping network that serves infinite probabilistic demands. Optimized designs based on proper network pipe sizes are analyzed. Optimal pipe radius ratios for T-shape networks and their corresponding pipe friction energy loss implications are also discussed. The results show that existing piping designs are not optimized for probabilistic demands and there is potential for energy loss reduction.

Keywords

Energy loss, optimization, unsteady demands, water supply, piping network

1 Introduction

Potable water demands are unsteady, random and intermittent [1]. Statistical methods for estimating appliance usage patterns and associated instantaneous water demands have been developed to size mains water pipes [2]. To ensure supply certainty rather than optimality, the existing design approach to determine fixture units may overestimate the simultaneous water demand and oversize water pipes [3]. Alternatively, Monte Carlo simulations can be used to decide the failure probability density function of the water supply system, which is influenced by the occupant load profile, for meeting the demand and assessing the performance [4].

Distributing a supply of water as uniformly as possible over a territory through piping networks is a classical problem of optimization. An urban water supply study showed that 45% of the total pumping energy needed to deliver water from the treatment plants to households was consumed inside buildings [5]. Apart from building height, energy loss at supply pipes is another concern. However, there are no existing models systematically addressing energy efficiency and interrelated issues with respect to the optimal operation of water supply networks in buildings where flow rates are unsteady.
This paper dealt with the energy loss optimization problems of a common basic T-shaped water supply piping network that serves infinite probabilistic demands and established a mathematical model for the required minimum water pumping energy under a fixed pipe volume constraint. Energy loss reduction potential through proper pipe size was also investigated. The results were discussed in terms of their implications for theory and practice.

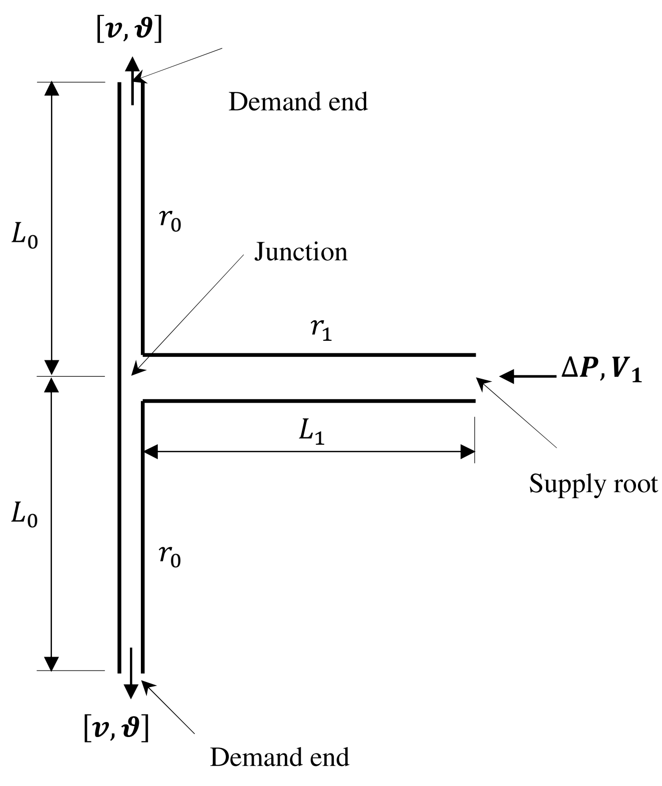


Figure 1. A basic T-shaped water supply piping network

2 Energy loss

Figure 1 shows a basic T-shape water supply piping network that a branch pipe of length L_0 and of radius r_0, fed by a centre main water pipe of length L_1 and radius r_1. The network consists a supply root and two demand ends as in a T-shape construct [6]. A demand in the network is due to a number of independently operated appliances

$n_1, n_2, \dots n_m$ at each of the two demand ends and each appliance demand is characterised by a constant flow rate $v = C_v$ and a probability $\varphi = \vartheta$. The flow rate between two consecutive demands is assumed zero with a probability $\varphi = 1 - \vartheta$. As an appliance is either 'in demand' (n=1) or 'not in demand' (n=0)), an appliance demand can be described by,

$$\boldsymbol{n_i}: \{0,1\};\ \boldsymbol{v_i}: \{0, v_i\};\ \boldsymbol{\varphi_i}: \{1 - \vartheta_i, \vartheta_i\};\ i = 1,2, \dots m \qquad \dots (1)$$

Appliances are arranged according to their 'in demand' flow rates $[v_1, \vartheta_1]$, $[v_2, \vartheta_2]$, …, $[v_m, \vartheta_m]$ such that $v_1 \le v_2 \le \dots \le v_m$ and expressed the flow rates in terms of $v_1 = C_v$ and $\boldsymbol{v} = \left[C_v \left\{0, \frac{v_1}{v_1}, \frac{v_2}{v_1}, \dots, \frac{v_{m-1}}{v_1}, \frac{v_m}{v_1}\right\}\right]$, then a demand at the demand end is given by,

$$\boldsymbol{v} = C_v\{0, 1, C_{V_2}, \dots, C_{V_{m-1}}, C_{V_m}\};\ C_{V_1} = 1 \le C_{V_2} \le \dots \le C_{V_{m-1}} \le C_{V_m} \qquad \dots (2)$$

The demands $v_{i,j}$ at the two branches i, j fed by the m binarily operated appliances are probabilistic. There are 2^m combinations of demands in each branch pipe, and $(2^m)^2$ cases at the junction where two branches meet, throughout the centre pipe or at the root. For a pair of demand ends i, j, the demand probability at any instant is $\varphi_i\varphi_j$ (denoted as φ_{ij}) and the corresponding demand probabilities are expressed by,

$$\boldsymbol{\varphi} = \{\varphi_{11}, \dots, \varphi_{(1)(2^m)}, \dots, \varphi_{(2^m)(1)}, \dots, \varphi_{(2^m)(2^m)}\};$$

$$\varphi_{ij} = \varphi_i\varphi_j;\ \varphi_i, \varphi_j = \prod_{l=1}^{m} \vartheta_l^{n_l}(1 - \vartheta_l)^{1-n_l} \qquad \dots (3)$$

i and j are dependent on the number of end demands m,

$$i, j = 1 + \sum_{l=1}^{m} 2^{l-1} n_l;\ n_l = [0,1] \qquad \dots (4)$$

The centre pipe demand at the root is the sum of demands due to branch pipes, and given by an expression below, where a total of $(2^m)(2^m)$ combinations of demand pairs are encountered,

$$\boldsymbol{V_1} = \boldsymbol{V_1}[\boldsymbol{v}, \boldsymbol{\varphi}];\ \boldsymbol{v} = \{v_{11}, \dots, v_{1(2^m)}, \dots, v_{(2^m)(1)}, \dots v_{(2^m)(2^m)}\};\ v_{ij} = v_i + v_j \ \dots (5)$$

Taking $C_0 = \frac{f\rho C_v^2}{\pi^2}$ as the unit pipe friction of turbulent flow, the total pressure loss of the network $\Delta\boldsymbol{P}$ is determined by the following equations, where $\Delta\boldsymbol{P_0}$ and $\Delta\boldsymbol{P_1}$ are the pressure losses in the branch and centre pipes respectively,

$$\Delta\boldsymbol{P}[\boldsymbol{p}, \boldsymbol{\varphi}] = \Delta\boldsymbol{P_0}[\boldsymbol{p}, \boldsymbol{\varphi}] + \Delta\boldsymbol{P_1}[\boldsymbol{p}, \boldsymbol{\varphi}];$$

$$\boldsymbol{p} = \{p_{11}, \dots, p_{1(2^m)}, \dots, p_{(2^m)(1)}, \dots, p_{(2^m)(2^m)}\}$$

$$\Delta\boldsymbol{P_0}: p_{ij} = \begin{cases} 0 & ; ij = 11 \\ \frac{C_0 L_0}{C_v^2 r_0^5} v_{i,j}^2 & ; ij \ne 11; v_{i,j} = max(v_i, v_j) \end{cases}$$

$$\Delta\boldsymbol{P_1}: p_{ij} = \frac{C_0}{C_v^2}\frac{L_1}{r_1^5} v_{ij}^2$$

… (6)

It is noted for the above expression, the pressure required at the junction between i and j is maintained for the higher flow rate $max(v_i, v_j)$.

As the pressure loss at the network is flow rate dependent and hence transient, the energy required for the pressure loss at the demands is chosen as the optimization parameter. The minimum energy E required for the water supply network is given by,

$$\boldsymbol{E}[\boldsymbol{e},\boldsymbol{\varphi}] = \Delta \boldsymbol{P}\boldsymbol{V_1};$$

$$\boldsymbol{e} = \{e_{11}, \dots, e_{1(2^m)}, \dots, e_{(2^m)(1)}, \dots e_{(2^m)(2^m)}\};\ e_{ij} = p_{ij}v_{ij};$$

$$E = e_{11}\varphi_{11} + \cdots e_{1(2^m)}\varphi_{1(2^m)} + \cdots e_{(2^m)1}\varphi_{(2^m)1} + \cdots e_{(2^m)(2^m)}\varphi_{(2^m)(2^m)} = \sum_{ij} e_{ij}\varphi_{ij} \quad \dots (7)$$

For a constant pipe volume C, the energy in Eq. (7) can be minimized by choosing a proper pipe radius ratio $C_R = (r_1/r_0)$ for pressure terms p_{ij} in Eq. (6) such that,

$$2L_0r_0^2 + L_1r_1^2 = C \quad \dots (8)$$

$$r_1 = \left(\frac{C}{L_1} - \frac{2L_0}{L_1}r_0^2\right)^{1/2} \quad \dots (9)$$

Let F be the frictional losses in the branch and centre pipes, where λ is an arbitrary constant in the pressure terms in Eq. (6), the general solution for the optimal pipe radius ratios $C_{R,opt}$ can be determined by taking derivative $F' = 0$,

$$F = \lambda_0L_0r_0^{-5} + \lambda_1L_1r_1^{-5} = \lambda_0L_0r_0^{-5} + \lambda_1L_1\left(\frac{C}{L_1} - \frac{2L_0}{L_1}r_0^2\right)^{-5/2} \quad \dots (10)$$

$$F' = -5\lambda_0L_0r_0^{-6} + \lambda_1L_1\left(\frac{-5}{2}\right)\left(\frac{C_T}{L_1} - \frac{2L_0}{L_1}r_0^2\right)^{1/2(-7)}\left(-\frac{4L_0}{L_1}r_0\right) = 0 \quad \dots (11)$$

$$-5\lambda_0L_0r_0^{-7} + 5\left(\frac{2\lambda_1L_1L_0}{L_1}\right)r_1^{-7} = 0 \quad \dots (12)$$

$$C_{R,opt} = \frac{r_1}{r_0} = \left(\frac{\lambda_0}{2\lambda_1}\right)^{-1/7} = \left(\frac{2\lambda_1}{\lambda_0}\right)^{1/7} \quad \dots (13)$$

The optimal pipe radius ratios $C_{R,opt}$ for Eq. (6) with probabilities φ_{ij} expressed below can be determined by taking derivative $C'_{R,opt} = 0$ with an optimum demand probability ϑ_{opt},

$$\boldsymbol{C_R} = [\boldsymbol{c},\boldsymbol{\varphi}];\ \boldsymbol{c} = \{c_{11}, \dots, c_{1(2^m)}, \dots, c_{(2^m)(1)}, \dots c_{(2^m)(2^m)}\} \quad \dots (14)$$

$$C_{R,opt} = F(\vartheta_{opt}) \quad \dots (15)$$

3 Optimal pipe radius ratios

Three cases for c_{ij} in calculating the pressure loss at pipe r_1 and r_0 are given below,

$$c_{ij} = \left(\frac{2\lambda_1}{\lambda_0}\right)_{ij}^{1/7} = \begin{cases} 2^{1/7} \\ 2^{1/7}\left(\frac{v_i+v_j}{max(v_i,v_j)}\right)^{2/7} \\ 2^{3/7} \end{cases} ; \quad v_{ij} = \begin{cases} v_i, v_j \to 0 \\ max\{v_i, v_j\};\ v_i, v_j \neq 0 \\ v_i + v_j \end{cases} \quad \dots (16)$$

It is noted for all positive demands, the term $1 \leq \left(\frac{v_i+v_j}{max(v_i,v_j)}\right) \leq 2$ for all demand probabilities φ_{ij}, the optimal pipe radius ratio $C_{R,opt}$ exists only in a range between $2^{1/7}$ and $2^{3/7}$, i.e.

$$2^{1/7} \leq C_{R,opt} \leq 2^{3/7} \quad \ldots (17)$$

According to an earlier study, the case of demand probability $\vartheta = 1$ is actually a steady flow condition and the optimal pipe radius ratio determined for it is $2^{3/7}$ [6].

Pipe radii at $C_R = 2^{3/7}$ optimized for the steady demand (at the demand probabilities $\vartheta_{ij} = 1$) are not energy loss optimized for the cases of minimum demands (i.e. $\vartheta_{ij} \sim 0$) and vice versa. An optimized probability ϑ_{opt} exists as the energy loss at a value of C_R.

The minimum energy loss E_{opt} can be approximated by the two extreme demand cases, i.e. $\vartheta_{ij} \sim [0,1]$. The optimal probability, given by F below, is determined by taking $F' = 0$ such that,

$$F = c_{11}\varphi_{11} + c_{2^m,2^m}\varphi_{2^m,2^m} \quad \ldots (18)$$

$$F = 2^{3/7}\left(1 - \vartheta_{ij}\right)^{2m} + 2^{3/7}\vartheta_{ij}^{2m} \quad \ldots (19)$$

$$F' = -2^{3/7}(2m)\left(1 - \vartheta_{ij}\right)^{2m-1} + 2^{3/7}(2m)\vartheta_{ij}^{2m-1} = 0 \quad \ldots (20)$$

$$\vartheta_{opt} = 2^{-1} \quad \ldots (21)$$

$C_{R,opt}$ can be determined for the two extreme demand cases (i.e. $\vartheta_{ij} \sim [0,1]$) using the general equations of order $m = 1$ and validated via the general equations of order $m = 2$. It should be noted that Eq. (20) approximates the optimum $C_{R,opt}$ without taking the influences of demand flow rates C_{V_i} in elements c_{ij}, where $ij \neq (1)(1), (2^m)(2^m)$, into account. This point would lead to errors and shall be examined in the validation section below.

4 Optimal pipe radius ratio (using general equations of order $m = 1$)

When $m = 1$, water is supplied to two identical binary operated appliances $\boldsymbol{n}$: $\{0,1\}$, one on each side of the T-shaped piping network. Hence, there are $2^m = 2$ demand combinations in each branch pipe and $(2^m)^2 = 4$ demand combinations at the junction, throughout the centre pipe or at the root of the network.

$$\boldsymbol{n_1}: \{0,1\}; \boldsymbol{v}: C_v\{0,1\}; \boldsymbol{\varphi}: \{1 - \vartheta_1, \vartheta_1\} \quad \ldots (22)$$

Centre pipe demand $\boldsymbol{V_1}$ is determined by $\boldsymbol{V_1} = \boldsymbol{V_1}[\boldsymbol{v}, \boldsymbol{\varphi}]$,

$$\boldsymbol{v} = \{v_{11}, v_{12}, v_{21}, v_{22}\} = \{v_1 + v_1, v_1 + v_2, v_2 + v_1, v_2 + v_2\} = C_v\{0,1,1,2\} \quad \ldots (23)$$

For the binary operated appliance n_1,

$$n_1 = \begin{cases} 0 & ; i,j = 1 \\ 1 & ; i,j = 2 \end{cases}; \varphi_1 = \left(1 - \vartheta_1\right); \varphi_2 = \vartheta_1 \quad \ldots (24)$$

$$\boldsymbol{\varphi} = \{\varphi_{11}, \varphi_{12}, \varphi_{21}, \varphi_{22}\} = \{\varphi_1\varphi_1, \varphi_1\varphi_2, \varphi_2\varphi_1, \varphi_2\varphi_2\}$$

$$= \left\{ \left(1-\vartheta_1\right)^2, \vartheta_1(1-\vartheta_1), \vartheta_1(1-\vartheta_1), \vartheta_1^2 \right\} \quad \ldots (25)$$

Taking the total pressure loss of the network $C_0 = \frac{f\rho C_v^2}{\pi^2}$, the total pressure losses of the network, branch and centre pipes $\Delta\boldsymbol{P}$, $\Delta\boldsymbol{P_0}$, $\Delta\boldsymbol{P_1}$ are determined by the following equations,

$$\Delta\boldsymbol{P}[\boldsymbol{p},\boldsymbol{\varphi}] = \Delta\boldsymbol{P_0}[\boldsymbol{p},\boldsymbol{\varphi}] + \Delta\boldsymbol{P_1}[\boldsymbol{p},\boldsymbol{\varphi}];\ \boldsymbol{p} = \{p_{11}, p_{12}, p_{21}, p_{22}\};$$

$$\Delta\boldsymbol{P_0}: \boldsymbol{p} = \left\{0, \frac{C_0L_0}{C_v^2r_0^5}v_2^2, \frac{C_0L_0}{C_v^2r_0^5}v_2^2, \frac{C_0L_0}{C_v^2r_0^5}v_2^2\right\} = C_0\left\{0, \frac{L_0}{r_0^5}, \frac{L_0}{r_0^5}, \frac{L_0}{r_0^5}\right\}$$

$$\Delta\boldsymbol{P_1}: \boldsymbol{p} = \left\{0, \frac{C_0L_1}{C_v^2r_1^5}v_2^2, \frac{C_0L_1}{C_v^2r_1^5}v_2^2, \frac{C_0L_1}{C_v^2r_1^5}(2v_2)^2\right\} = C_0\left\{0, \frac{L_1}{r_1^5}, \frac{L_1}{r_1^5}, \frac{4L_1}{r_1^5}\right\}$$

$$\Delta\boldsymbol{P}: \boldsymbol{p} = C_0\left\{0, \frac{L_0}{r_0^5} + \frac{L_1}{r_1^5}, \frac{L_0}{r_0^5} + \frac{L_1}{r_1^5}, \frac{L_0}{r_0^5} + 4\frac{L_1}{r_1^5}\right\}$$

… (26)

The energy loss E at the network is expressed by,

$$\boldsymbol{E}: \boldsymbol{e} = \{e_{11}, e_{12}, e_{21}, e_{22}\} = C_0C_v\left\{0, \left(\frac{L_0}{r_0^5} + \frac{L_1}{r_1^5}\right), \left(\frac{L_0}{r_0^5} + \frac{L_1}{r_1^5}\right), 2\left(\frac{L_0}{r_0^5} + 4\frac{L_1}{r_1^5}\right)\right\}$$

$$E = C_0C_v\left(0 + 2(1-\vartheta_1)\vartheta_1\left(\frac{L_0}{r_0^5} + \frac{L_1}{r_1^5}\right) + 2\vartheta_1^2\left(\frac{L_0}{r_0^5} + 4\frac{L_1}{r_1^5}\right)\right)$$

… (27)

Energy loss E is optimized under a given pipe volume constraint C. Taking $\vartheta_{opt} = 2^{-1}$, the optimal pipe radius ratio $C_{R,opt}$ is given by,

$$\boldsymbol{C_R}: \boldsymbol{c} = \left\{2^{3/7}, 2^{1/7}, 2^{1/7}, 2^{3/7}\right\} \quad \ldots (28)$$

$$C_R = 2^{3/7}(1-\vartheta_1)^2 + \left(2^{1/7}\right)2(1-\vartheta_1)\vartheta_1 + 2^{3/7}\vartheta_1^2 \quad \ldots (29)$$

$$C_R' = 2^{3/7}(1-\vartheta_1)^2 + \left(2^{1/7}\right)2(1-\vartheta_1)\vartheta_1 + 2^{3/7}\vartheta_1^2 = 0 \quad \ldots (30)$$

$$C_{R,opt} = 2^{3/7}\left(1-\vartheta_{opt}\right)^2 + \left(2^{1/7}\right)2\left(1-\vartheta_{opt}\right)\vartheta_{opt} + 2^{3/7}\vartheta_{opt}^2 = 2^{2/7}$$

… (31)

Figure 3 illustrates the relative energy loss E/E_{opt} required at a T-shaped water supply piping network when $m = 1$. They confirm the range of optimal pipe radius ratios $C_{R,opt} \in \left[2^{1/7}, 2^{3/7}\right]$ at the boundary conditions between the minimum and maximum demand probabilities are ϑ~0 and ϑ= 1 respectively.

Eq. (30) gives $\vartheta_{opt} = 0.5$, which when substituted into Eq. (29) yields $C_{R,opt} = 2^{2/7}$ as shown in Figure 3. If $C_{R,opt} = 2^{2/7}$ is applied to all demand probabilities, up to 4.2% more energy loss can be produced as compared with any optimal cases with a single set of demand probabilities. If $C_R = 2^{3/7}$ is optimized for the steady flow, the additional energy loss is 9-12% as compared with the optimal cases where demand probabilities are in between 0.001 and 0.1.

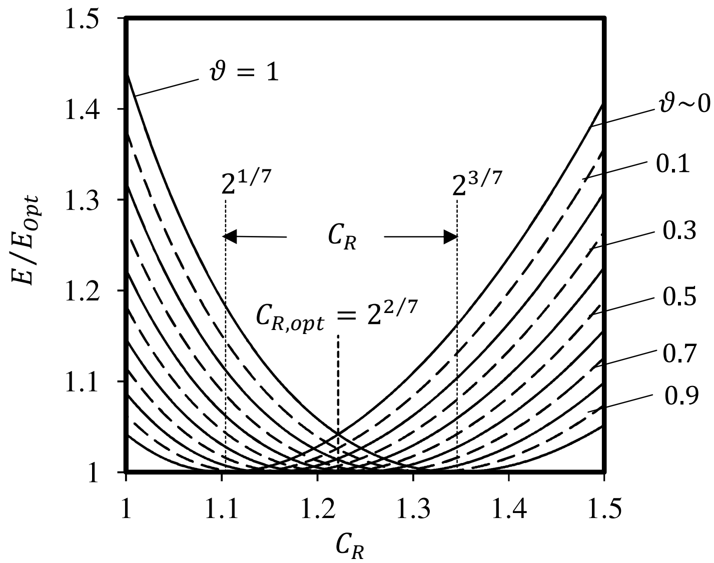


Figure 3. Relative energy loss at a T-shaped water supply piping network when $m = 1$

5 Optimal pipe radius ratio validation (using general equations of order $m = 2$)

Validity of the pipe radius ratio $C_{R,opt} = 2^{2/7}$ is tested in this case. When $m = 2$, two binary operated appliances (n_1, n_2) demand probabilities (ϑ_1, ϑ_2) and thus two demand flow rates (C_v, $C_v C_V$) exist at each demand end, i.e.

$$\boldsymbol{n_1}: \{0,1\};\ \boldsymbol{v}: C_v\{0,1\};\ \boldsymbol{\varphi}: \{1 - \vartheta_1, \vartheta_1\} \quad \dots (32)$$

$$\boldsymbol{n_2}: \{0,1\};\ \boldsymbol{v}: C_v C_V\{0,1\};\ \boldsymbol{\varphi}: \{1 - \vartheta_2, \vartheta_2\} \quad \dots (33)$$

There are 4 ($= 2^m$) demand combinations in each branch pipe,

$$\boldsymbol{v} = \{v_1, v_2, v_3, v_4\} = \{0,1, C_V, 1 + C_V\} \quad \dots (34)$$

Correspondingly, there are 4×4=16 ($= 2^{2m}$) demand combinations at the junction, in the centre pipe and at the root.

For the binary operated appliances n_1, n_2, the centre pipe demand $\boldsymbol{V_1} = \boldsymbol{V_1}[\boldsymbol{v}, \boldsymbol{\varphi}]$ is, with matrix elements of $\boldsymbol{v}, \boldsymbol{\varphi}$ are given in Table 1,

$$\boldsymbol{v} = \{v_{11}, v_{12}, v_{13}, v_{14}, v_{21}, \dots v_{44}\} \quad \dots (35)$$

$$i, j = 1 + n_1 + 2n_2;\ n_{1,2} = [0,1] \quad \dots (36)$$

$$\boldsymbol{\varphi} = \{\varphi_{11}, \varphi_{12}, \dots \varphi_{44}\};\ \varphi_{ij} = \varphi_i \varphi_j;\ \varphi_{i,j} = \vartheta_1^{n_2}(1 - \vartheta_1)^{1-n_2}\vartheta_2^{n_1}(1 - \vartheta_2)^{1-n_1} \quad \dots (37)$$

ij	$i: n_2, n_1$; $j: n_2, n_1$	$C_v^{-1}[v_i, v_j]$	$C_v^{-1}v_{ij}$	$\varphi_{ij} = \varphi_i\varphi_j$	$\Delta\boldsymbol{P_0}: C_v^{-1}C_0^{-1}p_{ij}$	$\Delta\boldsymbol{P_1}: C_v^{-1}C_0^{-1}p_{ij}$	$C_v^{-1}C_0^{-1}e_{ij}$	c_{ij}
11	0000	0,0	0	$(1-\vartheta_1)^2(1-\vartheta_2)^2$	0	0	0	$2^{3/7}$
12	0001	0,1	1	$(1-\vartheta_1)^2\vartheta_2(1-\vartheta_2)$	$L_0r_0^{-5}$	$L_1r_1^{-5}$	$L_0r_0^{-5}+L_1r_1^{-5}$	$2^{1/7}$
13	0010	$0, C_V$	C_V	$(1-\vartheta_1)\vartheta_1(1-\vartheta_2)^2$	$C_V^2L_0r_0^{-5}$	$C_V^2L_1r_1^{-5}$	$C_V^3(L_0r_0^{-5}+L_1r_1^{-5})$	$2^{1/7}$
14	0011	$0,1+C_V$	$1+C_V$	$\vartheta_1(1-\vartheta_1)\vartheta_2(1-\vartheta_2)$	$(1+C_V)^2L_0r_0^{-5}$	$(1+C_V)^2L_1r_1^{-5}$	$(1+C_V)^3(L_0r_0^{-5}+L_1r_1^{-5})$	$2^{1/7}$
21	0100	1,0	1				same with $ij = 12$	
22	0101	1,1	2	$(1-\vartheta_1)^2\vartheta_2^2$	$L_0r_0^{-5}$	$4L_1r_1^{-5}$	$2(L_0r_0^{-5}+4L_1r_1^{-5})$	$2^{3/7}$
23	0110	$1, C_V$	$1+C_V$	$\vartheta_1(1-\vartheta_1)\vartheta_2(1-\vartheta_2)$	$C_V^2L_0r_0^{-5}$	$(1+C_V)^2L_1r_1^{-5}$	$(1+C_V)(C_V^2L_0r_0^{-5}+(1+C_V)^2L_1r_1^{-5})$	$2^{1/7}\left((1+C_V)C_V^{-1}\right)^{2/7}$
24	0111	$1, 1+C_V$	$2+C_V$	$\vartheta_1(1-\vartheta_1)\vartheta_2^2$	$(1+C_V)^2L_0r_0^{-5}$	$(2+C_V)^2L_1r_1^{-5}$	$(2+C_V)((1+C_V)^2L_0r_0^{-5}+(2+C_V)^2L_1r_1^{-5})$	$\frac{2^{1/7}(2+C_V)^{2/7}}{(1+C_V)^{2/7}}$
31	1000	C_V,0	C_V				same with $ij = 13$	
32	1001	C_V,1	$1+C_V$				same with $ij = 23$	
33	1010	C_V, C_V	$2C_V$	$\vartheta_1^2(1-\vartheta_2)^2$	$C_V^2L_0r_0^{-5}$	$4C_V^2L_1r_1^{-5}$	$2C_V^3(L_0r_0^{-5}+4L_1r_1^{-5})$	$2^{3/7}$
34	1011	$C_V, 1+C_V$	$1+2C_V$	$\vartheta_1^2\vartheta_2(1-\vartheta_2)$	$(1+C_V)^2L_0r_0^{-5}$	$(1+2C_V)^2L_1r_1^{-5}$	$(1+2C_V)((1+C_V)^2L_0r_0^{-5}+(1+2C_V)^2L_1r_1^{-5})$	$\frac{2^{1/7}(1+2C_V)^{2/7}}{(1+C_V)^{2/7}}$
41	1100	$1+C_V$,0	$1+C_V$				same with $ij = 14$	
42	1101	$1+C_V$,1	$2+C_V$				same with $ij = 24$	
43	1110	$1+C_V, C_V$	$1+2C_V$				same with $ij = 34$	
44	1111	$1+C_V, 1+C_V$	$2(1+C_V)$	$\vartheta_1^2\vartheta_2^2$	$(1+C_V)^2L_0r_0^{-5}$	$4(1+C_V)^2L_1r_1^{-5}$	$2(1+C_V)^3(L_0r_0^{-5}+4L_1r_1^{-5})$	$2^{3/7}$

Table 1. Matrix elements for general equations of order $m = 2$

The pressure loss required at the network $\Delta \boldsymbol{P}$ and the corresponding pressure loss are given by, where the matrix elements p_{ij}, e_{ij} are summarized in Table 1 for easy reference,

$$\Delta \boldsymbol{P}[\boldsymbol{p}, \boldsymbol{\varphi}] = \Delta \boldsymbol{P_0}[\boldsymbol{p}, \boldsymbol{\varphi}] + \Delta \boldsymbol{P_1}[\boldsymbol{p}, \boldsymbol{\varphi}];\ \boldsymbol{p} = \{p_{11}, p_{12}, p_{13}, p_{14}, p_{21}, \dots p_{44}\} \quad \dots (38)$$

$$\boldsymbol{E}\text{: } \boldsymbol{e} = \{e_{11}, e_{12}, \dots, e_{44}\};\ e_{ij} = \left(\Delta \boldsymbol{P}\text{: } p_{ij}\right)\left(\boldsymbol{V_1}\text{: } v_{ij}\right) \quad \dots (39)$$

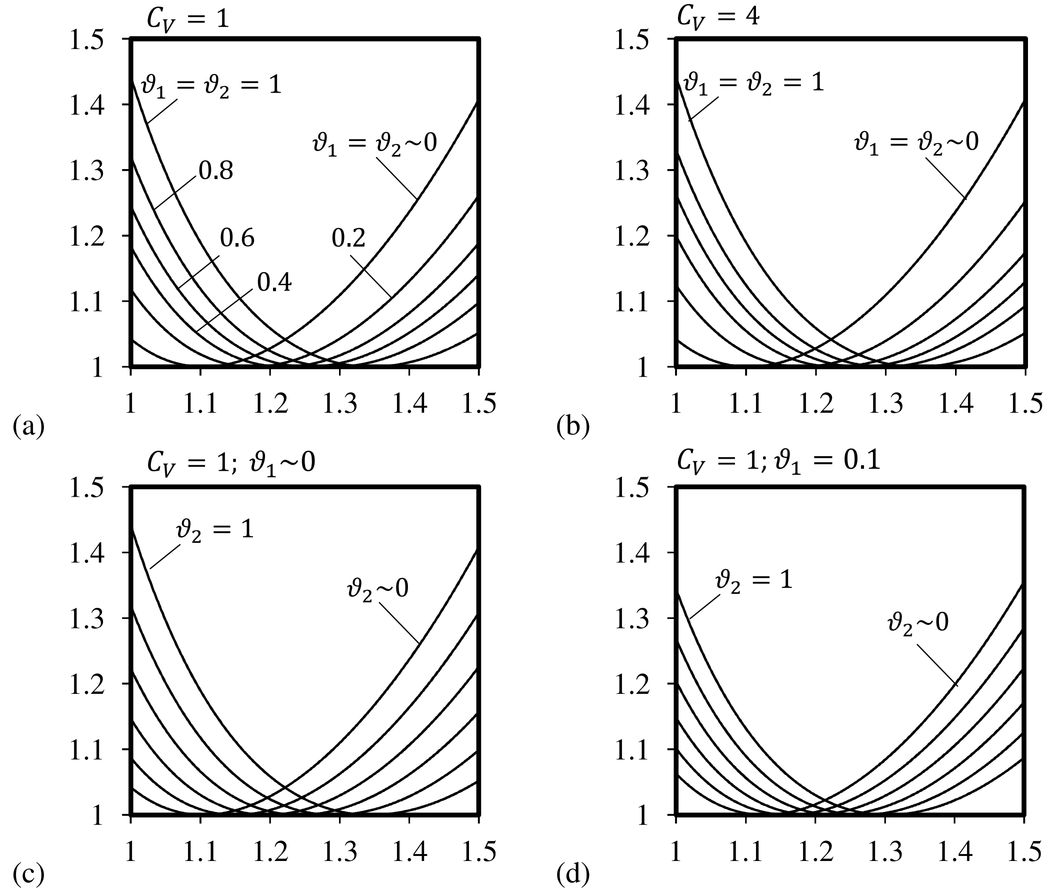
Figure 5 presents the relative energy loss for some demand cases while Figure 6 exhibits the optimal pipe radius ratios for various sets of demand flow rates and demand probability combinations. Again, they confirm the validity of the $C_{R,opt}$ range and boundary conditions as in case $m = 1$. It can be seen that demand flow rates (C_V>1) have some influences on the middle range of demand probabilities (e.g. $\vartheta = 0.1$ to 0.9), but not on $\vartheta > 0.9$ (steady flow) or $\vartheta < 0.1$ (minimal flow).

In Figure 6(a), the optimal pipe radius ratios for $\vartheta = 0.5$ are 1.247 and 1.251 when $C_V = 4$ and 40 respectively. It is noted that typical appliance flow rates are in the range 0.08 Ls^{-1} (shower) to 0.3 Ls^{-1} (kitchen sink) corresponding to a $C_V < 4$ (Plumbing service design guide 2002). In Figure 6(b), the $C_{R,opt}$ values for fixed demand probabilities $\varphi_1 = 0.2$, 0.4, 0.6 and 0.8 are 1.218, 1.239, 1.268 and 1.304 respectively if $\frac{\partial C_{R,opt}(\varphi_1,\varphi_2)}{\partial \varphi_2} = 0$. As expected, more frequent demands (i.e. 'larger' flow rates) lead to higher $C_{R,opt}$ values. The findings suggest that $C_R = 2^{2/7} \approx 1.22$ should be the optimal choice for the design of water supply piping networks that serve probabilistic demands (at uniformly distributed probabilities).

6 Energy implications of existing piping networks

Figure 7 shows the maximum relative energy loss for probabilistic demands with C_R = 1-1.5, illustrating a potential reduction of energy loss up to 38% at $C_{R,opt} = 2^{2/7}$. Table 2 exhibits the common pipe sizes available for water supply systems in buildings [7]. The pipe radius ratios C_R shown are in the range of 1.13-1.47 and many of them are very close to the optimal ratio value ($C_R = 2^{2/7} \approx 1.22$) proposed in this work. If the optimal value 1.22 substitutes 1.13 or 1.47, 9-30% savings in energy loss are achievable. In view of the fact that the smallest pipe is practically employed in end-use appliances, one more pipe size in between 15 mm and 22 mm, i.e. 15×1.22 mm or 22÷1.22 mm = 18 mm, is required for energy loss optimization. It should be noted that for a wide range of sanitation appliances operated at a demand probability typically lower than 0.1 [8,9], a pipe radius ratio based on steady flow conditions ($C_{R,opt}=2^{3/7}$) leads to an additional energy loss of 14% and 10% respectively, and thus the choice is not optimized for many water supply systems in buildings. Sizing pipes with $C_R = 2^{2/7}$ will be a better choice corresponding to a less energy loss of 2.6% and 1.5% as compared with the cases of known single set of demand probabilities.

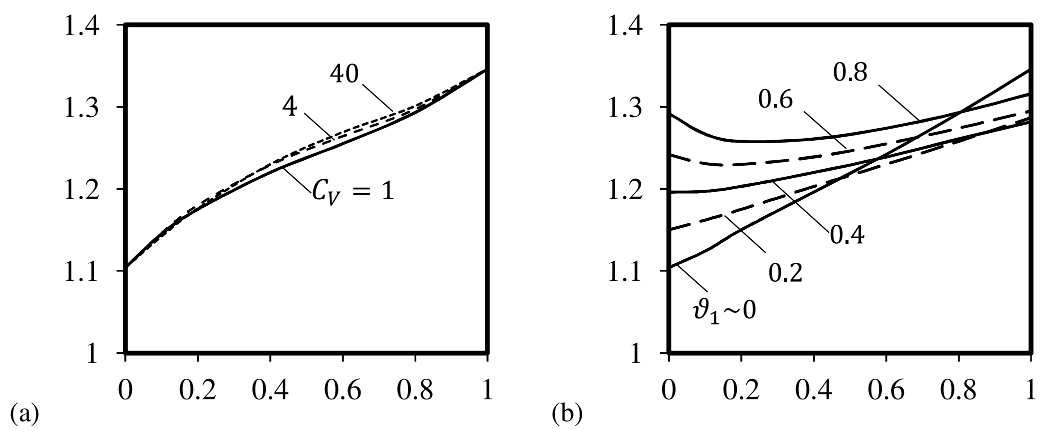
Typical water supply systems are designed to cope with a design condition of the probable maximum demand that sufficient pressure is available at all appliance outlets at its design flow rate. The outlet pressure control is achieved by the user through regulating the flow control valve of the appliance. However, this over-provided pressure relates to energy wastage. The significance of this paper is to understand the required pressure of probabilistic demands. With proper demand control on the appliance outlet pressure at probabilistic demands, potential pumping energy savings for water supply networks can be studied.



x-axis: Pipe radius ratio C_R

y-axis: Relative pumping energy E/E_{Opt}

Figure 5. Relative energy loss for a T-shaped water supply piping network when $m = 2$



x-axis: Probability ϑ_2

y-axis: Optimum pipe radius ratio $C_{R,Opt}$

Figure 6. Optimum pipe radius ratios, $m = 2$

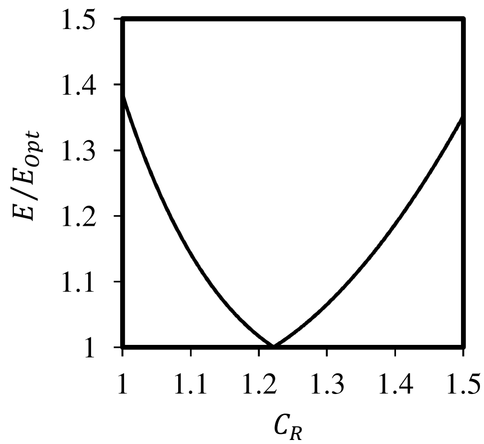


Figure 7. Maximum relative pumping energy at $C_{R,opt} = 2^{2/7}$

Table 2. Common pipe sizes for water supply systems in buildings [7]

Copper and stainless steel pipes		Plastic pipe	
Size	C_R	Size	C_R
15		16	
22	1.47	20	1.25
28	1.27	25	1.25
35	1.25	32	1.28
42	1.2	40	1.25
54	1.28	50	1.25
67	1.24	63	1.26
76	1.13	75	1.19
108	1.42	90	1.20
133	1.23	110	1.22
159	1.2	160	1.45

7 Conclusion

This paper presented the general equations for solving energy loss optimization problems associated with a common basic T-shaped water supply piping network that serves infinite probabilistic demands, and established a mathematical model for energy loss optimization under a fixed pipe volume constraint. Potential reduction of energy loss through proper pipe size was investigated and the optimal pipe radius ratios were found to be in between $2^{1/7}$ and $2^{3/7}$. The findings suggested that $2^{2/7}$ should be the optimal choice for the design of water supply pipe networks that serve probabilistic demands. They also showed that existing piping designs are not optimized for probabilistic demands and reduction of energy loss up to 38% can be made at supply networks, with proper demand control of pumping system.

8 Acknowledgement

The work described in this paper was partially supported by a grant from the Research Grants Council of the HKSAR, China (PolyU533709E).

9 List of symbols

C, c	Constant and its matrix element
E, e	Energy and its matrix element (J)
F	Function as defined
f	Friction factor (-)
i, j, l	Dummy variables as defined
L	Length (m)
m	Number of independently operated appliance
n	State of a binary operated appliance
P, p	Pressure and its matrix element (Pa)
ϑ, φ	Demand probability and its matrix element (-)
r	Radius (m)
V, v	Volumetric demand flow rate and its matrix element (m^3s^{-1})
Δ	Change of
$[\,], \{\,\}$	Matrix notation and matrix element group
ρ	Density (kg m^{-3})
λ	Dummy parameter group as defined

Superscript

$'$	Derivatives

Subscript

$0,1,2,3,4,\ldots$	Of conditions 0, 1, 2, 3, 4, … as defined
c	Of constant
i, j, l, m, n	Of i-th, j-th, l-th, m-th, n-th conditions as defined
max	Of maximum value
opt	Of optimum
R	Of pipe radius ratio
V, v	Of volumetric flow rate

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11 Presentation of Authors

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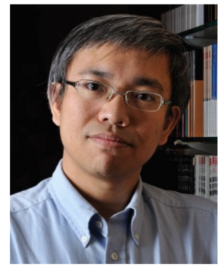

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Measurements of water consumption in apartment buildings

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Abstract

Total and/or hot water consumption has been measured in a number of apartment buildings of different sizes in Belgium. Each building was monitored during a minimum period of 1 month with a measurement interval of 1 second. Peak flow rates were deduced from these data for each building. The measured peak flow rates were compared to the peak flows as calculated in accordance with existing guidelines in order to determine the relevance of these guidelines for Belgium. Furthermore, the impact of measurement interval on peak flow rate was examined by averaging the data over longer intervals. Although more measurements will be needed to obtain statistically relevant results, existing guidelines seem to overestimate the peak flow rate by a factor of at least 2, and up to 3. Averaging of measuring data over intervals up to 5 seconds had no significant influence on the measured peak flow rate. However, it should be noted that measuring over an interval of 60 seconds would underestimate the peak flow rate significantly. A new approach using semi-logarithmic graphs is suggested to illustrate the correlation between maximum flow rate data and measuring intervals.

Keywords

Water consumption; apartment buildings; measurements; peak flow rate; measurement interval.

1 Introduction

As the energy-use for space heating continuously diminishes due to better performances of the building envelope, the energy use for hot water production becomes increasingly relevant. In passive houses and low-energy-houses this energy consumption can even be more important than the energy consumption for space heating. Since the recast of the Energy Performance of Buildings Directive [1] stipulates that by 2020 all new buildings in the European Union should be almost net zero energy buildings, reducing the energy use for hot water production, whilst maintaining the desired comfort level for the buildings occupants, becomes one of the challenges for the future. Furthermore, over-dimensioned hot water installations represent an important risk for the hygienic quality of drinking water, in terms of possible Legionella development in stagnant water.

On the other hand, the price of drinking water keeps increasing. In Flanders the integral water cost (€/m^3) for average families increased by 54% in the period 2005-2010 [2].

For the above mentioned reasons it becomes increasingly important to design efficient water-conveying installations in buildings. However the in Belgium generally used design methods (French, German, European and Dutch – there is no Belgian standard) are not based on the specific Belgian situation and most of them are not recent and possibly out-dated, because since their publication important shifts have occurred, as well in the desired comfort level of the building users (rain shower heads, Jacuzzis, etc.), as in the use of more appliances that minimize water use (dual-flush toilets, low-flow shower heads, etc.).

The purpose of this study is to assess if the design guidelines in use are still relevant for apartment buildings in Belgium. Therefore cold and/or hot water consumption was measured in a number of apartment buildings of different sizes. The measured peak flow rates were compared to the peak flow rates as calculated in accordance with the commonly used guidelines: the German standard DIN 1988-3 [3], the European standard EN 806-3 [4], the French specification DTU 60.11 [5] and the Dutch guideline ISSO 55 [6].

2 Method

2.1 Measurements and measured buildings

During 2011-2012 domestic total water (DTW)[1] use was measured in 3 apartment buildings, whilst domestic hot water (DHW)[2] use was measured in one apartment building with centralised hot water production.

Water consumption was measured for each building during a minimum period of 1 month, with a measurement interval of 1 second. This measuring period allows a sufficient view on weekly variations, but does not allow to appreciate seasonal ones. This has to be kept in mind whilst interpreting the results.

Table 1 gives the total number and type of apartments for each building, as well as the measurement period. Both buildings in Louvain-la-Neuve were occupied by a relatively important percentage of students.

[1] Domestic total water (DTW) is measured immediately after the water meter of the water distribution company. Part of DTW is used for the production of domestic hot water (DHW), part remains cold water.
[2] DTW-values in this study are always expressed as hot water at 60°C

Table 1 Measured apartment buildings and characteristics

Apartment building	Number of apartments	Measurement period
Louvan-la-Neuve 1 ("LLN1")	56	April-May 2011
Louvain-la-Neuve 2 ("LLN2")	16	June-July 2011
Brecht ("BR")	7	August-October 2011
Brussels ("BXL")	124	June 2012

In order to be able to calculate the peak flow rate using the existing guidelines, all equipment (type and number of appliances) in the buildings was listed.

2.2 Measurement equipment

For measuring the water consumption, ultrasonic flow meters were used. Since these meters have sensors which are fixed on the pipes outer wall, no modification of the installation in the building was needed. Sensors are either of the 'clamp-on' type or fixed with an element holder (Figure 1).

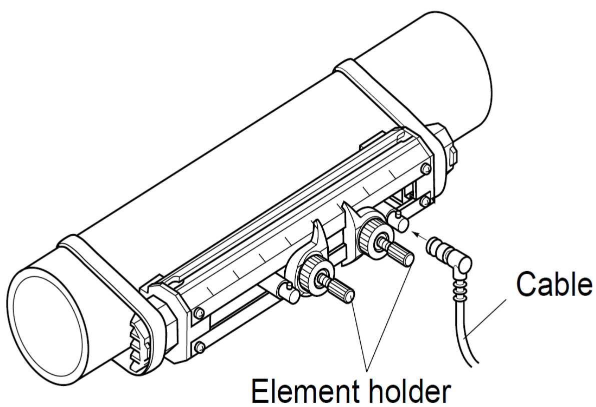

Figure 1 – Measuring sensors of ultrasonic flow meter fixed on pipe

DTW was measured immediately behind the water meter of the water distribution company. As in building "BXL" hot water production is centralised and the DHW-distribution contains a recirculating system, DHW was measured immediately in front of the hot water production. Cold and hot water temperatures were measured as well.

The measuring error was below 4% and was verified in laboratory conditions as well as by using the existing water meters in the buildings. For multilayer pipes (PEX-Al-PEX) an alternative measuring method was developed as the ultrasonic flow meters used in this study were designed for pipes with a wall composition of maximum two layers. The measuring error of the alternative method was below 4% as well.

The measured data were stored on a data logger with sufficient memory to cover a measurement period of several months. Both ultrasonic flow meters and the data logger were installed in a metal casing (Figure 2).

Figure 2 –Measuring unit composed of 2 flow meters and a data logger

3 Results

For each building the peak flows in DTW or DHW were determined from the measurements as well as calculated using the different existing guidelines. The effect of measuring with longer time intervals was studied by averaging the measured values (at 1 second interval) over longer intervals.

3.1 Domestic total water (DTW)

Figure 3 represents the measured peak flow rates for the DTW-use compared to the calculated peak flow rates. It should be noted that ISSO 55 is only applicable for buildings with a relatively limited number of appliances.

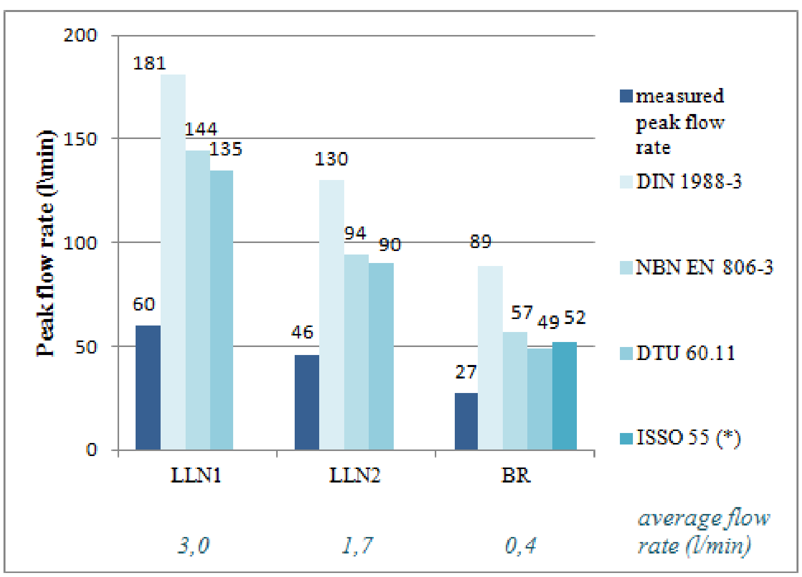

Figure 3 – Measured and calculated peak flow rate DTW in 3 apartment buildings (*) only applicable for buildings with a relatively limited number of appliances

The calculated DTW peak flow rates are systematically higher than the measured flow rates. For building LLN1, the German standard (DIN 1988-3) even results in a peak flow rate which is 3 times the measured peak flow rate. All existing guidelines overestimate the peak flow rate by a factor of at least 2. DIN 1988-3 seems to most overestimate DTW peak flow rate.

3.2 Domestic hot water (DHW)

Figure 4 represents, for the building in Brussels, the measured peak flow rates for the DHW-use compared to the calculated peak flow rates.

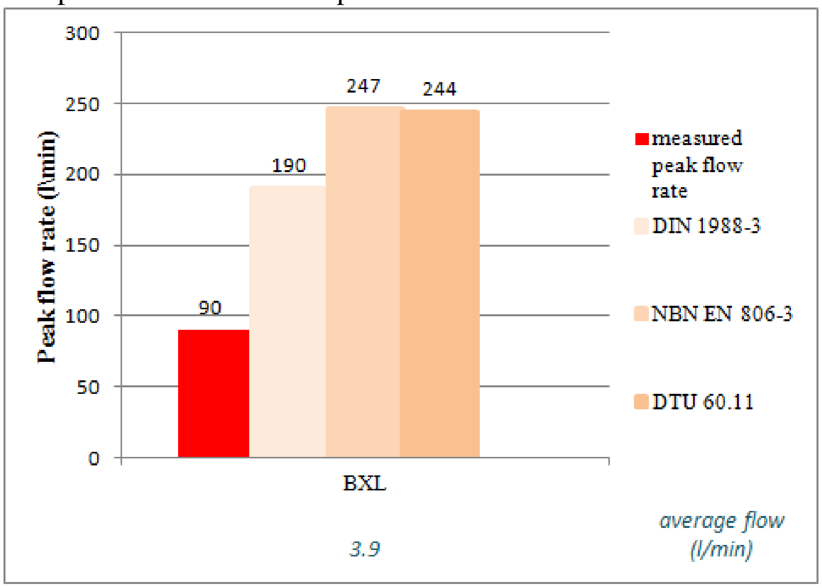

Figure 4 – Measured and calculated peak flow rate DTW (60°C) in an apartment building

The calculated DHW peak flow rates are systematically higher than the measured flow rate. The European standard (EN 806-3) even results in a peak flow rate which is 2,7 times the measured peak flow rate. All existing guidelines overestimate the peak flow rate by a factor of at least 2,1. In contrast with the DTW-consumption, and compared to the other guidelines, DIN 1988-3 seems to less overestimate DHW peak flow rate.

3.3 Impact of averaging the data

In order to evaluate the impact of the measurement interval on the measured peak flow, longer measurement intervals were simulated by averaging the data over longer time intervals. Figure 5 represents the DHW flow rate for a random day in the building with 124 apartments. The measured data at 1 second interval are shown together with the result of averaging these data over 60 seconds and 1 hour.

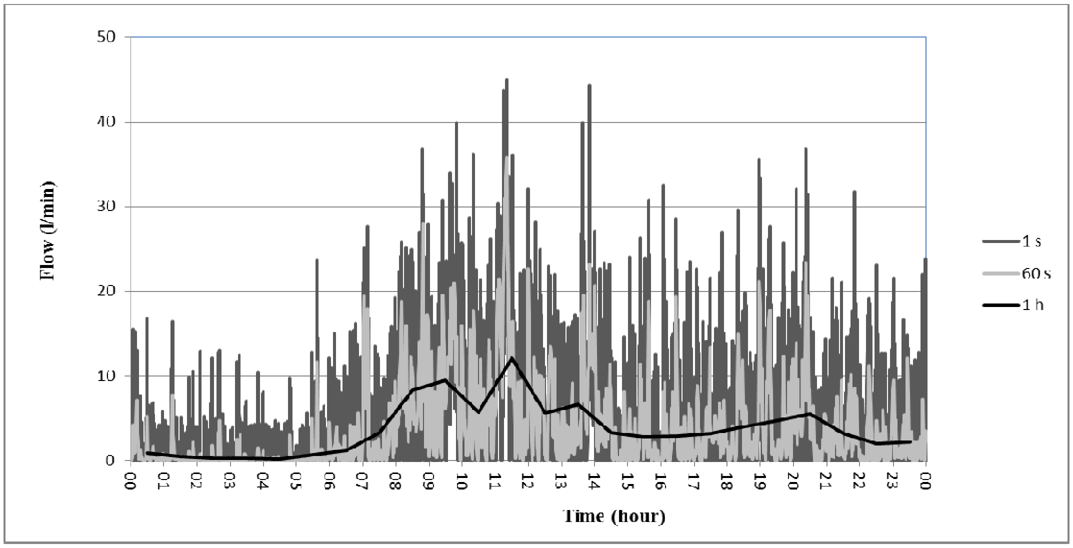

Figure 5 – Influence of measuring interval on DHW flow rate

For this day, measuring with an interval of 60 seconds would have underestimated the peak flow rate by 27%, while measuring with an interval of 1 hour would have resulted in an underestimation of 70%. It is clear that the measuring interval has an important impact on the measured peak flow rate. Only when measurement intervals are identical, measured peak flow rates can be compared with each other.

Figure 6 represents, for all buildings in this study, the effect of averaging the data on the maximum flow rate. For each averaging interval, the 1 second data were grouped and averaged. The maximum flow rate for the averaging interval was selected amongst the averaged flow rate values. The averaging interval is presented on a logarithmic scale and includes intervals up to one month. All flow rates are expressed in litres per minute.

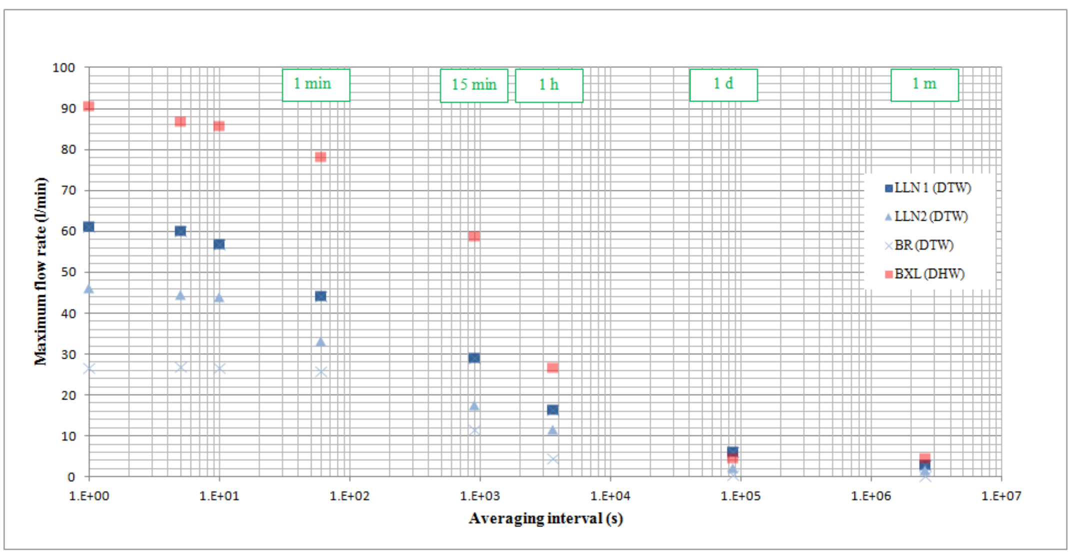

Figure 6 – Influence of averaging interval on maximum flow rate for 4 buildings (3x DTW and 1x DHW)

For both DTW and DHW the correlation between maximum flow rate data and averaging interval results in a typical (inverted) S-shaped curve. Up to an interval of 5 seconds, averaging the 1 second measurements had hardly any significant influence on the maximum flow rate. From 10 seconds onwards the maximum flow rate decreases for increasing averaging intervals. Measuring at an interval of 15 minutes would underestimate DTW peak flow rate by 57% and DHW peak flow rate by 35%.

The average flow rate over the total measurement period is indicated beneath Figures 3 and 4 for the different buildings. For DTW, the measured peak flow rates are 20 up to 70 times higher than the average flow rates in the same building. For DHW, the measured peak flow rate is 23 times higher than the average flow rate in the building.

Depending on the part of the water installation to be dimensioned, different types of flow rate can be necessary. Dimensioning pipe diameters or plate heat exchangers for DHW production should be based on peak flow rates, based on 1-5 seconds measurements. Dimensioning of other water appliances, eg an indirect heated DHW tank, might need flow rate data evaluated on hourly or even daily basis.

4 Conclusions

Although more measurements are needed to be able to obtain statistically relevant results, there is some evidence to state that existing guidelines over-estimate the peak flow by a factor of at least 2, and up to 3, both for DTW and DHW. Averaging of measuring data over intervals up to 5 seconds had no significant influence on the measured peak flow. However, it should be noted that measuring over an interval of 15 minutes for instance, would under-estimate the DHW peak flow by 35% and the DTW by 57%. Only when measurement intervals are identical, measured peak flow rates can be compared with each other.

Further research will extend the number of measured buildings and include other building types. Also the appropriateness for the Belgian situation of the different input parameters (e.g. nominal flow rates of appliances) of the existing design guidelines will be analysed in more depth.

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Anonymous investigation of user behaviour in toilet facilities

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Abstract

The main target of this work was the anonymous investigation of user behaviour in toilet facilities. For this purpose a data recording system based on the field-bus system „INTERBUS“ was created to collect and evaluate data from all sanitary facilities in a six-flour building of the Fachhochschule Gelsenkirchen University of Applied Sciences. This system determined the duration and average water consumption regarding one toilet use followed by the use of the washstand.

Keywords

user behaviour, data redording by field-bus system, water consumption

1 Introduction

This project describes the installation and programming of a data recording system in public toilets (restrooms). This publication is completely based on the dissertation Martin Lindemann submitted for his diploma at Fachhochschule Gelsenkirchen University of Applied Sciences in 2003.

For the purpose of examining user behaviour, a field-bus system “INTERBUS” was employed for the data recording system. The main attention was directed to the determination of the average total time spent on using sanitary facilities, e. g. a toilet and afterwards a washstand, and also to the recording of the respective water consumption. Furthermore, the use of the toilet seat and the way users handled the seat was looked at more closely.

In addition, the hydraulics in the waste water system was determined optically by means of video-recording. For this purpose the downpipe in the basement was connected to a collecting pipe made of a glass pipe which allowed a clear view of the waste water hydraulics in horizontal pipes. After synchronizing the time on the clocks, the successful video-recordings could be compared with the data-recordings and thus facilitating a further analysis of the transport speed and the flushing quality.

2 Test installations

The testing facility was installed in building B of Fachhochschule Gelsenkirchen University of Applied Sciences, a six-floor building with an additional basement where there was the room with the technical facilities including the transparent collecting pipe. As the single floors were used differently, different users' behaviour was to be expected as well. Therefore, the whole building was considered in the analysis.

6th floor: Laboratory for electrical engineering, offices
5th floor: CAD-room, IT-room and offices
4th floor: Laboratory for material technology
3rd floor: Seminar room, laboratories and offices
2nd floor: Laboratory for facility automation, laboratory for air-conditioning technology, offices
1st floor: Entrance, four seminar rooms and offices
Basement: Sports room, storage rooms and technical facilities' room

The following table 2.1 shows the sanitary facilities

Table 2.1- Toilet facilities (restrooms) by floor

	Ladies		Gents		
	toilets	washstands	toilets	washstands	urinals
6th floor	-	-	1	1	-
5th floor	1	1	2	2	3
4th floor	1	1	2	2	3
3rd floor	1	1	2	2	3
2nd floor	1	1	2	2	3
1st floor	1	1	2	1	3

The plan of the floors 1 to 5 is shown in the following picture 2.1

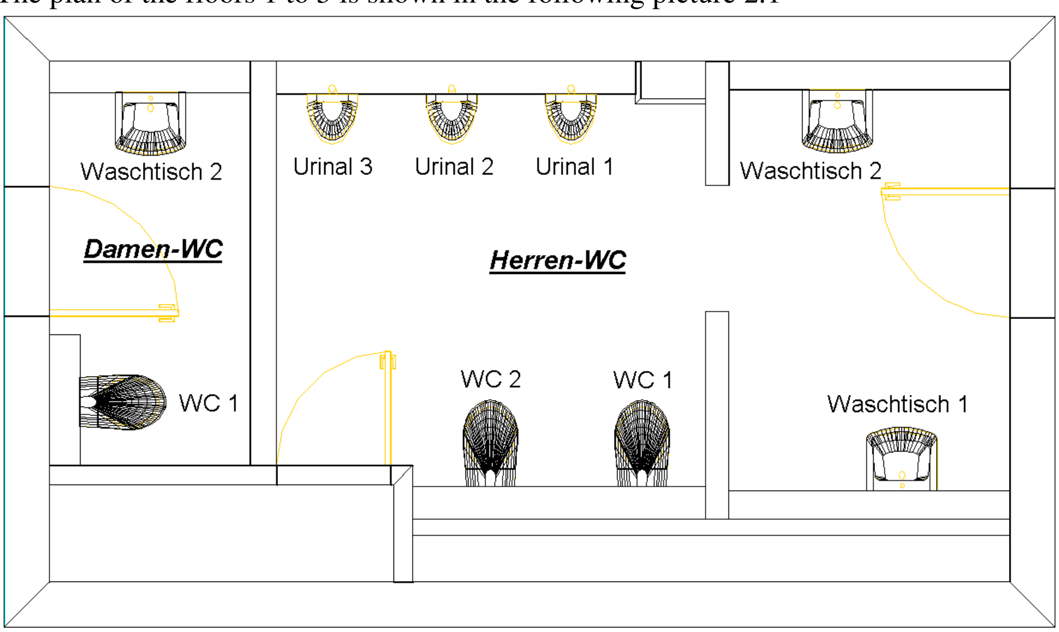

Fig 2.1- Facilities by room

In the basement there was the room for the technical facilities where the downpipes were connected to the collecting pipe made of glass. The toilet facilities and some washstands were connected to the downpipe with the size DN125. The second downpipe of the urinals and further washstands were connected to a downpipe with a size of DN 100. The collecting pipe was installed with the size DN 150. In order to evaluate the flushing quality and floating length in horizontal pipes connected to a downpipe, the maximum length possible in the building was chosen.

2.1 Data-recording system

Pre-conditions for recording data in this project were:

1. The existing sanitary facilities
2. Sensors
3. LOOP2/ring-loop per floor
4. Installation remote bus
5. Measuring computer with software programmes „PC Worx and DIAdem"

(Items 2–4: Hardware)

Data recording was effected by means of Phoenix Contact Interbus-System. The data collected by the sensors were transferred via the installation remote bus and then analyzed by the software.

2.1.1 Sensors

Different sensors were installed in order to collect the necessary data automatically.

- **Radar-Control** was used for all the 15 urinals
- **Infrared-detectors** made by Alarmcom, of the type IR150CD with a supply voltage of 12V were mounted to the ceilings of the WC-cubicles.
- **Flow meters** made by Conrad were used to determine the volume of water at the washstands and the flush tanks of the toilets.
- **Pulse dividers** were developed and all the flow meters were connected to the interbus via the pulse divider. One pulse at the outlet corresponded to 0.107 litre.
- **Relays** made by Siemens were used to receive information on the state of lighting in the sanitary room.

2.2 automatic Data processing, data storage and analysis

The INTERBUS transferred the data collected by the sensors to the computer. The respective programming made it possible to save data of all signals per day, including the corresponding information on the date, time and sensor. Alternatively it was also possible to export the data to Excel. But with up to 5000 lines per channel and 73 channels this did not seem to be useful.

Every kind of occurence and change in signal by the sensor were saved in the records. As with a change of one signal all the other signals were stored as well, looking at one sensor often resulted in constant figures. This can be explained with the help of the example given in picture 2.2 dated 20 May 2005.

When having a close look at column E you can see that there was no use until 08:48:52 a.m. At 08:48:54 a.m. the water consumption started and ended at 08:49:00 a.m. This lasted for 6 seconds and the user consumed 0.64 liter of water at the washstand. There was no user from the last mentioned time until 09:21:03 a.m. (For clarity reasons the lines 516 to 625 were skipped in the table). But as there were other sensors active collecting data on water consumption during this period of time, the unchanged signal contents of the flow meter being looked at was recorded at the same time. The next time water was used at 09:21:03 a.m.

	A	B	D	E
1	Name	Datum_Uhrzeit	D_1_WC_1_BM	D_1_WT_1
507	506	20.05.2003 08:48:44	1,00	0,00
508	507	20.05.2003 08:48:46	0,00	0,00
509	508	20.05.2003 08:48:47	1,00	0,00
510	509	20.05.2003 08:48:52	0,00	0,00
511	510	20.05.2003 08:48:54	0,00	0,32
512	511	20.05.2003 08:48:55	0,00	0,53
513	512	20.05.2003 08:49:00	0,00	0,64
514	513	20.05.2003 08:49:10	0,00	0,64
515	514	20.05.2003 08:50:10	0,00	0,64
626	625	20.05.2003 09:20:57	0,00	0,64
627	626	20.05.2003 09:20:59	0,00	0,64
628	627	20.05.2003 09:21:01	0,00	0,64
629	628	20.05.2003 09:21:03	0,00	0,85
630	629	20.05.2003 09:21:04	0,00	0,85
631	630	20.05.2003 09:21:06	0,00	0,85
632	631	20.05.2003 09:21:07	0,00	0,85
633	632	20.05.2003 09:21:10	0,00	0,85

Fig. 2.2 Extract of the data record 2003.05.20.xls.

2.3 User behaviour

The following information resulted from the automatic data analysis:

1. Use of toilet — time and duration of flushing
volume of water used for flushing
state of lighting at the beginning of use
2. Use of urinal — time of flushing
switch state of lighting
3. Use of washstand — time and duration
consumed water volume
state of lighting at the beginning of use

A special interest was taken in the use of the washstand and the time a user spent on washing his hands after using the toilet or the urinal. Furthermore, the total time spent on going to the toilet was calculated.

User behaviour regarding WC-seat

In this examination the attention was directed to the position of the ring and the lid after using the toilet. At the same time it was meant to examine the hypothesis whether women leave the toilet with the lid closed more likely than men.

In the period from 15 May to 30 May 2003 a record was kept of the toilet-seat position during
the daily inspection round.

Hygienic aspects:

- A closed lid can be expected to lead to an accumulation of bacteria because of the ventilation of the toilet.
- An open lid with the seat lowered leads to a better ventilation.
- The best ventilation is achieved when seat and lid are open
- Each body contact involves the danger of passing on bacteria from the user to the toilet seat and vice versa.

3 Result and validation

3.1 User behaviour

The data collected from 31 March until 1 June 2003 were presented visually in diagram 3.1

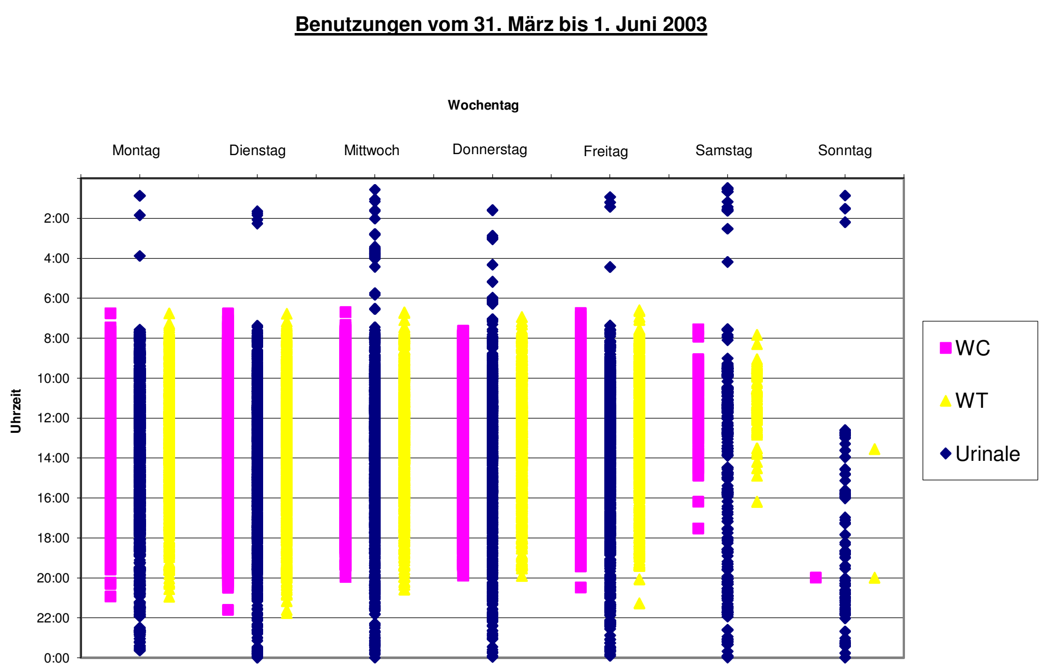

Diagram 3.1 All uses shown time wise, sorted according to weekdays

The diagram clearly shows:

- The main using time was between 07:00 a.m. and 08:00 p.m

- On Saturday the building hosted events between 08:00 a.m. and 03:00 p.m. and the toilets were used accordingly.
- The urinals did not only flush during the day when users were present, but also several times until midnight and a little more rarely between midnight and 07:00 a.m.
- On Sudays the urinals flushed very rarely between midnight and about 02:30 a.m., but regularly between noon and midnight.

In order to gain more precise information the data were weekly analyzed in diagrams. Break times were marked green, maintenance work was marked grey.
Diagram 3.2. shows the data collected from 7 April to 13 April 2003.

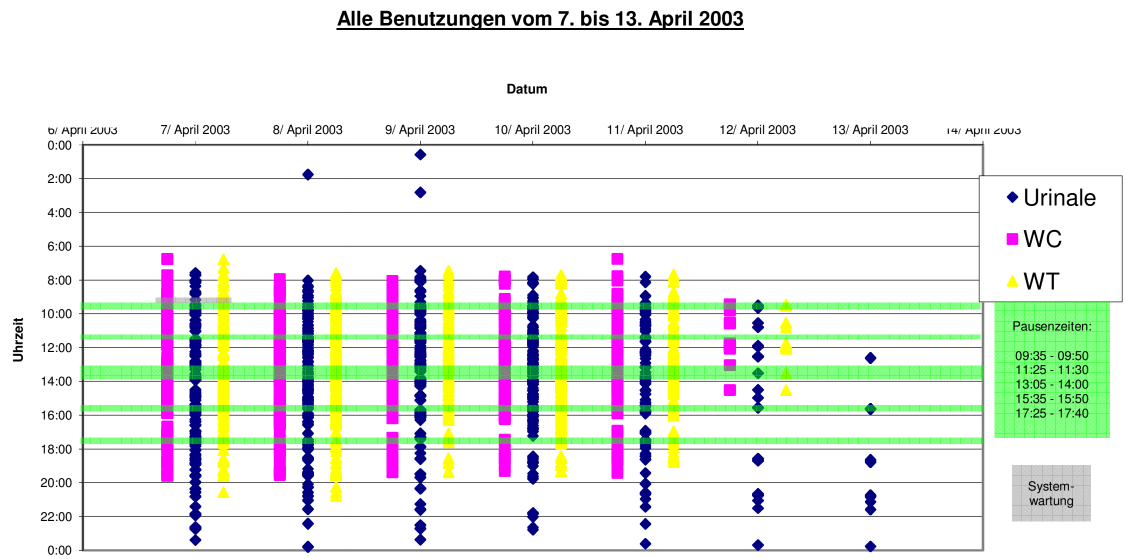

Diagram 3.2 shows all uses of WCs, urinals and washstands from Monday, 7 April to Sunday, 13 April 2003

On Saturday, 12 April 2003, there was an event in the building to be seen from the use of toilets and washstands between 09:00 am and 01:00 p.m. In addition several urinals were used. In most cases the use of the washstand is related timewise to the use of a toilet or a urinal.

The urinal flushings on Saturday after 03:00 p.m. were not activated by people, as the room lighting was switched off at that time. The data records showed the state of lighting, but it is not shown in the diagram. The flushings could be put down to the radar control. Apart from little differences the toilet uses were spread regularly over the time between shortly before 08:00 a.m. and 07:30 p.m, with one striking interruption in the toilet use between 04:10 p.m. and 05:10 p.m. on 9 and 11 April. Compared with the other weeks this interruption occured irregularly. It is clearly to be seen on 12 and 14 May. A possible explanation is the fact that the employees finished their work at the same time. Afterwards participants of various events arrived and used the sanitary facilities in the building until about 07:30 p.m. From 04:00 p.m. until 07:30 p.m. the cleaning personnel were also in building B. Cleaning the sanitary facilities requires flushing the toilets and washstands. But the resulting data could only be related to the cleaning personnel if their work routine was known and did not vary.

A relation between break times and a rise in frequency could not be found as they reflect the data of all floors. A separate look at each of the six floors would allow a further differentiation. On 7 April 2003 the sanitary facilities on the first floor were used more frequently during breaks than during the rest of the time. On the fourth floor the use was less frequent with more regular intervals.

A “normal use” means activating the flushing and using the washstand afterwards. In gents’ toilets there is the additional possibility of using the urinals. We confine ourselves to the data record of 7 April 2003 as given in the following table.

	Ladies	Gents
Number of WC-uses with using a washstand	30	30
Number of WC-uses without using a washstand	12	6
Number of UR-flushings with using a washstand	-	65
Number of UR-flushings without using a washstand	-	194
UR-flushings without room-lighting	-	23
Using a washstand only	6	30
Other use by cleaning personnel	6	16
Other use during inspection tour	3	4

Table 3.1 Results of the data analysis of 7 April 2003

29 percent of all ladies left the sanitary room after using the toilet without washing their hands. 17 percent of the gentlemen did not do so either. But after using the urinals 65 men out of 259 washed their hands. However, a small number of the remaining 194 flushings were partly activated due to malfunctions.

On 7 April 2003, 23 urinals flushed without having been used: the light in the room was not switched on, which implies that there was no user. This malactivations could not be put down to the automatic 24-hour flushing activated by the electronics as , apart from one, each urinal flushed at least once on that day. The automatic flushing would have been necessary only the day after. Strikingly high was the gents’ rate of use of the washstand. If the user is not detected and there is no flushing, this use is missing in the data record.

Table 3.2. shows the average duration of a toilet use followed by the user washing his hands.

For a normal use gents needed almost twice as much time as ladies.

	Ladies [min]	Gents [min]
Duration of WC-use with using a washstand	1:38	2:51
Duration of WC-use with using a washstand (*see text)	1:15	6:18*

Table 3.2 Duration of an average toilet use

In case the ladies did not wash their hands (twelve times on 7 April 2003), the duration of the use shortened to 1.15 minutes. As there were only six users who did not wash their hands, there was only half the number of data recorded in the gents' toilet. An extremely long use of more than nine minutes increased the average to 6.18 minutes. For a more precise analysis further data need to be collected.

The average water consumption for the toilet flushing followed by using the washstand added up to 4.58 litres in the ladies' toilet and 5.9 litres in the gents' toilet. This allows the conclusion that women use the water-saving two-volume flushing more often than men. The difference of 1.3. litres is the result of this different behaviour. A calibration measurement revealed that the recorded water volumes differed from the actual consumed volumes by up to 40 percent. That is because of the pulse dividers and has to be considered when continuing the work with this data recording system.

Urinals

According to the manufacturer the radar-controls are programmed in a way that 24 hours after the last use an automatic flushing is activated, which can be clearly seen from the data and is shown with the example of urinal 3 in the gents' toilet on the fifth floor. The urinal was last flushed at 4:50 p.m. on 30 May 2003. The fact that the washstand was used 5 seconds later is a hint that it was a normal use. The next flushing was activated at 7:50 p.m. – as the light was not switched on, a use could be excluded. The following weekend, from 31 May to 01 June 2003, the urinal flushing was activated at 07:55 p.m. on Saturday and at 08:00 p.m. on Sunday, again without lighting. This regularity confirmed the automatic flushing, however, there was a difference of three hours between the last use and the first automatically activated flushing. This fact indicated that the compulsory flushing was regularly activated at the same time of the day.

Furthermore it was found that the radar-controls of the urinal flushings were partly unreliable. The user detection did not work faultlessly. It happened that a urinal flushing was activated when a person passed by or it was not activated after a use. Checking and changing the sensitivity of the radar-conrol did not lead to any improvement.

User behaviour regarding the WC-seat

Once a day the position of the WC-seats was inspected visually and documented in the afternoon. The recorded data were corrected as not each WC was used every day. For this purpose the data collected by the recording system were considered, the unused toilet bowls were excluded from the analysis. Another influence was due to the cleaning personnel. On 28 May 2003, at 03:01 p.m. the toilet ring was lowered and the lid was open in the ladies' toilet. On 30 May 2003, at 03:06 p.m. both parts of the toilet seat were in an upright position. This change in position, however, was not caused by a user but by the cleaning personnel.

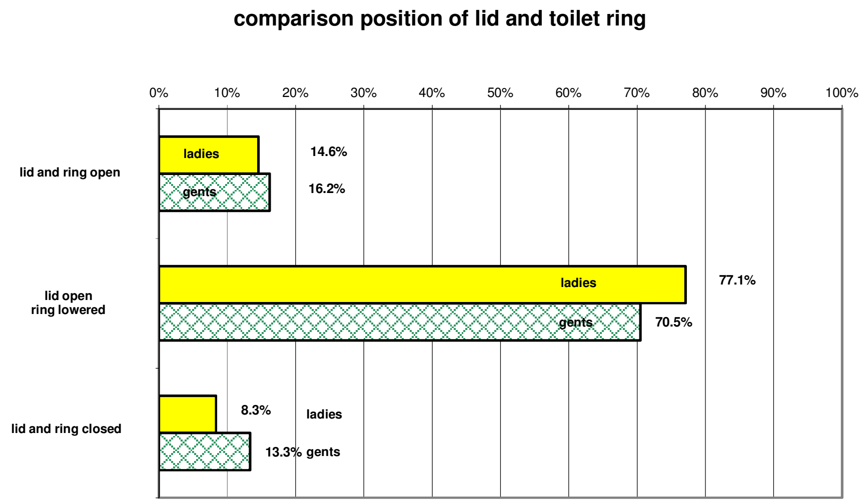

Diagram 3.1 Comparison of the position of the WC-seat after use

In 14.6 percent of all cases the ladies left the toilet bowl with both parts of the seat upright, and so did 16.2. percent of the gents. A possible explanation for this higher percentage could be the use of the toilet bowl as a urinal, another reason might be that it was not closed after having been cleaned with a brush.

More than 70 percent of the users leave the toilet with open lid and lowered ring. It turned out that men closed the toilet lid more often than women. 13.3 percent of all the gents and 8.3 percent of all the ladies observed did so.

These differences are based on hygienic reasons. Public toilet facilities like the ones at Fachhochschule Gelsenkirchen University of Applied Sciences are used by many people. The rate of use as well as the risk of infections caused by bacteria is substantially higher than at home.

That is why the lid and the ring were left in their normal position by 77.1. percent of the ladies. Touching them is not necessary. In 22.9 percent of all cases only part of the toilet seat was touched. The corresponding figure for the gents was 29.5 percent. This user behaviour should be examined more intensely as a visual inspection once a day cannot be regarded as being representative just documenting a momentary situation.

3.2 Waste water hydraulics

Flushings of the water closets and the data collected by the data-recording system were compared and documented. The following contains notes on five key data: date, kind of toilet, time, flush volume in litre, description of flushing

1) 25 MAR 2003, H5WC2, 12:37:07 hrs, 4.7 l
   Feces plunge down the downpipe and hit the horizontal part of the pipe between 12:37:14 hrs and 12:27:20 hrs, the following waste water flushes them away at 12:27:21 hrs

2) 25 MAR 2003, H4WC1, 13:18:13 hrs, 4.6 l
   3 seconds after activating the flushing the feces reach the horizontal part of the pipe
   and are flushed away by the running water at 13:18:23 hrs
3) 25 MAR 2003, H4WC1, 15:27:48 hrs, 4.4 l
   At 15:27:56 a small part of feces comes down almost at the same time as the waste water
4) 16 APR 2003, H1WC2, 11:03:47, 1.6 l
   Because of the little flush volume feces and rests of paper are lying in the pipe, at 11:26:18 hrs another flushing with a volume of 4.6 litres flushes all the rests away into the ground pipe
5) 16 APR 2003, H2WC1, 08:12:21, 4.1 l
   Until 08:15:00 hrs there has not been any flushing, which is a hint that either the toilet bowl or the connecting pipe is clogged

There were different intervals of time recorded between activating the flushing and the arrival of feces and wastewater in the basement. The feces came down before the wastewater because in a downpipe water runs down the pipe wall. This means more resistance to the water than to solid parts the free fall of which is only slowed down by pipe moldings.

Thus flushings of toilet bowls located on higher floors take longer than flushings activated on the first floor. This can be confirmed by several measurings. But the falling height is not the decisive factor regarding the time interval between flushing and arrival in the basement. The flushing of a toilet bowl depends on the volume of the flush water, how much toilet paper was used and on the amount of feces. The bigger the proportion of solids the longer does it take all the wastewater to run through the toilet siphon into the connecting respectively collecting pipe. Another factor is the distance to the downpipe. Already here, an unfavourable ratio of flushwater and solids can decrease the transport speed, which is also influened by piping and gradients.

The following flushings were chosen as examples:

1) 25 MAR 2003, D5WC1, 13:14:14 hrs, 4.7 l
   The feces reached the basement after 5 seconds, the wastewater did so after another 5 seconds
2) 16 APR 2003, D3WC1, 11:39:21, 4.8 l

After 14 seconds the feces reached the basement, the wastewater followed a second later. Despite a smaller difference in height, the flushing of the toilet bowl on the third floor took longer than the one from the fifth floor. By activating several flushings it would be possible to find a trend for each toilet, comparisons could reveal whether the positions of waste water pipes were unfavourable and thus influencing the flow of waste water negatively. The fill factor which should be achieved in a collecting pipe is 0.5. That means, the filling level in operation should be half the inside diameter, that is about 80 mm. Two flushings were recorded, activated at an interval of ca. 15 seconds, but the mentioned degree of filling was not achieved. Residues on the pipe walls (Pic. 3.1) suggested an average fill factor of 0.3.

Pic. 3.1 Horizontal collecting pipe in the basement with marked filling level

Owing to insufficient flushing efficiency and floatability, solids remained in the pipe. There were, however, no cloggings during the period of observation. In all the cases the remaining solids were washed out by follow-up flushings.

4. Conclusions

4.1 User behaviour in sanitary facilities

The analysis of the data record revealed that on weekdays sanitary facilities are mainly used between 07:00 a.m. and 08.00 p.m. On Saturdays the use was documented between 08:00 a.m. and 03:00 p.m. 24 hours after the last use, the urinal flush system was supposed to activate an automatic flushing. But diagrams showed that some urinals were already flushed three hours after the last use. The automatic follow-up flushings were activitated at regular intervals of 24 hours.

It was further found that the sesitivity of the radar controls was so high, that people passing by activated flushings. Adjustments of the controls were unsuccessful. Monday, 07 April 2003, was explicitly chosen for a data analysis. On this day, the ladies' toilets were used 42 times and the gents' toilets 36 times. 29 percent of the ladies and 16 percent of the gents did not wash their hands afterwards. There were 194 urinal flushings in the gents' toilet after which no washstand was used. Additionally 30 washstand-uses were documented. The single uses could not be put into relation. It is ,therefore, recommended to install further sensors, for instance, a photoelectric barrier in front of the urinal, to achieve more precise results. Moreover, the sensitivity of the radar-controls should be checked. A cooperation with the manufacturer would be helpful.

In order to filter out the flushings which were activated by the cleaning personnel, a questioning would be necessary. Precise information concerning start and finish of their work as well as the sequence of their cleaning round would be important.

On average it took ladies 1:38 minutes to use the toilet and wash their hands, the time it took the gents was with 2:51 minutes ¾ in excess of the ladies' time. It was possible to measure the time it took to use the toilet without using the washstand afterwards, but could only be verified for ladies (1:15 minutes). There were not enough data from the gents' toilets, apart from that they were unrealistically high. On average ladies consumed a total of 4.58 litres of water for a toilet flushing and using the washstand, the respective consumption by gents was 5.9. litres. This difference shows that in contrast to gents ladies use the water-saving button of the flush tank.

4.2 User behaviour regarding WC-seat

Regarding the WC-seat the user behaviour was definite: After using the toilet, about ¾ of all female users and over ⅔ of all male users left the WC-lid in an upright and the ring in a lowered position. Ladies changed the position of the WC-seat after ¼ of the uses, gents, however, did so after almost ⅓.

4.3 Wastewater hydraulics

The video-recordings of the wastewater pipe in the basement showed that solids reach the horizontal pipe before the waste water. The difference in time was one up to six seconds. This difference in time between activating the flushing and reaching the basement got bigger the higher the respective floor was. But it was found that this difference depends on many factors: flush volume, amount of solids, length of connecting pipe, piping and gradient are decisive regarding the transport speed to the downpipe, which was verified with an example.

The filling factor of the horizontal collecting pipe in the basement was examined. As a result it was found that the piping was over-dimensioned. Even with a higher frequency of use the fill factor reaches a maximum of 0.3. There was no risk of clogging due to solids remaining in the pipe, the follow-up flushings made all the solids float and transported them on. There were no cloggings to be found during the whole observation period.

5. References

Dissertation submitted by Martin Lindemann for his diploma in 2003

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Design of toilet facilities for public buildings

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Abstract

The regulations for public buildings, at least in Germany, do not contain sufficient information concerning design and equipment of toilet facilities, which have to vary in number according to the type of building and the nature of the events held there. In order to determine the necessary number of toilet facilities in different kinds of buildings, investigations and measurements were made in stadiums and other places where numerous people can gather. Additionally, the water consumption in an arena-type stadium was measured and the user behaviour examined. The results and findings served to draw up new guidelines and design new stadiums for the 2006 FIFA World Cup Germany. Part of those results and recommendations of the guideline will be presented.

Keywords

Number of toilet fixtures, user behaviour, water consumption, public buildings, stadiums

1. Introduction

Our project was started in 1997 and is still being continued. Our goal was and is to determine figures regarding the number of sanitary fixtures needed at assembly places and in particular at stadiums. On the one hand there should not be too many sanitary facilities being unused, but on the other hand waiting times in front of toilets should not be long during events.

In 1998 Schwacke [1] started a series of examinations at 8 open-air stadiums of the German federal state of North-Rhine/Westphalia and 2 stadiums in the Netherlands: Amsterdam ArenA and Gelredome Arnhem. These were regarded to be the first multi-functional stadiums of the Arena-type in Europe. Demiriz turned all these experiences combined with the results of his examinations at universities [2,3] into a new guideline, VDI 6000-3 [4]. In 2001 the most modern multi-functional football/soccer arena of that time was opened in Gelsenkirchen. Terlau carried out the first statistical examination of all the sanitary facilities of this stadium during various events [5]. For the purpose of keeping a careful record students were placed in front of each toilet area. In addition to the number of users they recorded waiting times as well as the times the users stayed in the toilet rooms. In the same year Kircheim designed and installed a data-recording system for a ladies' and gents' toilet [6]. Recordings and the first analyses carried out by Brauckhoff brought new data which could be utilized [7]. During all events flow measurements were carried out at the main supply pipe.

2 Experimental

For data recording the InterBUS Inline System was used. For the implementation the ladies' toilet (room No 3031) and the gents' toilet (room No 3029) were chosen as they are located in the "North Bend" (Figure 1), the stand of the Schalke-fans, which, as experience has shown, are the most frequented ones. Four cubicles and two washstands in the ladies' toilet and two cubicles, two washstands and ten urinals in the gents' toilet were fitted with measuring equipment.

The sensor technology comprised the following components:

- **Ladies' toilet**
  - 6 pulse flow meters (2 washstands, 4 flush tanks)
  - 8 Reed-contacts (4 cubicle doors, 4 flush activations)
  - 4 infra-red detectors (inner room of 4 cubicles)
  - 1 pressure detector (water supply pipe)
- **Gents' toilet**
  - 4 pulse flow meters (2 washstands, 2 flush tanks)
  - 4 Reed-contacts (2 cubicle doors, 2 flush activations)
  - 2 infra-red detectors (inner room of 2 cubicles)
  - 1 pressure detector (water supply pipe)
  - 10 urinal controls (use and flushing)

Figure 1 – Location of the reference toilets

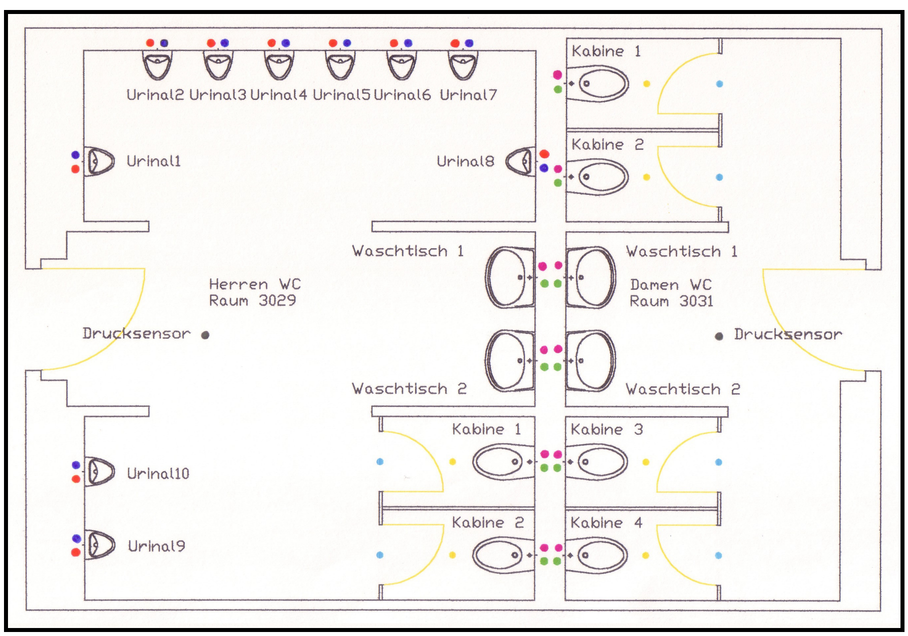

Figure 2 – Location and art of sensors

- Urinal Flush
- Urinal use
- Flow meter
- Push detector
- Door sensor
- Movement detector

An ultrasound flow meter of the type Panametrics was used for the flow measurements at the main supply pipe.

The following data and rates could be analyzed:

- Water consumption at the washstands
- Number of users and duration of use at the washstands tischen
- Number of users and number of flushings at the urinals
- Frequency of cubicle use without locking the door
- Frequency of cubicle use with locking the door
- Activation of flushing
- Intervals in use, frequency of use and simultaneity at all sanitary fixtures
- Total water consumption and peak flow

3 Result

Schwacke [1] calculated a simple rule for the number of sanitary fixtures in football (soccer) stadiums (Table 1). His methods comprised surveys, observations and counts in ten stadiums which in most cases were merely used for football/soccer.

	Urinal	WC	Wash basin
Men	10	3	3
Women		6	3

Table 1 – Number of sanitary fixtures for each 1000 spectators In football stadions according Schwacke[1]

Demiriz created a general table for public houses (=pubs) buildings and areas as a part of the guideline VDI 6000-3 [4] and integrated Schwacke's numbers in a slightly changed manner in this table (Table 2). Hereby more equality between men and women and the fact that the next generation of stadiums would be multi-functional was taken into consideration. In the year 2000 it was somewhat revolutionary to equalize the number of urinals for men to the number of WCs for women.

For stadiums the numbers given in the line for 1000 people in the part "medium level of simultaneous use" should be projected to the maximum number of spectators. This was the recommendation in the first announcement of the guideline VDI 6000-3. But DFB (German Football Association) contradicted to this method with the argument that it would make too many sanitary fixtures necessary in stadiums. That is why in the final version of the guideline [4] the numbers given in the line for 2000 people in the part "medium level of simultaneous use" were recommended to be taken into consideration. This was the state of the guideline at the end of 2001 for planning the football arenas for the 2006 FIFA World Cup in Germany.

Ten years later, the latest issue of the guideline shows a total equality of the sexes. Both have the same numbers of washbasins and the total number of the urinals and men's toilets is equal to the number of ladies' toilets (Table 2).

Number of People	Women		Men			Barrier-free WC cubicle
	WC	WB	UR	WC	WB	
low level of simultaneous use						
25	1	1	1	1	1	1W 1M
50	2	2	2	1	1	
100	2	2	2	1	2	
300	4	2	4	2	2	
500	4	3	4	2	3	
700	5	4	5	3	4	
1000	6	4	6	4	5	
1500	8	6	8	5	6	2W 2M
2000	9	7	9	6	8	
3000	12	10	12	8	10	
4000	14	12	14	10	12	3W 3M
5000	16	14	16	12	14	
6000	18	16	18	14	16	
Number of People	**Women**		**Men**			**Barrier-free WC cubicle**
	WC	**WB**	**UR**	**WC**	**WB**	
medium level of simultaneous use						
25	1	1	1	1	1	1W 2M
50	2	2	2	1	1	
100	3	3	3	1	2	
300	5	3	5	2	3	
500	6	4	6	3	4	
700	7	5	7	4	5	
1000	9	6	9	5	7	
1500	11	8	11	7	9	2W 2M
2000	13	10	13	9	11	
3000	17	14	17	12	14	
4000	21	18	21	15	18	3W 3M
5000	24	21	24	18	21	
6000	26	23	26	20	23	
Number of People	**Women**		**Men**			**Barrier-free WC cubicle**
	WC	**WB**	**UR**	**WC**	**WB**	
high level of simultaneous use						
25	2	2	2	2	2	1W 1M
50	3	3	3	2	2	
100	5	4	5	2	3	
300	8	5	8	3	5	
500	9	6	9	5	6	
700	11	8	11	6	8	
1000	14	9	14	8	11	
1500	17	12	17	11	14	2W 2M
2000	20	15	20	14	17	
3000	26	21	26	18	21	
4000	32	27	32	23	27	3W 3M
5000	36	32	36	27	32	
6000	39	35	39	30	35	

Table 2 – Figures of requirements for public buildings 2001[4]

Number of People	Women		Man			Barrier-free WC cubicle
	WC	WB	UR	WC	WB	
low level of simultaneous use						
25	2	1	1	1	1	1
50	2	1	1	1	1	
100	3	2	2	2	2	
300	4	2	2	2	2	
500	6	3	4	2	3	2
700	7	3	4	3	3	
1000	9	4	6	3	4	
1500	11	5	7	4	5	3
2000	14	7	9	5	7	
3000	16	8	10	6	8	
4000	20	10	13	7	10	4
5000	25	12	16	9	12	
6000	30	15	20	10	15	

Number of People	Women		Man			Barrier-free WC cubicle
	WC	WB	UR	WC	WB	
medium level of simultaneous use						
25	2	1	1	1	1	1
50	3	2	2	1	2	
100	4	2	2	2	2	
300	5	3	3	2	2	
500	8	4	5	3	4	2
700	10	5	6	4	5	
1000	12	6	8	4	6	
1500	15	7	10	5	7	4
2000	18	9	12	6	9	
3000	22	11	14	8	11	
4000	27	13	18	9	13	6
5000	35	17	23	12	17	
6000	40	20	26	14	20	

Number of People	Women		Man			Barrier-free WC cubicle
	WC	WB	UR	WC	WB	
high level of simultaneous use						
25	3	1	1	2	1	1
50	4	2	2	2	2	
100	6	3	4	2	3	
300	8	4	5	3	4	
500	11	5	7	4	5	2
700	14	7	9	5	7	
1000	18	9	12	6	9	
1500	22	11	15	7	11	4
2000	27	13	18	9	13	
3000	32	16	21	11	16	
4000	40	20	26	14	20	6
5000	50	25	33	17	25	
6000	60	30	40	20	30	

Table 3 – Figures of requirements for public buildings 2011[8]

The equal status for women was an explicit demand of a number of female architects who lent weight to their wish by means of a collection of signatures. The new table is based on the assumption that half the number of people visiting events are women and half the number are men. It may be true that women shy away from using public toilets, which would decrease the need for ladies' toilets, but the time it takes them to use the cubicles for urinating is three to four times longer than it takes the men. [7]. On average women also stay longer at the washstands than men. They use the washstand to put on make-up. Therefore, it is advisable to fit out the room with additional places for make-up equipped with mirrors, light and a place to put their things.

According to the new guideline [8] the number of sanitary fixtures in stadiums should be calculated according to the high level of simultaneous use shown in table 3.

The total water flow measurement does not only show that the maximum flow was at 32 litre/sec. It also shows the tension of the match:

The match started at 03:30 p.m. There were 68,000 visitors in the stadium. In the last 15 minutes before the start of the match all of them took their seats. The consumption went down to a minimum and varied on a low level. 15 minutes after kickoff, Schalke was leading 2:0, the fans began to celebrate, the situation was less tense, which gave them the chance and time to go the toilet. At about 04:20 p.m. Agali was shown the red card, the match got exciting. This led to a clearly visible low. At half-time the flow reached its maximum. In the second half the score rose to 2:2, the match remained exciting, theconsumption varied on a low level. There was a fight between the wish not to miss anything and the full bladder. Schalke was not granted a goal because of offside. The match remained exciting up to the end. After the final whistle a lot of spectators had togo to the toilet. The water consumption went up to 30 litres/sec.

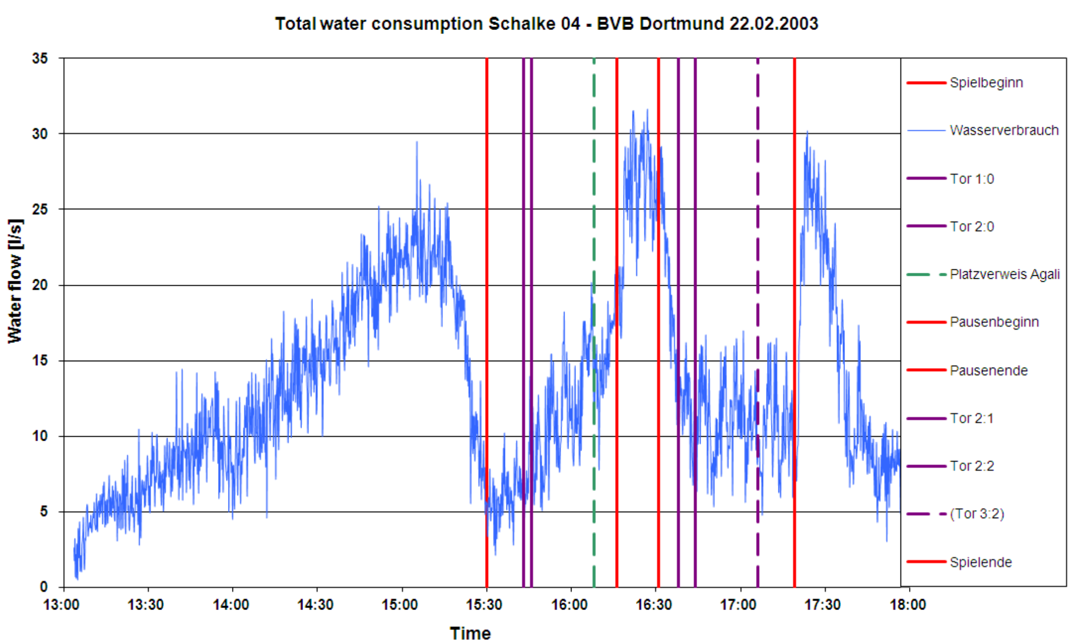

Figure 4 – Water consumption during a football match

4 Conclusion

By means of observations and measurements in football/soccer stadiums and assembly places tables were drawn up to help calculate the appropriate number of sanitary facilities and fixtures. Attention was also directed to the equality of the sexes.

Shortly before the match, at half-time and shortly after the match the water consumption reached a maximum.

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ASSE Professional Qualification Standard Series for Protecting the Health and Safety of Piping and Mechanical Industry Craftspeople

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Abstract

The American Society of Sanitary Engineering (ASSE) is a membership organization dedicated to the preservation of public health and safety through the use of proper plumbing, piping, and mechanical practices. This is accomplished in the spirit of its century-old motto "Prevention Rather than Cure." While there is an abundance of professional organizations representing various factions of the piping and mechanical industry, ASSE is one of very few addressing the critical nature of bloodborne pathogens, and other infectious diseases, and the roles they play throughout these industries. Although pathological diseases are as old as mankind the evolving nature of bloodborne pathogens, the impacts of the spread of disease, and how these affect plumbing and other pipe trades craftspeople have been basically ignored. In an effort to address this potentially hazardous situation ASSE is currently developing the voluntary consensus Professional Qualification Standard Series 12000. This unique standard series will address this critical issue and train pipe trades craftspeople - especially plumbers – on how to safely work within the environment of potentially deadly pathogens that could be present within their work sites. This is especially true regarding building sanitary drainage piping systems that all plumbers must eventually install, maintain, or replace.

Also included in this paper is a practical example of how plumbers successfully replaced – while still in service - a corroded 65 year old 12 inch (34.48 cm) inside diameter horizontal galvanized steel combination (sanitary and rain water) building drain, with multiple vertical stack connections, in a major USA hospital using ASSE Standard Series 12000 guidelines.

Key Words

Bloodborne pathogens, bacteria, disease, virus, sanitary building drain, professional qualification standards, voluntary consensus standards

1 Introduction

The bacteria and viruses that cause disease are called pathogens. Bloodborne pathogens are organisms that are present in the blood and certain other body fluids of infected persons. They can be transmitted when pathogen laden blood, or other potentially infectious fluids (OPIM), comes into contact with the blood of a healthy person. Examples of bloodborne pathogens are the human immunodeficiency virus (HIV), hepatitis B virus (HBV), and hepatitis C virus (HCV).

The typical occupational routes of transmission of bloodborne pathogens are by:

1) needlestick or cut from a contaminated sharp object,
2) splash to the eyes and mucous membranes of the nose or mouth,
3) contact with intact or non-intact skin.

Other pathogens that are not bloodborne can still be inhaled.

2 Supporting Standards

2.1 OSHA 29CFR 1910.1030

In the United States, in 1991, the Occupational Safety and Health Administration (OSHA) published the Bloodborne Pathogens Standard (BBPS), 29CFR 1910.1030. This was in response to rising concern over transmission of HBV and HIV to healthcare and other workers. The BBPS addresses blood and OPIM. OPIM includes the following body fluids: semen, vaginal secretions, cerebrospinal fluid, pleural fluid, pericardial fluid, peritoneal fluid, amniotic fluid, saliva in dental procedures, and any body fluid that is visibly contaminated with blood. The BBPS covers all employees who could be “reasonably anticipated” to contact blood and OPIM as a result of performing their job duties. OSHA places primary responsibility regarding compliance with this standard on the employer.

The BBPS mandates that the employer must:

1. Make a copy of the BBPA available to employees upon request.
2. Develop a written Exposure Control Plan detailing the specific measures taken to protect employees.
3. Identify the jobs and job classifications in which employees face occupational exposure to blood or other potentially infectious material.
4. Identify the specific tasks and procedures that may involve exposure and establish safe work procedures for performing the tasks.
5. Use engineering and work practice controls to minimize possible infection.
6. Provide personal protective equipment required to ensure that contact with blood or other potentially infectious material is avoided.
7. Provide equipment to ensure that contaminated or infectious material can be handled and disposed of safely. This also includes disinfectants to decontaminate contaminated surfaces.

8. Provide recurrent annual instruction that makes certain that employees have been informed about bloodborne disease and trained to perform their jobs safely.
9. Continually emphasize the use of the concept of "Universal Precautions (UP)." UP means each employee must always assume that blood and other potentially infectious material is infectious. An attitude of continual self protection must be maintained.
10. Provide hepatitis B vaccine at no cost to employees who have been designated to be at risk
11. Provide post-exposure evaluation and follow-up to exposed employees

Regarding personnel who work with building drainage piping and the required compliance with the OSHA BBPS Standard, it is the employer's responsibility to determine which job classifications of specific tasks and procedures may place the employee at risk. If there is doubt, OSHA will make a determination, based on a case by case basis, that sufficient evidence of reasonable anticipated exposure exists. The employer will be held responsible for providing all protections required by the standard to employees who are judged to have potential occupational exposure.

Piping industry personnel to certainly be considered at risk of occupational exposure are:
1. Maintenance personnel involved in sanitary sewer inspection
2. Maintenance personnel who perform maintenance work ("snaking" sanitary sewer drain piping systems to clear blockages)
3. Construction or maintenance personnel who repair, replace, or "breach" live sanitary sewer piping systems to connect new branches.
4. Personnel who clean-up sanitary sewer spills.

2.2 ASSE Professional Qualification Standards

Since the early 1960's ASSE's major expertise in its preservation of public health and safety pursuits has been in its development of product performance standards. ASSE's product performance standards developing activity was born out of its disease research. According to ASSE's "Procedures for the Development of Standards", these standards establish minimum performance and testing requirements for plumbing products that protect the health and safety of the public. Some of the products include various types of backflow preventers, anti-scald shower valves, etc. There are now 50 ASSE product performance standards. Virtually every plumbing code throughout the USA requires that only products that meet the performance requirements of the majority of the 50 ASSE standards are installed, where applicable, in each code's jurisdiction.

During 1987 the ASSE Board of Directors decided that the plumbing industry was in need of not only "product performance standards" for products that protect the health and safety of the public, but also "people performance standards" were needed for people who also protect the health and safety of the public. During its April, 1987 meeting the ASSE Board of Directors recognized this plumbing industry need and voted to develop the ASSE/ANSI Professional Qualification (PQ) Standard Series 5000 for individuals involved with backflow prevention (the protection of potable water piping distribution systems from contamination through hazardous cross connections). Like ASSE product performance standards it was decided that this flagship ASSE PQ standard would establish minimum industry requirements for backflow prevention assemblies testers, repairers, and cross connection control surveyors. This voluntary consensus PQ standard series was the first in the plumbing and water supply fields to establish minimum requirements for qualified professionals to perform at their expected skill levels. The standard was issued by the ASSE Board of Directors in 1990. It was approved by the American National Standards Institute (ANSI) as an American National Standard in November 1991.

2.3 The American National Standards Institute (ANSI)

All ASSE standards – both product performance and professional qualification – are promulgated and accredited in accordance with procedures developed by ANSI. ANSI accreditation insures that the standard was developed using the consensus process. Consensus, which is defined as general agreement, but not necessarily unanimity, includes an ANSI approved process for attempting to resolve objections by interested parties. The accreditation assures that all requirements for a voluntary consensus standard are met.
The requirements are:

1. Openness – Openness means that participation shall be voluntary and open to all persons who are directly and materially affected by the standard and that timely notice of intent to act on a standard, or proposed standard, has been given. There can be no financial or organizational membership requirements that determine potential developing committee members' qualifications to serve.
2. Balance – Balance means that the development process shall consist of a committee that has a balance of interests and expertise. The development process shall not be dominated by any single interest category, individual, or organization.
3. Consensus – Consensus means that all concerned parties must reach an agreement that the standard is the best technical document based on available information.
4. Due Process – Due process means that anyone interested or affected by the standard has the right to participate by:
    a. Expressing a position with technical basis
    b. Having their position considered
    c. Appealing if adversely affected.

All ASSE ANSI accredited standards are revisited, and updated as needed, every five years

2.4 The International Association of Plumbing and Mechanical Officials (IAPMO)

IAPMO is a membership organization, based in the USA, that has been protecting the public's health and safety for more than eighty-five years by working in concert with government and industry to implement comprehensive plumbing and mechanical systems around the world.

IAPMO utilizes the open consensus process in the continual improvement of its flagship *Uniform Plumbing Code* and *Uniform Mechanical Code*. ASSE and IAPMO recently joined into an agreement to jointly own ASSE developed PQ standards.

3 ASSE Professional Qualification Standard Series 12000

Recently ASSE recognized the need to develop a consensus professional qualification standard to educate piping industry craftspeople – especially plumbers – on how to safely work within the environment of potentially deadly pathogens – both bloodborne and others - within their work sites. As a result the ASSE Board of Directors approved the development of ASSE Standard Series 12000 – "Professional Qualifications Standard for the Health and Safety of Construction and Maintenance Industry Personnel." This standard series addresses the need for all construction and maintenance – especially pipe trades – personnel and employers to become proficient in identifying and managing potential situations where they may be exposed to bloodborne or other pathogens. It is based on the requirements of the OSHA BBPS standard. It is being promulgated and will be accredited in accordance with the requirements of ANSI.

Currently there are five standards being developed in the Standard Series 12000

#12005 – Health and Safety of Construction and Maintenance Personnel (General knowledge for anyone with an interest in identifying and managing potential bloodborne pathogens and infectious disease exposure in the workplace)
#12010 – Biological Pathogens Standard for Construction and Maintenance Personnel
#12020 – Biological Pathogens Standard for Construction and Maintenance Employers
#12030 – Legionella Standard for Construction and Maintenance Personnel
#12040 – Infection Control Standard for Construction and Maintenance Personnel

Standards Series 12000, as all ASSE product performance and professional qualification standards, will be published using ASSE's standard format:

A. Each ASSE standard must have a standardized cover.
B. Each ASSE standard must have a Forward that includes:
   1. A brief history of the need for and the development of the standard
   2. A statement that the Standard does not imply ASSE's endorsement of a product which conforms to its requirements
   3. A statement saying that compliance with the Standard does not imply acceptance by any code body or Authority Having Jurisdiction (AHJ)
   4. Other required ANSI, or other related association, boiler plate language
   5. A statement indicating the Forward is not part of the standard
   6. The standard's original issuance date and all ensuing revision dates
C. Each standard in the standard series contains:

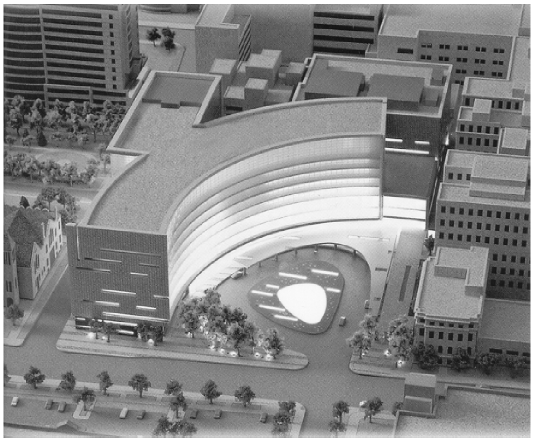
1. Scope – a brief explanation of the information encompassed by the standard and discipline the standard pertains to
2. Purpose
3. Limitations – a statement emphasizing that compliance with one particular Series 12000 standard does not imply compliance with any other Series 12000 standard
4. Reference and Industry Standards – other standards referenced
5. General Knowledge
6. Vaccination Knowledge
7. Exposure Control Plan
8. Precautionary Measures
9. Documenting and Recording
10. Terminology
11. Certification and Recertification Requirements

After the completion of this training, and successful completion of a third-party proctored written exam, each craftsperson will receive a certification confirming that the craftsperson has met all requirements of each particular standard in the series.

4 Practical Example of the use of Standard Series 12000

Cleveland Clinic, founded in 1926, is an internationally renowned medical center in Cleveland, Ohio USA. Its central campus consists of a multi building 1350 bed multi discipline medical facility whose water distribution and sanitary and storm water drainage systems were installed from 1926 to the present. Central campus's Heart and Vascular Institute was recently rated #1 throughout the entire USA – for the 17th consecutive year – for its innovation and positive patient outcomes. The Cleveland Clinic Health System consists of multiple facilities throughout the USA and around the globe.

Recently at Cleveland Clinic central campus licensed journeyperson plumbers successfully replaced – while still in service - a corroded 65 year old 12 inch (34.48 cm) inside diameter horizontal threaded galvanized steel combination (sanitary and rain water) building drain. Connected into it are: one 4 inch (10.16 cm) sanitary sump pump connection, multiple 4 inch (10.16 cm) vertical stack connections, one 6 inch (15.24 cm) rainwater drain connection, and one 10 inch (25.4cm) backwater valve. The entire horizontal piping system replaced - 12 inch (15.24 cm) down to 4 inch (10.16 cm) - is approximately 100 feet (30.48 m) long. (See photos - below)



Arnold and Sydell Miller Heart and Vascular Institute at Cleveland Clinic's central campus

Corroded Sanitary Building Drain to be replaced

During this challenging sanitary building drain replacement the plumbers referenced and made use of ASSE PQ Standard Series 12000 draft guidelines. Because of extreme patient use the building drain could not be shut down for an extended period. A method had to be created to replace the entire building drain, and re-connect the existing branches, while the branches were still in service.

The challenges were many: How can the piping be replaced while still in use? How can the safety of the plumbers, and everyone else in the building, be protected from the health hazards of potential raw sewage and air contaminated with pathogens? How can the patient and employee egress hallway, that one-half of the building drain is located in, be immediately "sanitized" clean after its reopening?

It was decided that two entire weekends would be required. Because the stacks and sump pump had to remain in service, decisions had to be made regarding how to provide for a temporary "live" building drain. It was determined that two temporary connections to provide for this could be improvised. To make the first temporary connection available an old floor janitor sink, that was due for replacement, was removed. The floor was chopped out and a new underground branch "wye" fitting was installed and extended above the floor as temporary connection #1. The underground janitor sink trap was replaced and a new sink installed. Upon completion of the job this temporary connection was cut off and converted into a new floor cleanout. Temporary connection #2 was the 4 inch (10.16 cm) cleanout in the 12 inch (34.48 cm) "wye" at the basement wall where the combination building drain exits the building. (See photos below)

Temporary Connection #1

Temporary Connection #2

Safety precautions that were used during the entire job were numerous. Immediately at the beginning of the first weekend fire rated plastic sheeting was placed on all walls. Temporary non-porous floor material was installed and the area was air-sealed. HEPA air filter units, that remove both potentially hazardous vapors and pathogens from the area and provide fresh air for the plumbers, were installed. The first task was to install temporary connection #1 and the temporary drain pipe and fittings. (See photo – below left) When this was completed, the plumbers, wearing protective suits, gloves, and eye equipment (according to requirements of draft Standard Series 12010 and Annex A & C) carefully disconnected the vertical stacks and connected them with temporary tubing to the temporary drain. Before each stack was disconnected and re-routed other plumbers went up to the patient floors and made sure that no fixtures on the stacks being cut off and temporarily connected were used. (See photo – below right)

Temporary drain and HEPA Filters

Fire rated plastic sheeting is installed and protective suits and equipment worn to keep work area and craftsmen free from contaminants

After the stacks were tied into the temporary drain the plumbers cut out the very corroded and heavy galvanized horizontal pipe and fittings. (See photos below)

Temporary drain with flexible connections   Two of many replaced corroded fittings

This process, using temporary piping and tubing, provided adequate drainage for the entire building drain replacement time period. The removed corroded pipe and fittings were replaced with lighter cast iron band-coupling connected pipe and fittings.

When the building drain section was replaced the temporary tubing was disconnected and the vertical stacks were permanently reconnected into the new building drain section. All temporary piping in the egress hallway was removed, all wall plastic and temporary flooring was removed, and Building Services sanitized the hallway. The same process was used during the second successful weekend. (See photos below)

New band-connected pipe and fittings

New pipe and 10 inch (25.4 cm) backwater check (above duct)

During this entire process the referencing and use of the applicable requirements and recommendations of ASSE PQ Standard Series 12000 helped tremendously! The craftsmanship, professionalism, and teamwork displayed by the plumbers, along with Building Services, were astounding!

Because of these extremely skilled and dedicated plumbers a very large and corroded combination sanitary building drain was replaced, with virtually no disruption of service, to the patients of a major USA hospital. Also, because of their efforts they, along with many Cleveland Clinic patients and other employees, were sheltered from potential physical harm and pathogenic disease! This major effort has become another, of many, testimonials to the time-honored USA slogan – "**The Plumber Protects the Health of the Nation.**"

5 CONCLUSION

Throughout its one-hundred year history the goal of all American Society of Sanitary Engineering members has been the preservation of public health and safety through the use of proper plumbing, piping, and mechanical practices. ASSE's statement of direction, that established this goal, was created when in 1926 its founder – Henry B. Davis, Chief Plumbing Inspector of the District of Columbia (Washington, DC) – stated that his hope was that the organization would "bring about a more uniform plumbing practice than exists at present."

ASSE's most proficient method of achieving this esteemed goal is in the development of both product performance, and now also professional qualification, voluntary consensus standards. These ASSE standards provide uniform minimum requirements, developed by a consensus of the industry, that all jurisdictions can reference and codify when choosing the most optimal products and methods to protect the health and safety of their constituents regarding proper plumbing practices. Standard Series 12000, when completed, will become yet another valuable ASSE/IAPMO/ANSI PQ standard series that provides guidance, minimum requirements, and certifications that jurisdictions can use to protect the health and safety of construction and maintenance craftspeople, and building occupants, from the hazards of pathogens that might be present in building drainage piping systems – especially healthcare facilities. The practical example, explained above, of the replacement of the very large corroded horizontal hospital combination building drain, using Standard Series 12000 Draft guidelines and requirements, is the first documented use of Standard Series 12000 to achieve this goal

6 – References

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(3) American National Standards Institute
(4) ASSE Procedures for the Development of Standards for the Plumbing Industry
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Acknowledgements

The author acknowledges the assistance of the following organizations and person in helping to make this paper possible. First - the American Society of Sanitary Engineering for creating and initiating its "Procedures for the Development of Standards, allowing my extensive 25 year participation in its many organizational activities, and providing the funding for this paper and my travel. Second - Cleveland Clinic, who throughout its history - and my 35 years of employment – always has and will champion a culture of continual innovation and improvement that allows and encourages every one of nearly 40,000 employees – no matter what their discipline – to perform as far above the level of their job descriptions as they choose to assist Cleveland Clinic in making its many major contributions in creating the leading edge of the global healthcare industry. Third - Daniel Patrick Kelly, current Chief Plumbing Supervisor of Cleveland Clinic's central campus, for creating and leading the implementation of the ingenious method of proficiently and safely replacing the very large, possibly pathogen laden, building drain –while still in service - referred to in this paper.

7 Presentation of Author

Edward J. Lyczko is newly retired as a master plumber who was employed in Facilities Engineering of the 1,350 bed internationally renowned Cleveland Clinic's central campus, Cleveland, Ohio USA for 35 years (18 years as Chief Plumbing Supervisor).
Lyczko is a Past International President of ASSE. He is a member of the ASSE Professional Qualifications Standards Committee and Chair of the ASSE Hospital Systems and Medical Gas Advisory Committees. He is immediate Past Chair of the ASSE Product Standards Committee. He is a voting member of the USA's National Fire Protection Association's NFPA 99 – 2012 HEA-PIP anesthesia/medical piped gas distribution systems installation code committee and is Chair of ASSE/IAPMO/ANSI PQ Standard Series 6000 for Anesthesia/Medical Gas Piped Distribution Systems Personnel.

Visualization Experiments and CFD Analysis of Confluence Flow Rate in T-shaped Piping

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Abstract

Distribution of appropriate flow rates in header piping systems, which are used frequently for water supply and drainage piping and air conditioning piping, allows for smaller diameter header piping, thereby contributing to machinery space reduction, improved workability, and construction cost savings. Moreover, energy savings can be achieved by reduction of pump power used for transporting fluids. In this study, using an experimental device having two branches, we measured the flow rate and grasped flow characteristics at piping branch parts through visualization experiments using particle image velocimetry (PIV). Using a numerical calculation model of the experimental device, we analyzed flow patterns at branches and joining parts of piping having complicated configurations using computation fluid dynamics (CFD). For grid partitioning of CFD, a hexa-mesh type unstructured grid was regarded as suitable for analysis of bending parts of the piping. We compared the results of analysis with experimentally obtained values and verified them to ascertain the recurrence of flow characteristics in the piping using CFD analysis and to grasp the influences of differences in the computational grid number, grid arrangement, and grid profile upon analysis results. The flow rate and grasped flow characteristics at piping branch parts obtained by CFD analysis were confirmed as generally agreeing with the actual measurement results.

Keywords
T-shaped branch, visualization experiments, CFD , hexa-mesh, turbulence model

1 Introduction

Using an experimental device with two T-shaped branches, we conducted flow rate measurements and visualization experiments in this study to attain the following objectives. (1) Grasp of flow characteristics at T-shaped branches by visualization. (2) Collection of comparison data for flow rate and speed distribution using CFD analysis. Furthermore, CFD analysis conducted by applying an unstructured grid by hexa-mesh was made using a computational model under the same conditions as those of the experimental device for comparison and verification with experimental values for the following items: Furthermore, CFD analysis conducted by applying an unstructured grid by hexa-mesh was made using a computational model under the same conditions as those of the experimental device for comparison and verification with experimental values for the following items: (1) Reproducibility of flows in the piping by CFD analysis. (2) Grasping of influences of differences of the number of computational grids, grid configuration and grid shape on CFD analysis results. (3) Grasping of influences of differences of turbulence model on CFD analysis results.

2. Flow rate measurements and visualization experiments

2.1 Outline of experimental device

Figure 1 presents the external appearance of the experimental device for flow visualization and flow rate measurement. The experimental device consists of a water tank (4 m^3 capacity), pump, main pipe (100 mm diameter), two branch pipes (50 mm diameter), two T-shaped branches, by-pass piping, and a pulsation prevention device for prevention of wave generation. Room temperature water was forcibly circulated by the pump. Figure 2 shows the flow rate meter and the location of visualization. Flow rate measurements were taken at four locations: the main pipe, two branch pipes and the by-pass. Visualization was performed at the T-shaped branch of the right branch pipe. A circular pipe made of transparent acrylic resin was used. Figure 3 presents details of the branch part. The main pipe diameter is 100 mm, the branch pipe diameter is 50 mm, and T-shaped branches are present at 1,200 mm and 1,700 mm from the elbow at the rear of the pulsation prevention device. Particle image velocimetry (PIV) consisting of a sheet laser transmitter, high-speed digital camera, and a PC for analyses was used for measurements of flow velocity. Figure 4 portrays an outline of flow velocity measurements (visualization). Table 1 presents specifications of the equipment used for measurements and visualization.

2.2 Flow velocity measurement experiments and analysis

Five experimental patterns were considered using the inflow velocity of the main pipe as parameters: 0.1, 0.25, 0.5, 0.75 and 1.0 m/s. Table 2 presents experimental cases and the shutter speed. The flow rate was measured using an electromagnetic flow meter. The results were displayed by the average of 1 min while sampling was made every 10 s. Cross sectional flow velocity distribution at piping branch part was measured by particle tracking velocimetry (PTV), which is a sort of PIV. Tracer particles (nylon, grain size 80 µm, specific gravity 1.02 kg/ m^3)

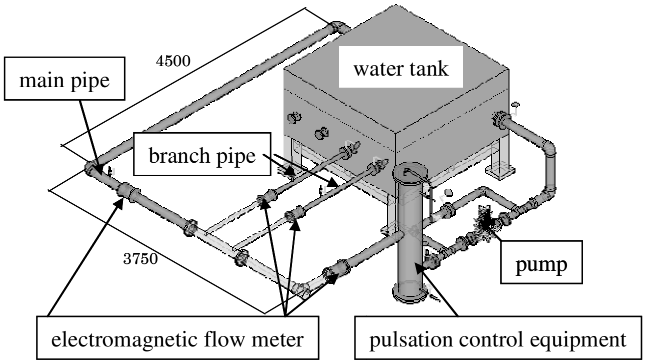


Figure 1 External appearance of experimental device.

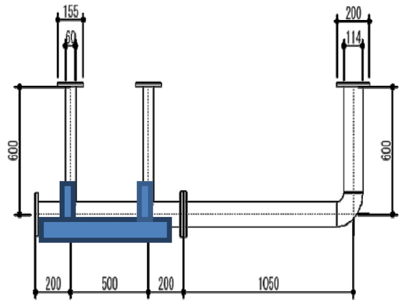
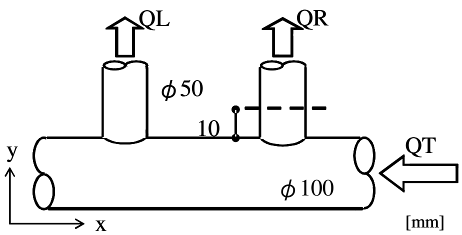


Figure 2 Location of visualization.



$QT = QR + QL$

QR : flow rate of right branch pipe

QL : flow rate of left branch pipe

QT : flow rate of main pipe

Figure 3 Details of T-shaped branch part.

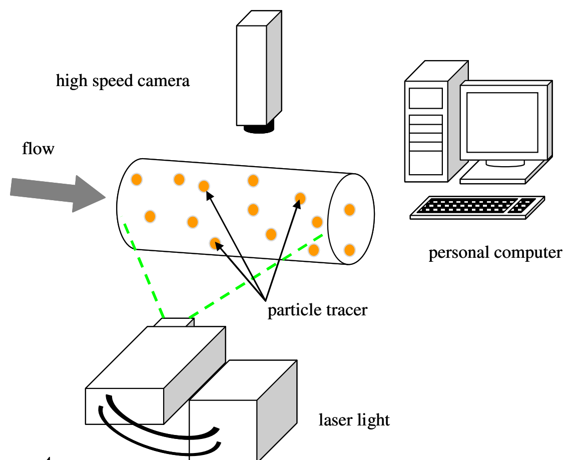


Figure 4 Outline of flow velocity measurement (visualization).

Table 1 Specifications of equipment used for measurements and visualization

instrument	specifications
light source	YAG laser, output power;5W, wavelength;532nm, optical system;fiber sheet shutter speed;max.1/500 thousand s, DPGL－ 5W（production：Oxford Lasers）
camera	hi-speed camera,HAS-550（production：DITECT）
tracer particle	material;nylon,particle size;80μm,specific gravity;1.02[kg/m^3]
analysis software	DIPP-FLOW(ver.2.00, production：DITECT)
pump	circulation pump, discharge diameter;80mm, lift;17.5/4.5[m], discharge;0/1.35[m^3/min.]
buffer tank.	pulsation prevention device, polyvinyl chloride pipe; 300mm, 1,850mm height

were thrown into the water storage tank, and laser light sheet was irradiated from the lateral side of the pipe in a Y-axis direction. Photographs were taken using a high-speed camera from 500 mm above. Considering the flow velocity, the camera shutter speed was changed for every case: from 200 fps (case 1) to 1,000 fps (case 5). PIV analysis software (DIPP-FLOW) was used for cross-sectional flow velocity distribution of the flow. The flow velocity vector was calculated from the average of results of experiments in which 100 particles were pursued by PTV.

Table 2 Experimental cases and shutter speeds

case №	case 1	case 2	case 3	case 4	case 5
inflow velocity [m/s]	0.10	0.25	0.50	0.75	1.00
shutter speed [fps]	200	500	1000	1000	1000

3. Outline of CFD Analysis

3.1 Analysis target domain

The experimental device presented in Figure 1 was regarded as the CFD analysis target. The region from the pulsation prevention device until the water storage tank outlet was modeled. Figure 5 portrays an outline of the CFD analysis model. Five analysis cases, from 0.10 m/s (case 1) to 1.00 m/s (case 5), were examined depending on differences of inflow velocity in a similar manner as that used for experiments. Table 3 presents CFD analysis conditions. Commercial code STAR-CD (ver. 4.14) was used for analysis software and unstructured grids by hexa-mesh were used for CFD analysis. Experimental values given for the boundary conditions at the flow inlet and flow outlet were regarded as free outflow. Wall surface boundary conditions in the pipe were regarded as following the log law (smooth state). Isothermal steady analysis was performed, and the SIMPLE method was used for the calculation algorithm. The number of calculation iterations was 2,000 times. The convergence test value was 1.0 x 10^{-6}.

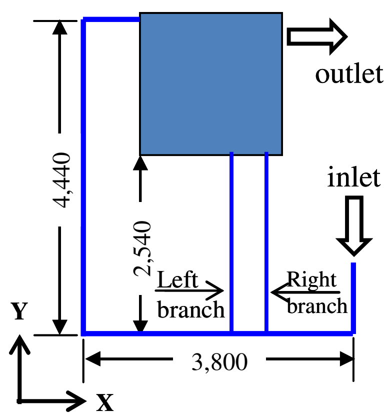


Figure 5 Outline of CFD analysis model.

Table 3 CFD analysis conditions

CFD software	star-CD(ver.4.14)
Solution	SIMPLE method
calculation munber	2,000 steps
convergence judgment value	1.0×10^{-6}
boundary condition	inflow condition ; experiment value
	outflow condition ; free outflow
	wall surface; log-low

3.2 CFD analysis conditions

(1) Verification of analytical accuracy for different mesh configurations at the branch part.

To confirm the influences of the differences of mesh configurations at the branch part on analysis results, CFD analysis was performed for three circular pipe mesh configurations. Figure 6 shows a cross section of the circular pipe and mesh configuration at the branch part used for CFD analysis. With model 1 (basic model), no particular consideration was given for the grid configuration at a branch part to branch pipe. With model 2 (node point correction model), the model is modified so that the main pipe cross-sectional direction might contact with the node point of the branch pipe at the grid node point at the branch part. When generating model 1 (basic model), slippage is shown to occur between the node point of the branch pipe and main pipe. Therefore, with model 2, the node point in the y-axis direction is moved so that the node point with the branch pipe might agree. Furthermore, with model 3 (segmentalized model), the mesh of branch part to the branch pipe of model 2 was further segmentalized. Regarding the turbulence model, a high-Reynolds number type k-εmodel was applied to all cases.

Table 4 CFD analysis conditions

model №	model name	mesh nanber	turbulent model
model 1	basic model	about 681,000	hight-ReNo. k-ε 2-equations model
model 2	node point correction model	about 681,000	
model 3	segmentalized model	about 704,000	
model 4	low-Re number type model	about 751,000	low-ReNo. k-ε 2-equations model
model 5	high-Re number type model	about 639,000	high-ReNo. k-ε 2-equations model

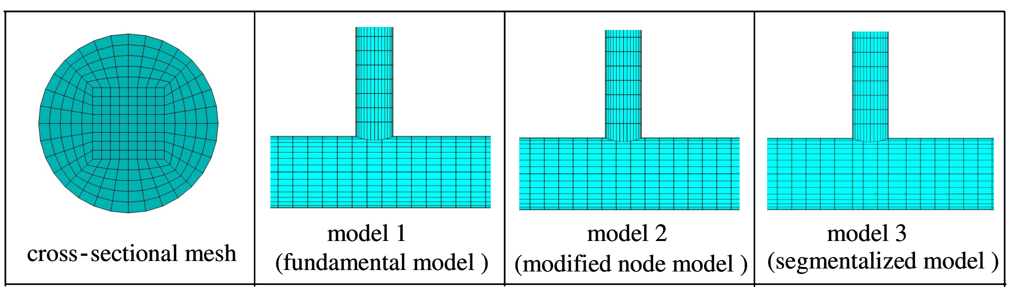


Figure 6 Cross section of circular pipe and mesh configuration at the branch part.

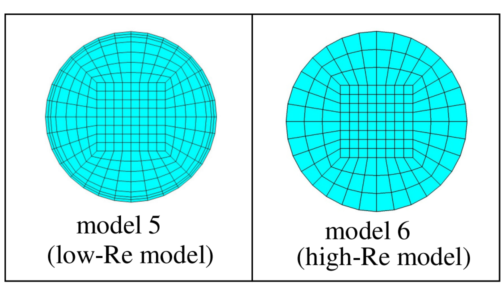


Figure 7 Boundary layer mesh configuration at the circular pipe section.

(2) Verification of analysis accuracy by boundary layer mesh configuration.
With model 3, the first layer of the pipe wall surface was segmentalized in the circumferential direction and CFD analysis was performed for two models to verify the influence on analysis results. With model 4 (low-Reynolds number type model), for the inflow velocity of case 1 to case 5, the boundary layer was segmentalized to have fine grid width so that the y+ value might be within the range where low-Reynolds number type model is applicable to the turbulence model. For model 5 (high-Reynolds number type model), the boundary layer was segmentalized to have mesh configuration so that y+ value might be within the range where high-Reynolds number type k-ε model is applicable to the turbulence model. Figure 7 presents a mesh configuration at the circular pipe section of the model used for CFD analysis. The thickness of the outermost layer grid of the main pipe is about 1.25 mm for model 4 and about 8.32 mm for model 5. Table 4 shows the number of meshes and turbulence models used in (1) and (2).

4. Comparison between actual measurements and CFD analysis results

4.1 Comparison of flow rate distribution of branch pipe

Figure 8 shows the flow rate distribution ratio of right and left branch pipes between experimental values and CFD analysis results for different mesh configurations at branch part (model 1 – model 3). According to the experiment, the flow rate ratio tends to decrease gradually as the inflow velocity increases. This tendency is particularly remarkable in the inflow velocity range from 0.1 m/s (case 1) to 0.5 m/s (case 3).
According to CFD analysis, model 3 (segmentalized model) showed good agreement in terms of tendencies, whereas cases 3, 4, and 5 generated errors. Moreover, the obtained values were smaller than those of the experiments. If comparison is made in terms of the difference of mesh configuration, then case 3, where the branch part mesh was segmentalized, yielded values most closely approximating the experiments. Figure 9 shows the flow rate distribution ratio between experimental values and CFD analysis for boundary layer mesh configurations (model 4, model 5). CFD analysis results from model 4 (low-Reynolds number model) and model 5 (high-Reynolds number model) show generally good agreement with the experiments. The error is about 3% for all cases (case 1 – case 5). Furthermore, the flow rate distribution ratio of both models shows similar values. Moreover, the influences of different turbulence models on flow rate to right and left branch pipes are known to be slight.

4.2 Flow rate distribution ratio for the total flow rate

Figure 10 shows experimental values and results of CFD analysis of flow rate distribution ratio (QR/QT) of the right branch pipe flow rate (QR) to the total flow rate (QT) for different branch part mesh configurations (model 1 – model 3). According to the experiment results, the flow rate distribution ratio tends to become slightly lower as the flow rate increases. It is nearly uniform with inflow velocity from 0.25 m/s (case 2) to 1.0 m/s (case 5). According to CFD analysis results, all models showed similar tendencies, although error was caused in case 1 (0.1 m/s) with experiments. case 3 showed the closest value to the experiments. It might then be said that changes in the branch part mesh configuration influence the flow rate distribution ratio. Figure 11 shows experimental values and results of CFD analysis of flow rate distribution ratio

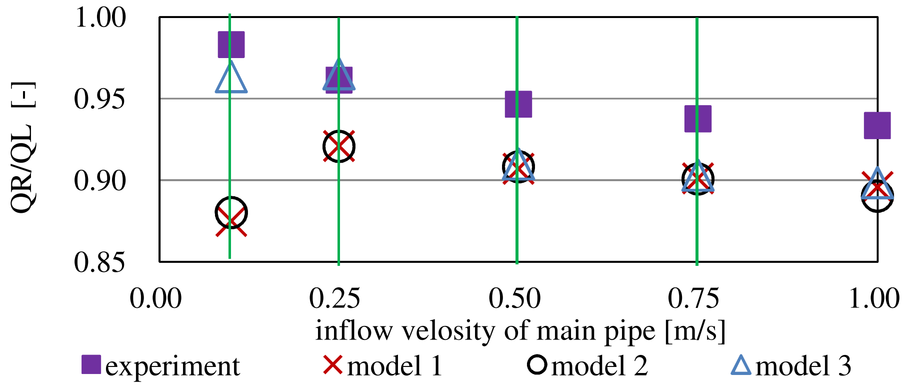


Figure 8 Flow rate distribution ratio for different mesh configurations at the branch part (model 1 – model 3).

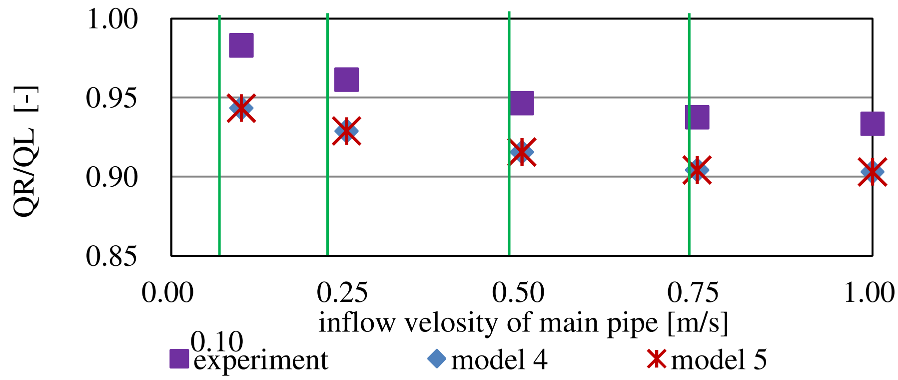


Figure 9 Flow rate distribution ratio for different mesh configurations at the boundary layer (model 4, model 5).

(QL/QT) of the left branch pipe flow rate (QL) to total flow rate (QT). Experimental values are contradictory to those of the right branch pipe the flow rate distribution ratio increases in proportion to increased inflow velocity. Results of CFD analysis differ depending on the models in such that with model 1 (basic model), the values obtained are close to the experiments, whereas model 3 (segmentalized model) showed a tendency similar to those of experiments. Values became greater as the inflow velocity increased, and the error was only 4% at a maximum. Regarding verification of flow rate accuracy with regard to branch part mesh configuration, node points of branch pipe branch part of the model are modified. A further segmentalized model (model 3) showed the highest agreement with experiments and tendency of changes in inflow velocity (case 1 – case 5). Figure 12 presents a comparison of the flow rate distribution ratio of the right branch pipe between experiments and CFD analysis results from model 4 (low-Reynolds number model) and model 5 (high-Reynolds number model). The CFD analysis results reproduced the tendency of experiments in every model. Particularly the error of flow rate ratio of model 4 (low-Reynolds number model) is as low as 1.5 at maximum. Consequently, higher accuracy can be reproduced. Figure 13 shows experimental values of the flow rate distribution ratio of the left branch pipe and CFD results from model 4 and model 5. Regarding the flow rate distribution ratio of the left branch pipe, CFD analysis results from model 4 (low-Reynolds number model)

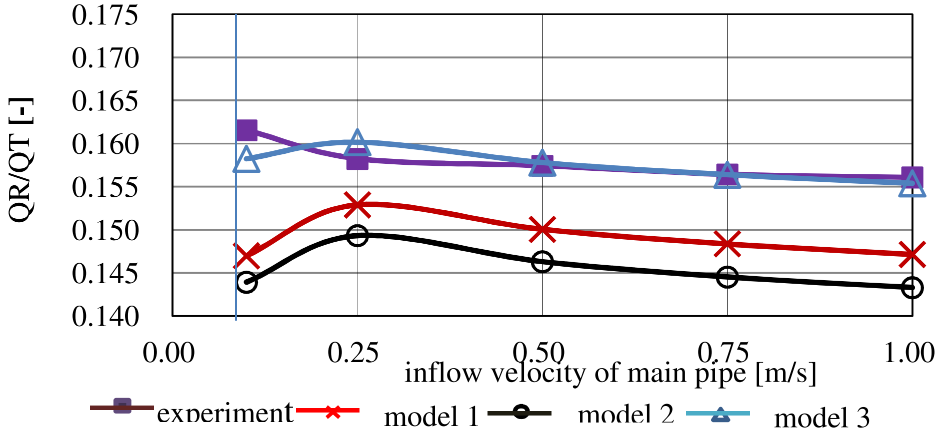


Figure 10 Flow rate distribution ratio of right branch pipe for different mesh configurations at the branch part (model 1 – model 3).

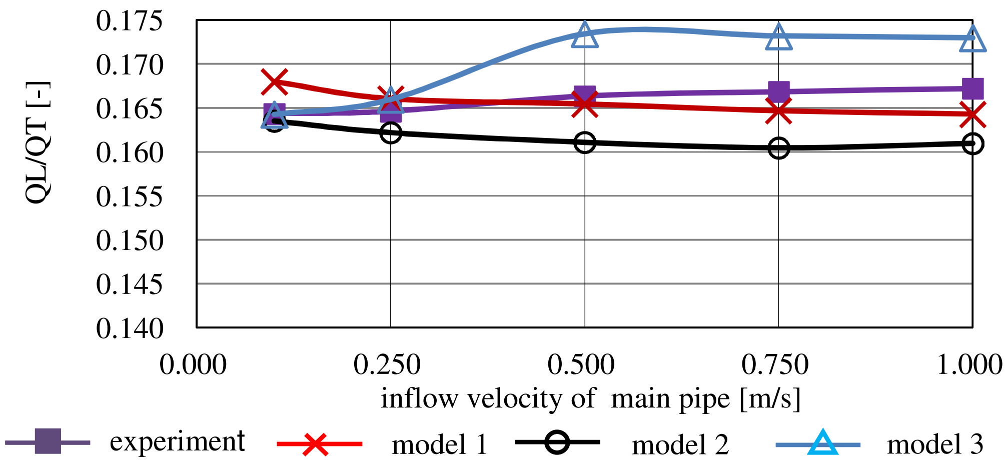


Figure 11 Flow rate distribution ratio of left branch pipe for different mesh configurations at the branch part (model 1 – model 3).

generally agree with experimental values similar to the right branch pipe. Based on the observations described above, the comparison of five types of models (model 1 – model 5) reveals that CFD analysis results from model 4 (low-Reynolds number model), in which boundary layers are segmentalized, most closely approximate the experimental values.

4.3 Dimensionless flow velocity distribution in comparison reference line

Figure 15 shows the dimensionless flow velocity distribution of the y-component in the comparison reference line (see Figure 2) in case 1 (inflow velocity 0.1 m/s). Comparison of the influences of differences of turbulence model on flow velocity distribution is made between results from model 3 (segmentalized model) and model 4 (low-Reynolds number model). Meanwhile, conversion to dimensionless flow velocity was made using the average flow velocity of the main pipe. With PIV, such a tendency was observed that the flow velocity reaches maximum at the left in the pipe anddecreases suddenly around the pipe center. CFD analysis from model 3 revealed that

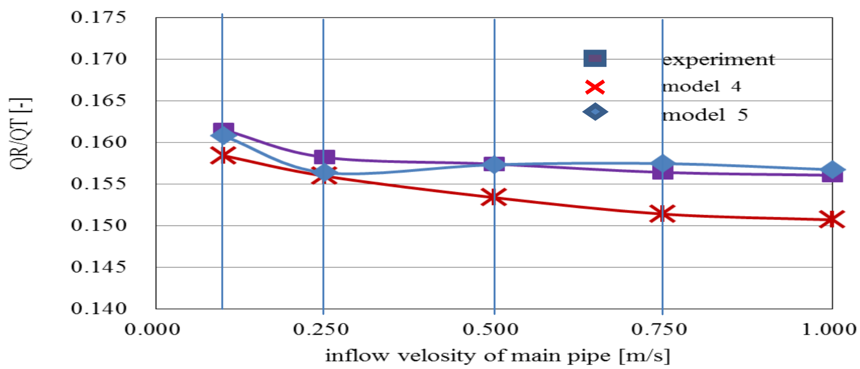


Figure 12 Flow rate distribution ratio of right branch pipe for different mesh configurations at the boundary layer (model 4, model 5).

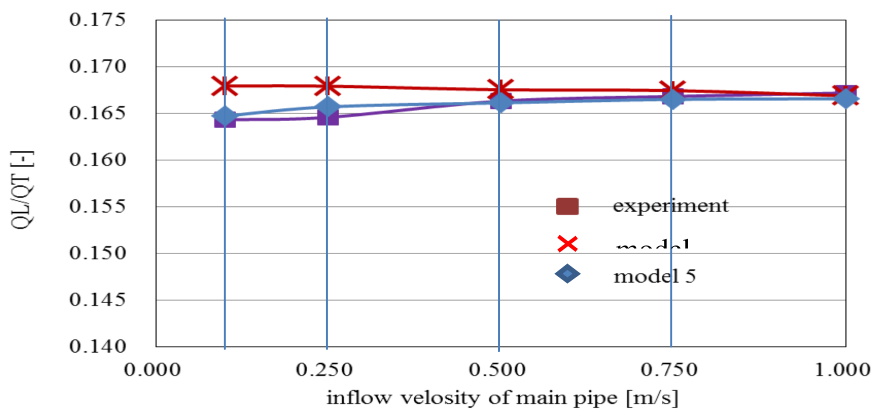


Figure 13 Flow rate distribution ratio of left branch for different mesh configurations at the boundary layer (model 4, model 5).

although the point at which the flow velocity decreases suddenly is shifted slightly to the right of the pipe from the point in PIV, a generally similar tendency with actual measurements is shown which is closer to actual measurements than those from model 4. Figure 15 shows the dimensionless flow velocity distribution at the comparison reference line of case 5 (inflow velocity 1.0 m/s). CFD analysis results from model 3 revealed that the flow velocity becomes maximum at the left in the pipe and decreases suddenly around the pipe center in a similar manner as that shown in case 1 (inflow velocity 0.1 m/s), which are closer to experimental value than Model 4 (low-Reynolds number model).From the observations described above, it was confirmed that dimensionless flow velocity distribution is unaffected by the average flow velocity of the main pipe for both PIV and CFD.

4.4 Comparison of PIV and CFD at pipe center section

Figure 16, 17 presents the dimensionless flow velocity distribution at the pipe center section at the branch part of the right branch pipe in case 1 (inflow velocity 0.1 m/s) and case 5 (1.0 m/s). With PIV, the flow velocity reaches maximum at the left in the pipe

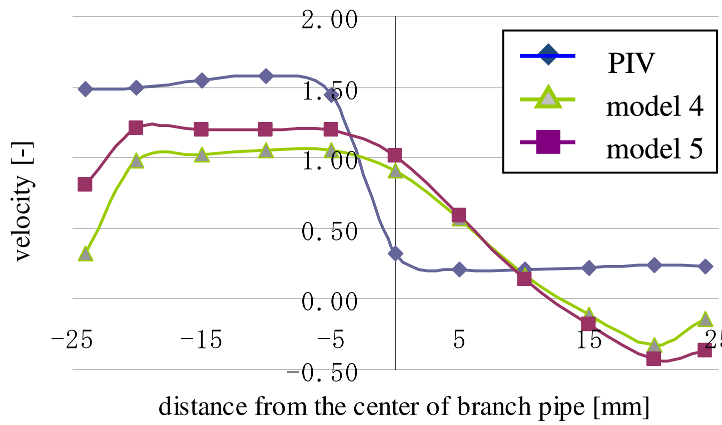


Figure 14 Flow rate distribution ratio of right branch pipe for different mesh configurations at the boundary layer (model 4, model 5).

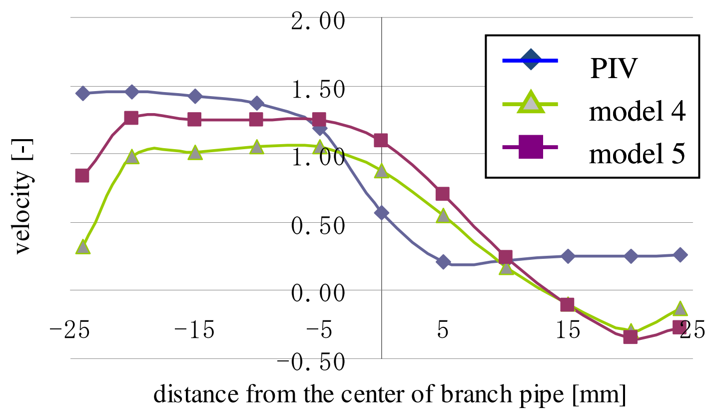


Figure 15 Flow rate distribution ratio of left branch pipe for different mesh configurations at the boundary layer (model 4, model 5).

and water velocity entered after branching becomes faster in every case. Generation of more than one vortex is confirmed at the right in the pipe after branching. In the CFD analysis of case 1 (inflow velocity 0.1 m/s), analysis results from model 3 (segmentalized model) and model 4 (low-Reynolds number model) well reproduced results of PIV. Particularly with analysis results from model 4 (low-Reynolds number model), the fact that flow velocity becomes faster immediately before the branch part and flow velocity of the main pipe after branching generally agree with those of PIV.
Although analysis results from model 5 (high-Reynolds number model) generally reproduce the tendency in the experiments, there are differences in the flow velocity of the main pipe after branching. Generation of more than one vortex was confirmed by the experiment, although CFD confirmed one big vortex. This difference is regarded as attributable to the fact that flows were averaged because of analysis by RANS. Although comparison between model 3 and model 4 for case 5 (inflow velocity 1.0 m/s) shows a difference in the flow tendency in the main pipe, for flow velocity distribution after branching and aspect of flowing into branch pipe, both models generally captured

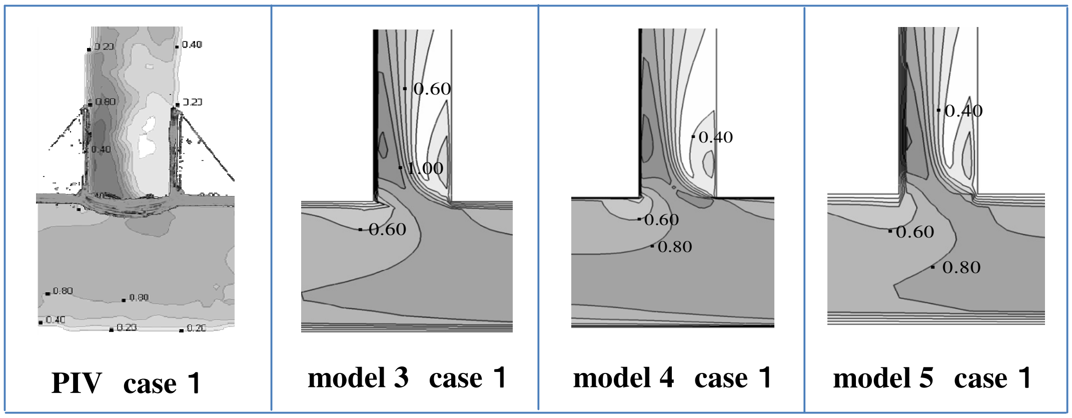


Figure 16 Dimensionless flow velocity distribution of the y-component in case 1 (inflow velocity 0.1 m/s).

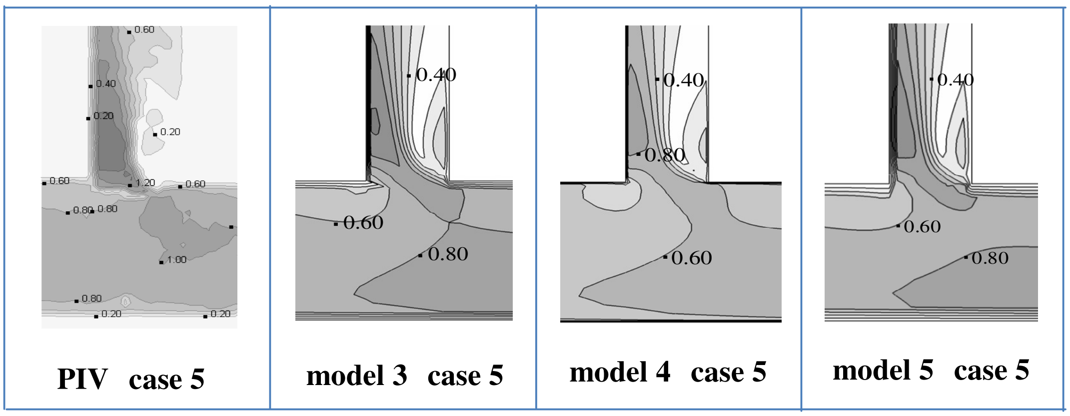


Figure 17 Dimensionless flow velocity distribution of the y-component in case 5 (inflow velocity 1.0 m/s).

the tendency of PIV.In the experiment, more than one vortex was generated in case 5 (inflow velocity 1.0 m/s), although one big vortex was confirmed in the experiment. The cause of this difference is regarded as the influence of RANS on the analysis, in a similar manner to that in case 1. If a comparison is made with respect to a difference of inflow velocity (case 1 – case 5), then the flow velocity distribution shows a generally similar tendency in all cases and it has been revealed that the difference of the inflow velocity has no influence on flow behaviors.

5. Conclusions

In this study, to reproduce flows in the piping and to grasp influences of differences of the number of computational grids, grid configuration and grid shape on analysis results, experimental values and results of CFD analysis applying unstructured grid were compared and verified. Results indicate the following findings.

[1] Comparison with regard to differences of mesh configuration at branch part showed

that node points of branch pipe connection part were modified, and that the segmentalized model (model 3) was the closest to the experimental value.
[2] Comparison with regard to differences of mesh configurations of the boundary layers showed that Model 4, in which the outer-most layer was segmentalized and low-Reynolds number type k-ε model was used for the turbulence model, yielded the most favorable results.
[3] A low-Reynolds number type k-ε model (model 4) was able to reproduce experimental values with higher accuracy for minute behaviors attributable to differences of main pipe inflow velocity.
[4] A low-Reynolds number type k-ε model (model 4) takes a longer time for grid generation than other models. The greater the number of grids, the longer the calculation time is. With a segmentalized model (model 3), which allows easy grid generation, the error of flow rate distribution ratio is 4% at a maximum. It is therefore necessary to construct a model to meet the objectives of the analysis and investigation items.

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7. Acknowledgements

The authors express their thanks to Mr. Yuichiro Seki (Hibiya Engineering, Ltd.), and the Meiji University students for their great cooperation extended during actual measurements and analyses. Their valuable cooperation in performing simulations, collating data, drawing figures, etc. was instrumental for this study.

8. Presentation of Author

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Technological Evolution on Materials for Building Water Piping Systems

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Abstract

The original water piping systems were installed with metallic solutions, but after decades of use of metallic water piping systems, the chemical corrosion effects created problems related to water quality, and durability of the installations. The solution to the chemical corrosion on metallic materials came with the stainless steel piping systems; however, the cost of the new systems increased considerably the total cost of the installations.

The first synthetic materials installed in water piping systems were the polyvinyl chloride (PVC) and the polyethylene (PE), but the low thermal resistance doesn´t allow their use for hot water piping networks. To overcome this limitation was developed the chlorinated polyvinyl chloride (CPVC), obtained by changing the chemical nature of the PVC, and the cross linked polyethylene (PEX), obtained by cross linking of HDPE.

Some other thermoplastics materials emerged since then on the market, among which we can highlight the polypropylene copolymer (PPR), the polybutylene (PB) or the resins of acrylonitrile-butadiene-styrene (ABS). More recently the multilayer water piping systems tried to synthesize in one single technological solution, the main advantages of the metallic systems, with the main advantages of the synthetic materials.

This paper follows the one presented in the 37th CIB W062 International Symposium, September 25th-28th 2011, in Aveiro-Portugal, named “New Materials and Technologies in Building Water Piping Systems”, and its aim is to increase a deeper view on the materials and technologies for water piping systems that were not covered before, by studying properties and characteristics, linking techniques, application methods, and advantages and limitations of these systems, in a way to be able to solve any lack of information that exists in this area.

Keywords

Water Piping Systems, Materials and Technologies, Installation Procedures, Traditional Materials and Joining Techniques, New Materials and Joining Techniques, Advantages and Limitations of the Systems.

1 Introduction

The design of the piping systems for hot and cold water installations should be able to preserve the quality of the water supplied, as well as the safety and the comfort of the consumers. For that, all materials and installed equipments shall accomplish the applicable European standards or, in the absence of specific legislation, shall be subjected to approval by local competent authorities. [1]

The designer should be able to select the materials and technologies used for drinking and sanitary water piping networks, based on the study of its main characteristics, properties, and joining techniques, in order to increase the quality of the water supplied, and to minimize the intervention of the installer, reducing the working time and lowering the cost of manpower. [1]

For selection of the most suitable sanitary water piping system materials and technologies, the designer must assume that there are no perfect materials and technologies. There are, however, materials and technologies that seem to be more appropriate for a particular type of installation. [1]

Throughout the paper the author don´t intended to make a value judgment that seek to overestimate the performance of a system compared to the other, but only carry out an analysis, from a technological point of view, that can allow to condense much of the information dispersed in technological catalogs, engineering journals and magazines. It is also intended to compile a practical knowledge shared by installers in their everyday practice.This paper follows the one presented in the 37th CIB W062 International Symposium, September 25th-28th 2011, in Aveiro-Portugal, named “New Materials and Technologies in Building Water Piping Systems” [2]. In the first paper [2] it was presented the main advantages and limitations of two metallic piping systems (copper and galvanized steel), two plastic piping systems (PEX and PP-R) and a composite piping system (multilayer).

In chapters 2 and 3 of this paper is presented, respectively, a metallic piping system (stainless steel), and three other plastic piping systems (UPVC, CPVC and PB), all with specific application for drinking and sanitary water supply networks. It will be emphasized in each chapter, the main advantages and limitations of the systems, and described the main joining techniques between pipes and pipes and fittings.

2 Stainless Steel Piping Systems for Hot and Cold Water Installations

The stainless steel is an iron, chromium and carbon alloy, which may contain some other important additions, such as nickel, molybdenum, niobium, and titanium. Those elements can modify its structure, mechanical properties, and the corrosion resistance.

Its application for water piping systems requires high corrosion resistance, so the types of stainless steel better suited for this application are the ferritic and austenitic steels, which generally are characterized by having chromium over 16%. Due to its physical characteristics (Table 1) the austenitic stainless steel is the most used for water piping systems, and it is the only type that can be applied in the pressfitting jointing system.

The austenitic stainless steel is placed in AISI 200 and 300 series. It has low carbon content (less than 0.15%), the content of chromium varies between 12 to 25%, and the nickel content varies from 8 to 20%. It may have additions of up to 7% of molybdenum to improve corrosion resistance. In the AISI 200 series, nickel is partially replaced by manganese [3].

Table 1 - Physical properties of the austenitic stainless steel [3]

Tensile Strength (MPa)		≥500
Yield Strength (MPa)	0,2 %	≥195
	1 %	≥230
Extension (%)		≥40
Thermal conductivity (W/m.K)		16
Longitudinal thermal expansion coefficient (m/m.K)		0,000016
Softening temperature (ºC)	Min	1000
	Max	1120
Time for sensitization at 650ºC (min.)		15

The stainless steel pipes are electrowelded and commercially presented in straight sections with 4 to 7 meters long. The main advantages of stainless steel water piping networks are: high mechanical resistance, good fire behavior, low longitudinal thermal expansion coefficient (α= 0.016 mm/mºC), a wide range of sizes of pipes and fittings (3/8" to 6"), quick installation by the use of the pressfitting joining system, high resistance to electrochemical corrosion (avoid its use in the distribution of water with chlorides content over 213 mg/l, and with temperature above 50° C), low surface roughness with no inlays and low loss of pressure, hygienic and non-toxic without altering the composition of the water transported, and recyclable. The main limitations of the system include: high cost, high thermal conductivity (λ= 16 W/mºC), reduced sound insulation, high density with higher transportation costs and difficulties of installation work, difficult workability, need for skilled labor for installation (except for pressfitting joining system).There must be avoided the direct contact between stainless steel pipes installed behind walls and the mortar, which materials can produce chloride solutions that causes oxidation of the external surface of the pipes.

The most common joining methods for stainless steel tubing are the following: soldering with capillarity solder, compression mechanical coupling method, and the pressfitting jointing system.

Soldering with capillary solder

Just like copper pipes, stainless steel water supply pipes can be joined together by soldering. **W**hen the pipes are joined with fittings, there is a very small gap between the fitting and the pipe. When the pipe and fitting are heated, and solder is touched to the pipe, the solder melts and is drawn up into the gap through capillary action. Once the gap is filled, and the heat removed, the solder forms a seal and makes a watertight joint. The solder should be free from cadmium and zinc, it is recommended to use materials rich in silver. The solder should have a melting point lower than the melting temperature of the stainless steel.

For the soldering, a non-aggressive soldering flux is recommended. A good flux will dissolve and remove traces of residual oxides from the surfaces to be joined, protect the surfaces from re-oxidation during heating and promote the wetting of the surfaces by the solder.

After both surfaces are properly fluxed, they should be assembled by placing the fitting on the tube, making sure the tube seats against the base of the fitting socket (Figure 1). A slight twisting motion is suggested to ensure even coverage by the flux. Care must be taken to assure that the tube and fittings are properly supported with a reasonable, uniform capillary space around the entire circumference of the joint. Uniformity of capillary space will ensure good filler metal penetration.


Figure 1 – Flux application followed by joint assembly [1]

Heating should begin with the flame perpendicular to the tube. This preheat will conduct the initial heat into the socket for even distribution of heat inside and out. Preheating depends upon the size of the joint. The flame should not be moved onto the fitting. It should be moved from the fitting socket onto the tube, a distance equal to the fitting socket. The solder should be touched to the joint. If the solder does not melt, should be removed and continued the heating process. When the melting temperature has been reached, heat may be applied to the base of the cup to aid capillary action in drawing the solder into the cup.

When the tube is in a horizontal position, the solder should be placed slightly offcenter of the bottom of the joint. It should be continued across the bottom of the fitting and up to the top-center position and then return to the point of beginning, overlap the starting point and proceed up the uncompleted side to the top. Molten solder will be drawn into the joint by capillary action regardless if the solder is being fed upward, downward or horizontally.

After the joint has been completed, natural cooling is best (Figure 2). Shock cooling may cause unnecessary stresses on the joint and may result in eventual failure.


Figure 2 – Soldering the joint after preheating followed by natural cooling [1]

Compression Mechanical Coupling Method

The components of the compression mechanical coupling, as depicted in Figure 3 and Figure 4, are a threaded compression nut, a grip ring and a fitting [4].


Figure 3 – Components of the compression mechanical coupling

The grip ring, when compressed, grips the outside surface of the pipe, making a pressure-tight seal, and providing a pullout resistance which exceeds the yield strength of the stainless steel pipe. The components are normally made of brass. After the assembly is done, the grip ring will assure the tightness and gets hidden behind the coupling (Figure 4).

Figure 4 – Typical Compression Nut Type Mechanical Coupling

Pressfitting Jointing System

In the Pressfitting Jointing System, the assembly is achieved by pushing the two components together utilizing a mechanical press tool to generate the needed force to join the fitting to the tubing. To that end, pressfitting technology relies on compressive strength and compression to form a plumbing connection. [5] [6] [7] [8]

The fittings are manufactured from stainless steel (preferably form the same AISI series of the pipe) in order to promote an efficient jointing of stainless steel tube. The connection is made by ensuring that the tube is fully inserted into the fitting, the clamping jaws of the press tool are placed around the collar of the fitting, which contains a butyl or EPDM 'O' ring. With the jaws at a 90º angle to the fitting, the press tool is activated and the clamping jaws compress the 'O' ring tightly onto the tube creating a joint. The heat-free principle of the jointing process is one of the major benefits of the system. [5] [6] [7] [8]

Figure 5 shows the sequence of operations needed to form the plumbing connection. The operations are the following: 1. the pipe is cut to a custom length; 2. the residues due to the cut operation shall be eliminated; 3. the position of the 'o' ring must be verified inside of the fitting; 4. the tube shall be inserted into the fitting, rotating and pushing to ensure that is fully inserted; 5. a mark shall be made on the tube which allows the positioning of the press tool; 6. the press tool shall be prepared with the installation of the clamping jaws compatible with the tube diameter 7. The clamping jaws of the press tool are placed around the collar of the fitting, which contains the 'O' ring; 8. The press tool is activated and the clamping jaws compress the 'O' ring tightly onto the tube creating a joint; 9. The pressfitting plumbing connection is finally done [5] [6] [7] [8].

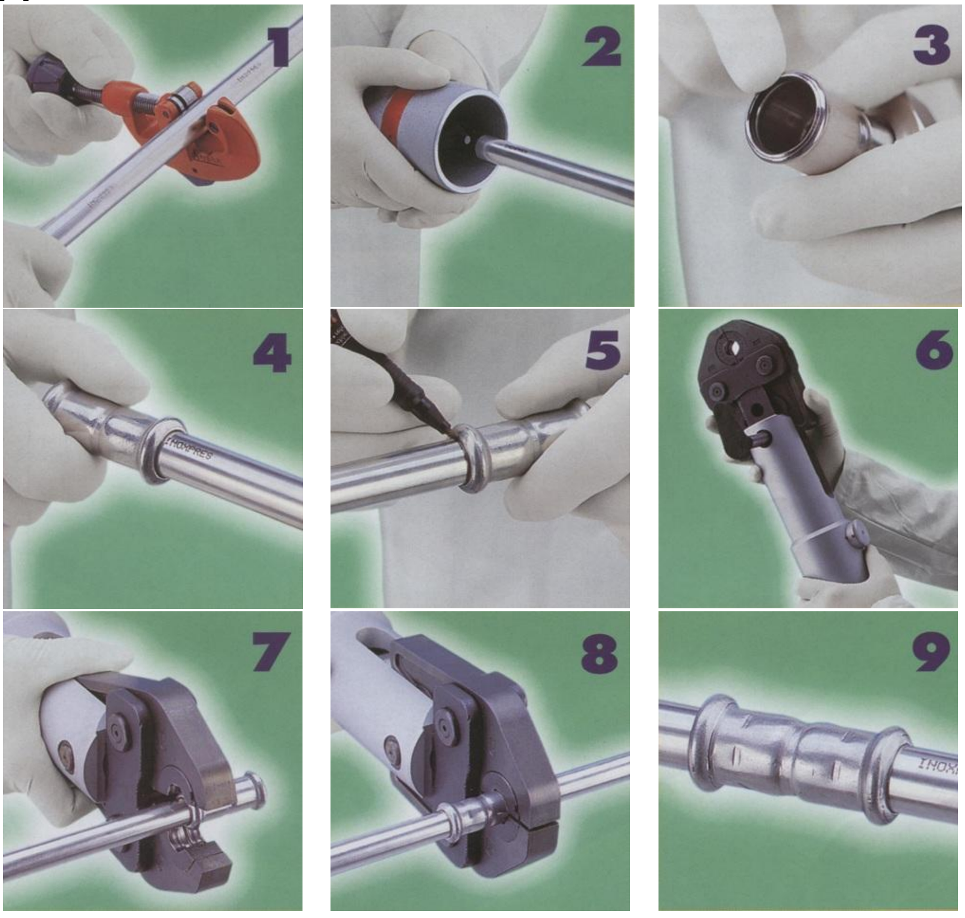

Figure 5 – Sequence of operations in the Pressfitting Jointing System [5] [6] [7] [8]

3 Plastics Piping Systems for Hot and Cold Water Installations

3.1 Sanitary Water Piping Network in UPVC

The unplasticized poly(vinylchloride) (UPVC) piping is a system of pipes and fittings. UPVC pressure pipes are manufactured from unplasticized polyvinyl chloride polymer (a thermoplastic material) with additives such as stabilizers and antioxidants using the extrusion process. UPVC pressure fittings (bends, tees, reducers, and valve connectors) are produced by the mould injection process [10].

The UPVC pressure pipes are suitable for service temperatures between 0°C and 50°C. However, since UPVC is a thermoplastic material, pressure ratings must be reduced for higher temperatures. Table 2 shows the percentage of the pressure rating recommended for various working temperatures about 20° C with a fluctuation not exceeding 5° C. UPVC pressure pipes should not be used for pressure duties if the operational temperature exceeds 50° C [9].

Table 2 – Thermal re-rating factors [9]

Maximum Service Temperature	Multiplication Factor for Pressure
20	1.00
25	0.94
30	0.87
35	0.78
40	0.70
45	0.64
50	0.58

The UPVC pipes are commercially supplied in straight sections with 3 to 6 meters long with plain ends or socketed at one end for solvent cement weld.

The main advantages of UPVC water piping networks are: high resistance to electrochemical corrosion, wide range of dimensions of pipes and fittings (DN20 to DN800 **[9]**), low surface roughness with no inlays and low loss of pressure, higher Young´s modulus with when compared to other thermoplastics, low thermal conductivity (λ = 0.15 W/mºC), high resistance to stray electric currents, higher density when compared to other thermoplastics, however with low transport costs and handling (light and easy to handle), easy workability (don´t need for skilled labor for installation), hygienic and non-toxic without altering the composition of the water transported, recyclable. The main limitations of the system include: low resistance to ultraviolet radiation, low mechanical resistance to external loads (UPVC pipes may distort under high loads), low thermal resistance. **[10]**

The installation of UPVC pressure piping system follows two distinct processes: a conventional installation with the execution of a solvent weld joint, in diameters ranging from DN20 and DN160, and an installation with the execution of a rubber ring joint, with diameters ranging from DN 90 and DN 400.

Solvent Weld Joint

To achieve a leak free solvent weld joint in a pressure UPVC pipe, it´s important to execute the following sequence of operations:

1. The spigot shall be cut as square as possible, and all swarf and burrs shall be removed from both inside and outside edges of the pipe. Swarf and burrs if left will wipe off the solvent cement and prevent proper jointing. The pipe and the fitting shall be checked for proper alignment. [11] [12]
2. The spigot shall be marked at a distance equal to the internal depth of the socket. For pressure pipes the interference fit must be reached before the spigot is inserted fully to the mark. [11] [12]
3. The inside part of the socket and area between the mark and the spigot end, shall be thoroughly clean with a cotton cloth dipped in priming fluid (avoid synthetic material) to remove dirt and grease, and to soften the UPVC surface. [11] [12]
4. A thin, uniform coat of solvent cement shall be applied to socket and to the spigot up to mark (Figure 6). The joint shall be quickly assembled before the cement dries, by pushing the spigot firmly into the socket, as far as the mark, ending with a quarter turn to spread the cement evenly. The joint shall be held in this position for at least thirty seconds without movements (Figure 7). [11] [12]
5. The excess of solvent cement shall be wiped off from the outside of the joint and where possible from the inside of the joint. Any movement may break the initial bond. [11] [12]
6. The cure time is the time taken for the solvent weld joint to reach the pressure rating of the pipe. It will take at least 24 hours. [11] [12]

Figure 6 – A thin, uniform coat of cement is applied to the spigot and socket

Figure 7 – The joint shall be quickly assembled before the cement dries

Rubber Ring Joint

To achieve a leak free rubber ring joint in a pressure UPVC pipe, it´s important to execute the following sequence of operations:

1.The UPVC rubber ring jointed pipes are supplied with a rubber ring which integrity shall be checked (Figure 8). The ring is fitted at the time of manufacture and subsequently must not be removed. If the ring is tampered with or damaged in any way after leaving the factory, then the socket and the affected ring must be cut off and scrapped. It is essential to use a bactericidal jointing fluid with the rubber ring. [11] [12]

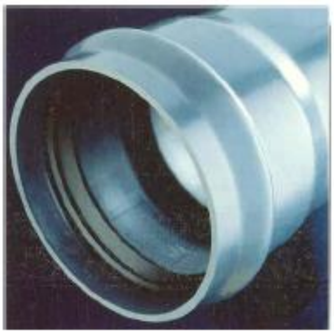

Figure 8 – The UPVC pipes are supplied with a rubber ring to not remove [11] [12]

2.The UPVC pipes can be cut to length on site. It is important to ensure that the cut end is then chamfered with an appropriate field-lathing tool to the correct length. The chamfer and new witness mark shall replicate the manufactured dimensions. All dust and dirt shall be removed from the pipe spigot and socket, paying particular attention to the cleanliness of the fixed ring. The lubricant shall be applied to the spigot, fully covering the circumference up to the witness mark. The lubricant is also applied to the pipe chamfer. [11] [12]

3.The leading edge of the spigot shall be inserted into the socket mouth. It is essential that the pipes be aligned in a straight line before attempting to make the joint. A small, longitudinal force applied to the socket end of the pipe is sufficient to insert the spigot into the adjacent pipe socket. It is important to ensure that the pipe is not under-inserted. Under-insertion is signified by the witness mark not being pushed up to the end of the socket (Figure 9). [11] [12]

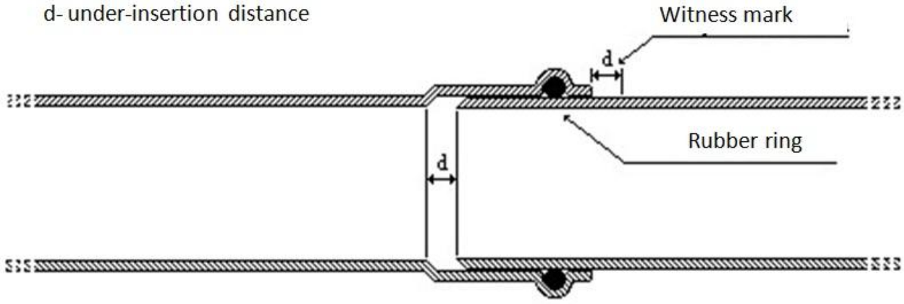

Figure 9 – Under-insertion example [11] [12]

If the simple insertion past the witness mark occurs there´s no significant risk to the performance of the joint. Only if the spigot has been forced so hard that it has stressed the transition region at the back of the socket to the barrel of the pipe is there a cause for concern. [11] [12]

Threaded Joints (forbidden!)

UPVC pipes can´t have threads on the ends to screw into fittings. However it is sometimes a common practice to use threaded pipe joints on UPVC pipes (Figures 9 and 10). The resistance of the pipe is permanently affected. The connection to brass fittings will result in a leaking joint.

Figure 9 – Screw thread cut on the outer surface of a UPVC Pipe (forbidden!)

Figure 10 – UPVC pipes with threaded joints connected to brass fittings (forbidden!)

3.2 Sanitary Water Piping Network in CPVC

The chlorinated poly (vinyl Chloride) (CPVC) piping is a system of pipes and fittings. CPVC pressure pipes are manufactured from CPVC compounds using the extrusion process. CPVC pressure fittings (bends, tees, reducers, and valve connectors) are produced by the mould injection process. The CPVC pressure pipes are suitable for hot and cold water distribution. [13]

The CPVC pipes are commercially supplied in straight sections with 6 meters long with plain ends. Smaller diameter tube is also sold in coils.

The main advantages of CPVC water piping networks are: high resistance to electrochemical corrosion, good fire resistance, low surface roughness with no inlays and low loss of pressure, low thermal conductivity (λ = 0.16 W/mºC), high resistance to stray electric currents, higher density when compared to other thermoplastics, low transport costs and handling (light and easy to handle), easy workability (don´t need skilled labor for installation), high resistance to oxygen diffusion, hygienic and non-toxic without altering the composition of the water transported, recyclable. The main limitations of the system include: narrow range of dimensions of pipes and fittings (½” to 2”), low resistance to ultraviolet radiation, low flexibility (the flexural elasticity modulus is higher when compared to other thermoplastics; E(bend)=about 3000 MPa), high longitudinal thermal expansion coefficient (α= 0.08 mm/mºC). [13]

The installation of CPVC pressure piping system follows a conventional installation process with the execution of a solvent weld joint. CPVC tubing can be joined to metal piping with the use of compression couplings and adapters.

Solvent Weld Joint

The sequence of operations to achieve a leak free solvent weld joint in a pressure CPVC pipe is very similar to the one described for UPVC. The description will be shortened:
1.After cutting the pipe with a tubing cutter, the end must be chamfered and removed any burrs. All cuts should be made so they are square to the tubing. Before the joint is solvent cemented, a check dry fit shall be done (Figure 11). It verifies the pipe outside diameter and the fitting socket tolerances. The pipe should go into the socket 1/3 to 2/3 of the socket depth, before it makes contact with the socket wall. This interference is necessary and provides a joint that will quickly attain the desired handling strength and give good, long-term service. [14]

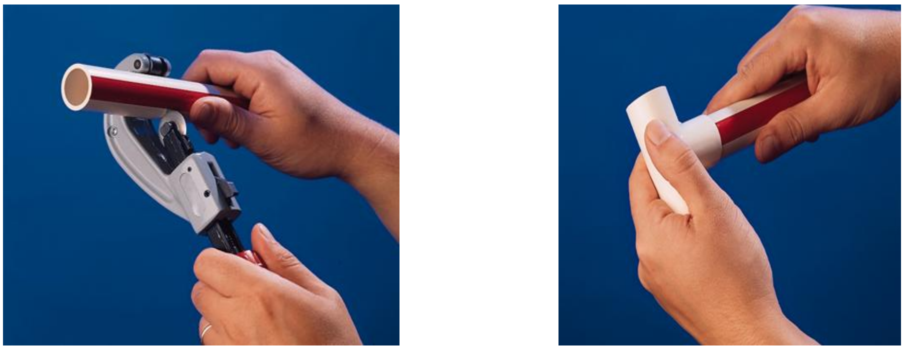

Figure 11 – After cutting and chamfering, a check dry fit shall be done [14]

2, CPVC pipes and fittings are joined with CPVC cements. The solvent cement process can be a one or a two step process. The one-step process does not require the use of a primer. The two-step process does require the use of a primer. Both types of cements are manufactured under specific normalisation for use with CPVC hot and cold water piping. If primer is required, it shall be applied to the outersurface of the pipe end and the inner surface of the fitting socket (Figure 12). After the primer, a light coat of CPVC cement shall be applied to the socket contact surface, and a full layer to the pipe end contact surface. [14]

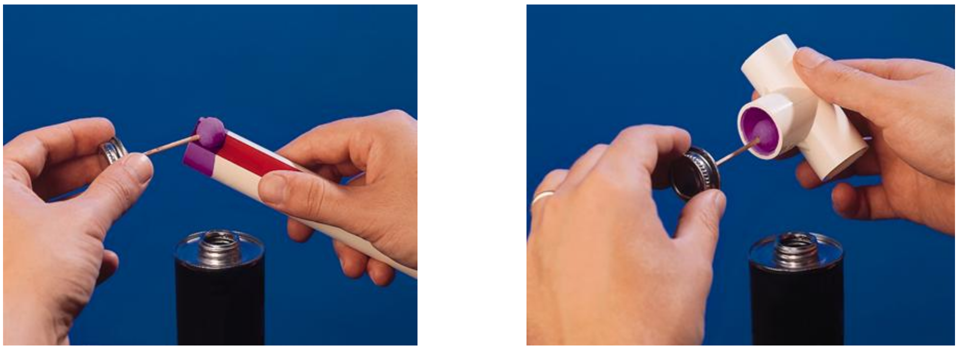

Figure 12 – Primer application in a “two-step” solvent cement process [14]

3. After cement application the pipe shall be immediately inserted into the socket, and placed into the bottom with a ¼ turn. The pipe shall be held in the socket firmly for 10 to 15 seconds. When released, the pipe shall not “push out” of the socket. A good job of cementing is evidenced by an even bead or filet of cement all around the pipe at the socket interface. Solvent set and cure times are a function of pipe size, temperature, and relative humidity. [14]

3.3 Sanitary Water Piping Network in PB

The Polybutylene (PB) piping is a system of pipes and fittings. PB pressure pipes are manufactured from Polybutene-1 that is a member of the polyolefin family of thermoplastic materials which also includes polyethylene and polypropylene.
Polybutene-1 can be processed via injection moulding or extrusion in the manufacture of pipes for hot and cold pressurised water systems.

In comparison with other polyolefin materials, Polybutene-1 provides to PB piping a better mechanical and thermal behaviour, and a higher level of resistance to chemical attack and flammability resistance.

The PB pipes are commercially supplied in straight sections with 6 meters long with plain ends, and also in coils. The most common sizes for PB pipes are 3/8", ½", ¾" and 1".

The main advantages of PB water piping networks are: high resistance to electrochemical corrosion, higher fire resistance compared to other thermoplastics, low surface roughness with no inlays and low loss of pressure, high flexibility (the flexural elasticity modulus is lower when compared to other thermoplastics; E(bend)=450 MPa), low thermal conductivity (λ = 0.22 W/mºC), high resistance to stray electric currents, high resistance to oxygen diffusion, low density, low transport costs and handling (light and easy to handle), easy workability (don´t need for skilled labor for installation), hygienic and non-toxic without altering the composition of the water transported, recyclable. The main limitations of the system include: narrow range of dimensions of pipes and fittings (3/8” to 1”), low resistance to ultraviolet radiation, high longitudinal thermal expansion coefficient (α= 0.13 mm/mºC), low resistance to high chlorine levels in domestic water (above 2 ppm). [15] [16]

Modern jointing technology for PB piping systems, whether the jointing is pre-fabricated in the workshop, or carried out on the building site, provides different methods. However the “Push fit” plumbing systems are the most common for domestic plumbing, because it´s quick to install, without the need for tools, glues or heat. These systems are normally patented “O”-ring-sealed mechanical couplings. Each system uses its own coupling, and they're often not interchangeable with those of other systems**.** In all cases the manufacturer's specific installation instructions should be followed when installing push fit fittings.

“Push Fit” Plumbing System

All push fit fittings comprise of four basic elements: a fitting body, in which all the components are housed, together with a cap (which may or may not be removable) to hold the components in the fitting; a sealing mechanism, usually either an 'O' ring or ring seal; an integral gripping mechanism which permanently grips the pipe firmly in position; and a support sleeve which fits into the end of the pipe to prevent deformation when the pipe is inserted into the fitting. [15] [16]. Although push fit fittings are very simple to use, there are certain steps which must be taken to ensure that an effective joint is made:

1.Pipes carry depth insertion marks at intervals along the pipe. The pipe should be cut square at a depth insertion mark, using a purpose-designed cutter. The end should be free of swarf. The support sleeve should be inserted into the pipe end (Figure 13). [15] [16]

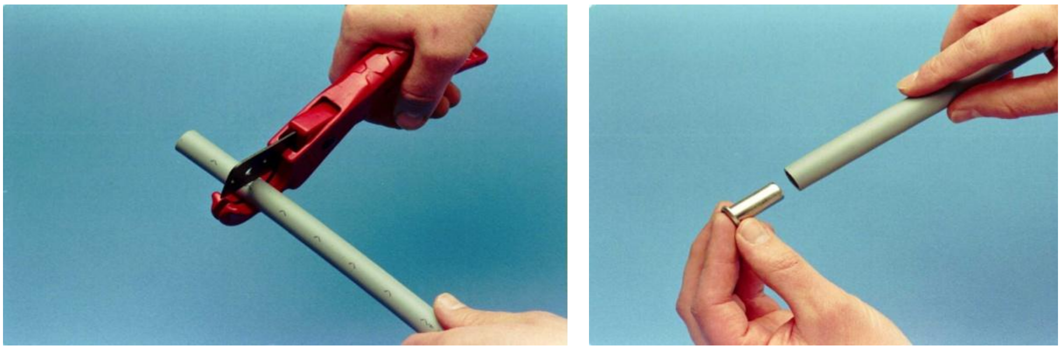

Figure 13 – Square cut of the pipe followed by support sleeve insertion [15] [16]

2.The pipe should be pushed firmly into the fitting until the next depth insertion mark reaches the end of the cap. The pipe should be tugged back, to ensure that the gripping mechanism has engaged on the pipe (Figure 14). [15] [16]

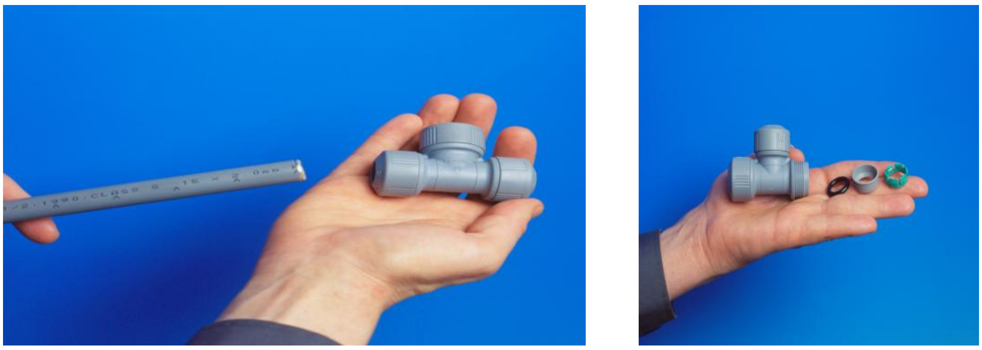

Figure 14 – Pipe insertion into the fitting [15] [16]

4 Analysis and conclusions

This paper follows the one presented in the 37th CIB W062 International Symposium, September 25th-28th 2011, in Aveiro-Portugal, named “New Materials and Technologies in Building Water Piping Systems” [2]. In the first paper [2] it was presented the main advantages and limitations of two metallic piping systems (copper and galvanized steel), two plastic piping systems (PEX and PP-R) and a composite piping system (multilayer). In this paper is analyzed the main advantages and limitations of a metallic piping system (stainless steel), and three plastic piping systems (UPVC, CPVC, and PB). For both papers the conclusions are similar, and are the following:

1) Despite the rapid technological evolution of the systems used for sanitary water installations, as a result of the recent emergence of new piping systems that seek the high performance with the low installation time and cost, we can conclude that there are no perfect water piping systems [2].
2) There are, however, systems that seem to be more suitable or appropriate for a particular type of installation. In fact, if it is intended to install a sanitary piping network with high extension, subjected to a high thermal gradient, for which the mechanical resistance to external loads is an important issue, a metallic water piping system, as stainless steel, is a solution almost unbeatable.
3) If it is intended to install a sanitary piping network with a complex design, with low thermal losses, for which the cost of a skilled installation has a considerable weight, the plastic water piping systems like CPVC or PB are easier to install.
4) It is expected, in future, that the evolution of the sanitary water piping installations won´t be at the level of the materials and technologies, but especially at the level of the installation methods. Pipes behind walls or under floors are doomed to failure [2].
5) All water piping systems should be installed inside a accessible duct, or inside a false ceiling that covers up the exposed piping network. The construction of technical galleries, ducts or removable ceilings in buildings is the answer to reduce leakage damages and to avoid moisture pathologies.

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6 Presentation of Author

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Soluble components from rubber used to waterproof of stainless steel pipe fittings in pure water

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Abstract

In production facilities such as pharmaceutical plants and food processing plants, pure water, water that has been further decontaminated, is supplied for use as service water for production and cleaning in order to prevent pollution in water-related activities. In a plumbing system for supplying pure water, in the case where the required pressure is high and the system is subject to disinfection by hot water, etc., thin-walled stainless steel tubes with a wall thickness of 1 mm to 1.5 mm are employed. In recent years, as the number of craftsmen of construction decreases and grow younger, junction by pipe fitting of the mechanical type which allows thin-walled stainless steel tubes to be processed and connected at construction sites has become mainstream in place of welding junction by TIG for junction of thin-walled stainless steel tubes at construction sites. Gaskets used on seal points in pipe fitting of the mechanical type employ O-rings made from synthetic rubber for product weight saving and construction simplification, etc. However, components, etc., that dissolve in water from locations where synthetic rubber contacts pure water are still not well understood . This study has applied an accelerated test to pipe fittings used for the system supplying pure water and clarified components dissolved from synthetic rubber used on seal points.

Keywords

Synthetic rubber; pure water; soluble components; pipe fitting of the mechanical type

1 Introduction

The water and hot water supply systems in Japan are built on the premise that water supplied by them is safe to drink. Therefore the following factors must be taken into account in terms of safety, durability and economy of the system:

a) Water supplied by the system should be free of any toxic substances.
b) The system should be reasonably durable against corrosion, earthquake, etc.
c) The materials used to build the system should be 100% recyclable.

To meet these requirements, stainless steel has been widely used for both public water and interior piping systems particularly in buildings such as hospitals, hotels, and other pubic buildings where safety, durability and economy play an important role.

These plumbing systems make use of thin-walled stainless steel tube with thickness of 1 mm to 1,5 mm having good manipulability as prescribed in JIS G3448, and pipe fitting of mechanical type that is easily handled and connected on construction sites.

Recently a number of factories have begun to use stainless steel plumbing systems, and the types of fluids for which the systems can be used are also growing in number. Some production facilities and semiconductor plants use pure water for cleaning. In contrast to regular water supply systems, systems that run pure water must be protected from water contamination caused by soluble components of the piping material. For this reason degreased and cleaned thin-walled stainless steel tubes that have received passivation treatment have been employed to prevent water quality as measured by electrical conductivity, TOC, etc. from degrading.

Although pipes in the pure water supply system are normally put together through welding or using flanges made of PTFE (Poly tetra fluoric ethylene), the use of mechanical type pipe fitting is expected to grow in the future because of its ease of manipulability.

However, there are some concerns about water contamination as chemical components of synthetic rubber used in pipe fitting of mechanical type are known to dissolve into pure water.

In this study an accelerated test was conducted using HNBR, synthetic rubber for general purpose, which is widely used in gaskets of mechanical type pipe fitting and newly developed fluororubber as test samples. The test samples were dipped into pure water to determine what components of synthetic rubber are likely to dissolve into pure water.

2 Materials of rubber

1.HNBR
Hydrogenation-acrylonitrile-butadiene Rubber
2. Fluororubber
Vinylidene fluoride- fluoromethyl vinyl ether -tetrafluoroethylene terpolymer
3. Identification method
JIS K 6230:2006 Rubber-Identification-Infrared spectorometric method
JIS K 6231:2004 Rubber-Identification of polymers (single polymers and blends)-
Pyrolytic gas chromatographic method

3 Dipping treatment in pure water

Treatment conditions
1. Dipping liquid : pure water prepared by equipment Nimi pure S-100,
electrical conductivity 0.020mS/m
2. Wetted part area : 20cm^2/L (JIS K6353:1997 Rubber goods for water works)
3. Treatment temperature: 20°C, 60°C, 80°C
4. Treatment time : 300 hours
5. Test specimen : Dumbbell Die 7(JIS K 6251:2010)
6. Dipping bottle : Heat-resistant glass (PYREX), Cap: Fluororesin (PTFE)
7. Stirring bar : Fluororesin (PTFE)
8. Stirring condition: 250 rpm by electromagnetism stirrer

4 Examination

4.1 Observation of Sample surface by scanning electron microscope (SEM)

1. Equipment : JEOL JSM-5610
2. Accelerated voltage : 10Kv
3. Magnification : ×500, ×1000
4. Observation samples : before treatment, after dipping test
5. Surface preparation : Gold sputtering

4.2 Hardness test and tensile test

1. Hardness test
(a) Test methods : JIS K 6253(2012) Rubber, vulcanized or thermoplastic –
Determination of hardness
(b) Room temperature : 23 ^{o}C
(c) Number of specimens: 5 specimens

2. Tensile test
(a) Test methods : JIS K 6251(2010) Rubber, vulcanized or thermoplastic –

Determination of tensile stress-strain properties
(b) Speed of testing : 200mm/min
(c) Tester capacity : Load cell type 100 N
(d) Equipment : INSTRON 5567A system for materials test
(e) Room temperature : 23 ^{o}C
(f) Number of specimens : 3 specimens

4.3 Electrical conductivity of the dipping water

1. Test Method : Standard Methods for the Examination of Water 2001 VI-1 10.2, electrode method
2. Measurement samples: Using the dipping water treatment of 20°C, 60°C, 80°C and hold 8 hours room temperature in airtight bottle.
3. Measurement temperature: 23 °C
4. Blank : The examination water without a test rubber sample

4.4 Measurement for dipping water of Total Organic Carbon (TOC)

1. Test Method : Combustion oxidation - infrared method of TOC
2. Measurement samples: Dipping water treatment of 20°C, 60°C, 80°C
3. Number of specimens : 2 specimens

4.5 Analysis of organic component in dipping water

1. Gas Chromatograph - Mass Spectrometry (GC-MS)
2. Equipment : Agilent Technologies 6890 Series, 5973N
3. Column : J&W DB-5 length 30m, inside diameter 0.25mm, film thickness 0.25μm
4. Column temperature : 60 °C (2 min) — (10 °C / min)→280 °C (20 min)
5. Temperature of injection Port: 280 °C
6. Temperature of transfer line : 280 °C
7. Carrier gas : He
8. Injection method : Pulsed splitless
9. Injection volume : 1μL
10. Measurement mode : SCAN
11. Scan range : m/z = 30~ 550

4.6 Analysis of anion in dipping water by Ion Chromatography

1. Equipment : Metrohm compact IC 761
2. Column : Shodex IC SI-90 4E 4mm ID×250mmL
3. Column temperature : 23 °C
4. Eluent : 1.8mM-Na_2CO_3+1.7mM-$NaHCO_3$
5. Flow rate : 1.2 mL/min
6. Detection : conductivity detector
7. Injection volume : 20μL

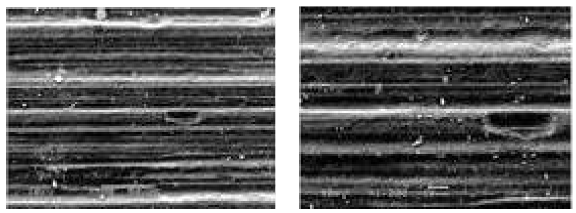
5 Results of examination

5.1 Observation of sample surfaces by scanning electron microscope (SEM)

The results of observation are shown in Figures 1-1 ~ 2-2.

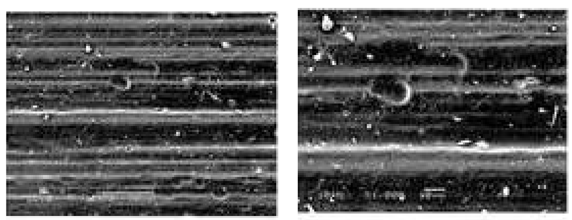
1.HNBR

Observation at high magnification revealed no cracks or ruggedness on the surfaces of the samples under any dipping temperature conditions indicating there have been no changes in the samples before and after processing.



×500 ×1000

Figure 1-1 Before treatment (HNBR)



×500 ×1000

Figure 1-2 After treatment at 80 ^{o}C (HNBR)

2. Fluororubber

Observation at high magnification revealed no cracks or ruggedness on the surfaces of the samples under any dipping temperature conditions indicating there have been no changes in the samples before and after processing.

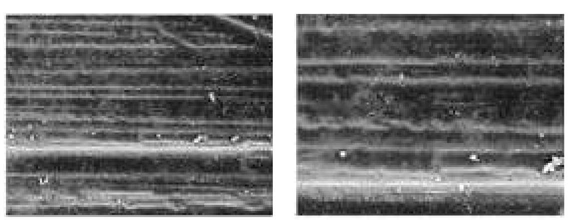


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Figure 2-1 Before treatment (Fluororubber)

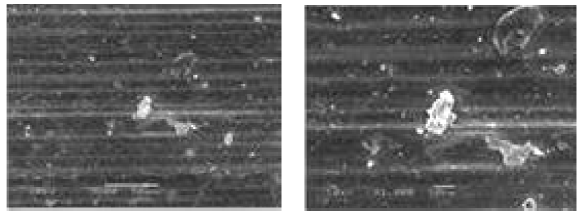

Figure 2-2 After treatment at 80 °C (Fluororubber)

5.2 Hardness test and tensile test

The results of hardness test are shown in Figures 3-1,3-2, and the results of tensile test are shown in Figures 4-1~5-2.

1.Both HNBR and fluororubber showed some indications of softening after dipping.

2.Neither HNBR nor fluororubber showed any changes in tensile strength, 100% / 300% tensile stress or stretches in cutting before and after dipping.

3.Changes in hardness were less than 2. Practically no changes were seen in tensile strength or tensile stress, and there were no significant changes relative to temperature in stretches in cutting.

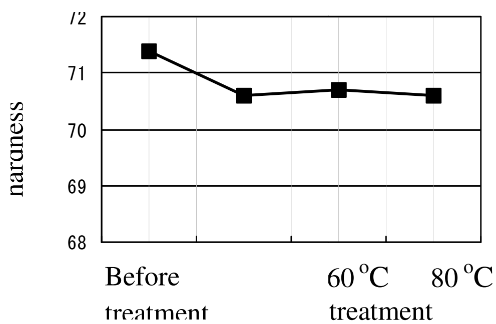

Figure 3-1 Change of the hardness in HNBR(5 samples average)

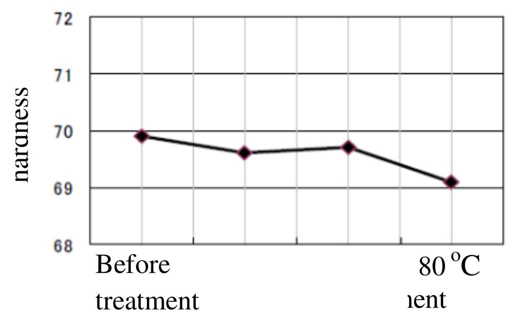

Figure 3-2 Change of the hardness in Fluororubber(5 samples average)

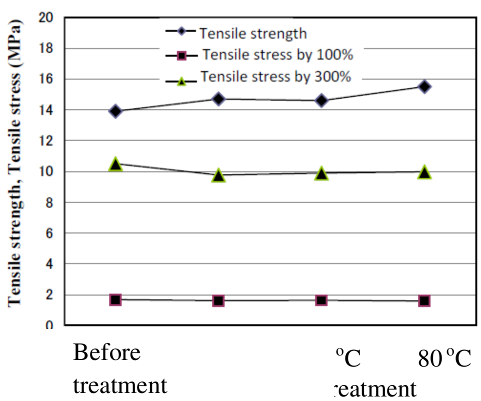

Figure 4-1 Tensile strength, Tensile stress by 100%and300% in HNBR(3 samples median)

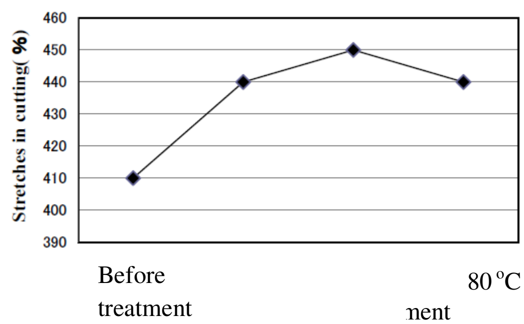

Figure 4-2 Stretches in cutting in HNBR(3 samples median)

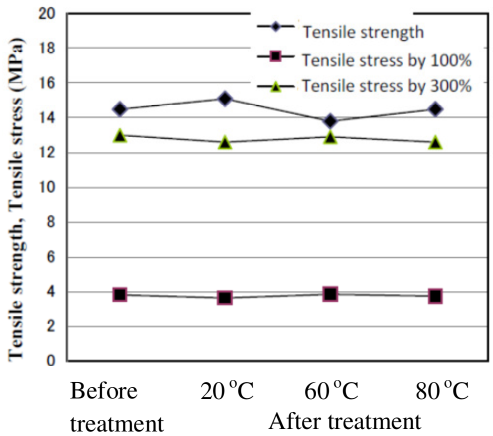

Figure 5-1 Tensile strength, Tensile stress by 100%and300% in Fluororubber (3 samples median)

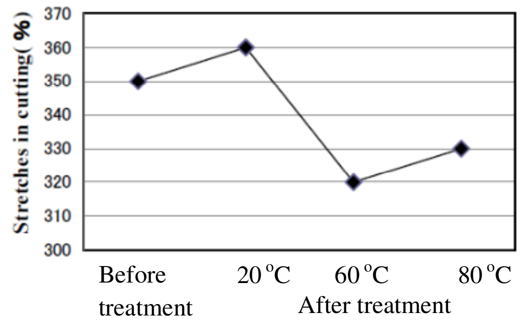

Figure 5-2 Stretches in cutting in Fluororubber (3 samples median)

5.3 Electrical conductivity of the dipping water

The differences in electrical conductivity between the blank without a test rubber sample and dipping water with a test rubber sample are shown in Figure 6.

1.HNBR samples showed increase in electrical conductivity after dipping .

2.Fluororubber also showed some increase in electrical conductivity after dipping at 20 °C~80 °C, but the increase was much smaller than HNBR and therefore its influence on water quality is considered negligible.

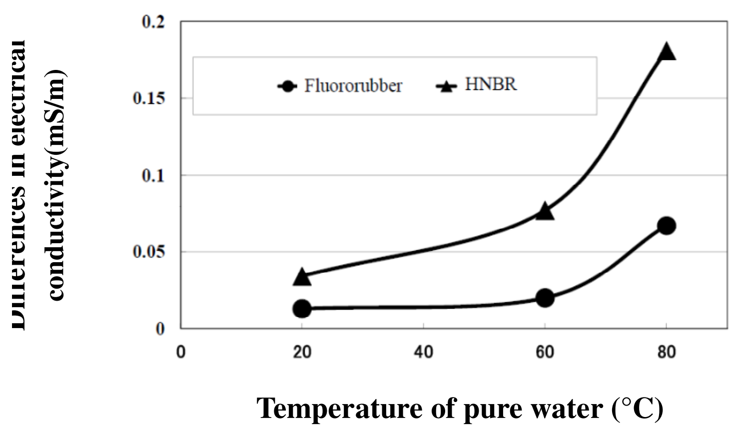

Figure 6- Differences in electrical conductivity

5.4 Measurement for dipping water of total organic carbon (TOC)

The measurements of total organic carbon (TOC) are shown in Table 1.

1.Total organic carbon (TOC) was detected under all temperature conditions in dipping water with HNBR samples.
2.No total organic carbon was detected under any of temperature conditions in dipping water with fluororubber samples.

Table 1 Total organic carbon (mg/L)

After treatment according to the temperature	HNBR	Fluororubber	Before treatment
20 °C	1.21	N.D. (<0.2)	N.D. (<0.2)
60 °C	3.95	N.D. (<0.2)	
80 °C	5.48	N.D. (<0.2)	

5.5 Analysis of organic component in dipping water

Major ingredients detected in dipping water are shown in Table 2.
1.Organic ingredients were found in dipping water with HNBR samples under all temperature conditions.
2.Though no organic additive ingredients were found in dipping water with fluororubber samples at 20 °C, co-cross-linking agent (TAIC) was detected in small amount at 60 °C and 80 °C.

Table 2 The organic ingredients in the treatment water which was detected in GC/MS

After treatment according to the temperature	The main detection ingredients	
	HNBR	Fluororubber
20 °C	・diisopropyl phenol ・biacetyl benzene※1 ・4'-(1-Hydroxy-1-methylethyl)acetophenone※2 ・2-Mercaptobenzimidazole※3	Organic additive ingredient isn't detected.
60 °C、80 °C	・diisopropyl phenol ・biacetyl benzene※1 ・4'-(1-Hydroxy-1-methylethyl)acetophenone※2 ・2-Mercaptobenzimidazole※3 ・Di (Butoxy ethoxy Ethy) Adipate ※4	TAIC (Triallyl isocyanurate)

※１ : The resolvent of the organic-peroxide cross-linker
※２ : The resolvent of the organic-peroxide cross-linker
※３ : The benzimidazole antioxidant
※４ : The adipate plasticizers

5.6 Analysis of anion in dipping water by Ion Chromatography

Table 3 shows anion analysis of dipping water.
No anion was detected in any of dipping water with HNBR or fluororubber samples.

Table 3 The result of anion analysis of HNBR and Fluororubber

anion	After treatment according to the temperature			quantitive lower limit (mg/L)
	20 °C	60 °C	80 °C	
F^-	N.D.	N.D.	N.D.	0.02
Cl^-	N.D.	N.D.	N.D.	0.05
Br^-	N.D.	N.D.	N.D.	0.05
NO_3^-	N.D.	N.D.	N.D.	0.1
NO_2^-	N.D.	N.D.	N.D.	0.1
PO_4^{3-}	N.D.	N.D.	N.D.	0.2
SO_4^{2-}	N.D.	N.D.	N.D.	0.2

6 Considerations and conclusions

6.1 HNBR

1. No degradation of physical properties, cracks or ruggedness on the surface was seen at 20 °C, 60 °C, or 80 °C, but there were some indications of softening.
2. Electrical conductivity went up at 20 °C, 60 °C, and 80 °C in the ascending order with the highest at 80 °C and the lowest at 20 °C.
3. TOC was detected under all temperature conditions: the amount was the greatest at 80 °C and the least at 20 °C.
4. According to analysis of organic ingredients, benzimidazole antioxidant was detected at 20 °C, benzimidazole antioxidant and plasticizer at 60 °C and 80 °C, and resolvent of the organic-peroxide cross-linker in all dipping water samples.
5. Anion was not detected under any of the temperature conditions.

It can be concluded from the above findings that HNBR does have influence on water quality as electrical conductivity went up, and TOC and organic ingredients were detected at the temperature range of 20 °C ~ 80 °C.

6.2 Fluororubber

1. No degradation of physical properties, cracks or ruggedness on the surface was seen at 20 °C, 60 °C, or 80 °C, but there were some indications of softening.
2. Electrical conductivity in dipping water went up at all temperature conditions (20 °C, 60 °C, 80 °C), but the increase was minimum at 20 °C.
3. No TOC, organic ingredients or anion was detected in dipping water at 20 °C.

4. Although no TOC was detected at 60 ^{o}C and 80 ^{o}C, co-cross-linking agent (TAIC) was found in small amount at these temperature.

As seen in the above, no components of fluororubber, a cross-linked peroxide, dissolved into dipping water at the temperature around 20 ^{o}C. Therefore it can be concluded that fluororubber has relatively no effects on the quality of pure water and can safely be used as a gasket material of pipe fitting.

Although co-cross-linking agent (TAIC) contained in fluororubber was found in minuscule amount in dipping water over 60 ^{o}C, this finding should not negate the effectiveness of fluororubber as a gasket material since the area of a gasket used in mechanical type pipe fitting for a thin-walled stainless steel tube that comes in contact with water is only 10 to 20% of the whole surface area of a gasket, and it is highly unlikely that water quality is affected to any significant degree.

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8 Presentation of Author

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Case Analysis of Stainless Steel Corrosion in Hot Spring Waters and Using Titanium as a Measure against Corrosion

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Abstract

In hot spring facilities in Kusatsu, Gunma Prefecture, in about two months, SUS304 stainless steel handrails corroded and dissolved uniformly in acid sulfate-chloride spring water containing hydrogen sulfide. Corroded samples were analyzed, remaining handrails were observed closely, an immersion test was conducted at the sources of springs, and corrosion potentials were measured. The result showed that the causes of the corrosion were low pH (pH 2 or less) and the corrosion action of free hydrogen sulfide. Because the handrails corroded in only the type of spring water containing hydrogen sulfide at the two sources of springs with a pH of 2 or less, hydrogen sulfide had a particularly significant impact on the corrosion and accelerated the active dissolution of SUS304 stainless steel. As a measure against corrosion, titanium instead of SUS304 stainless steel was used for handrails. Rusting or local corrosion was not observed about 18 months after use.

Keywords

stainless steel, corrosion, hot spring water, pH, H_2S, corrosion products, corrosion potential

1 Introduction

Various special qualities can be seen in the natural water of hot springs as a result of geological characteristics. Depending on the hot spring, the construction and equipment materials used in the hot spring facilities can be affected by the water quality, and in particular metal materials can corrode in a short period of time.[1)-3)] This paper introduces a case study of corrosion in a short period of time of stainless steel (SUS304) handrails in the bathtubs at Kusatsu Hot Spring in Gunma Prefecture. Of the SUS304 handrails that were installed at one location in each of the four bathtubs, the part of the handrail immersed in the No. 1 bathtub (below the waterline) was dissolved by corrosion after about two months. Likewise for bathtub No. 2, the part of the handrail immersed in the bathtub (below the waterline) was dissolved by corrosion after about eight months. A site survey was performed after about 12 months, in which the state of corrosion of each of the handrails in the bathtubs was investigated. The source water of bathtubs Nos. 1 through 3 was acid sulfate-chloride spring water containing hydrogen sulfide (source A), and the water of bathtub No. 4 was acid sulfate-chloride spring water not containing hydrogen sulfide (source B). Table 1 shows the source name and location of each bathtub. The survey included visual inspection, analysis of corrosion products, water quality analysis, and measurement of corrosion potential of handrails on site. Also, as a measure against corrosion, handrails made from the alternative material titanium were used. The following is a report on results of the corrosion analysis of the stainless steel handrails, and the results of a survey of the state of corrosion of the titanium handrails 18 months after start of use.

Table 1 Source name and location of each bathtub

Bathtub No.	1	2	3	4
Source name	A	A	A	B
Location of bathtub	Indoor	Open-air	Indoor	Open-air

2 Survey, Test Methods, and Analysis Results

2.1 State of corrosion of SUS304 handrails

In bathtubs Nos. 1 through 3 which use acid sulfate-chloride spring water containing hydrogen sulfide (source A) for which corrosion was significant, the immersed parts of the handrails in bathtubs Nos. 1 and 2 were dissolved by corrosion after about 2 months and 8 months respectively, as stated above, and the lower parts of the handrails had sunk to the bottom of the bathtubs. The state of corrosion of handrails Nos. 1 and 2 is shown in Figs. 1 and 2. Below the waterline the thickness had been reduced and the metal disappeared, and the remaining lower part of the handrail (the bottom part) was significantly corroded so it was considered that there was uniform corrosion of the SUS304. In the handrail of bathtub No. 3 which was exposed to the same source A, after about 12 months, many microbubbles were generated from the immersed parts of the bathtub as shown in Fig. 3. Thin dark brown corrosion layer formed on immersed parts (See Fig. 4). On the other hand, in the handrail of bathtub No. 4 which is the only bathtub that uses acid sulfate-chloride spring water not containing hydrogen sulfide (source B), off-white scale adhered to the handrail directly above the water line, and below and around the scale pitting corrosion and discoloration with rust was seen. However, localized corrosion or discoloration with rust was not seen in the immersed parts or the parts exposed to air.

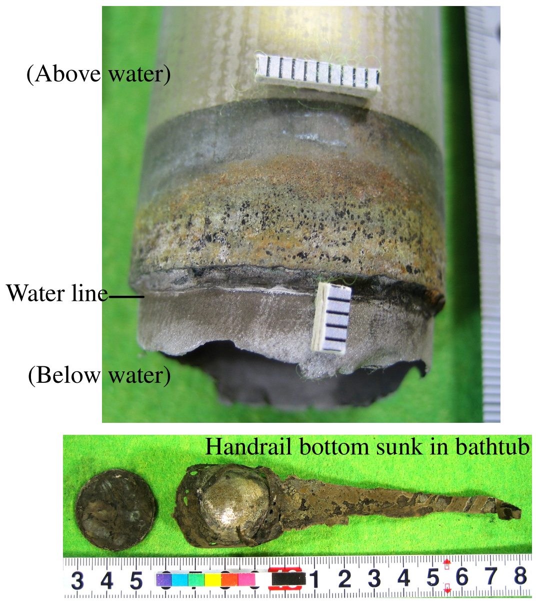

Figure 1 - State of corrosion of handrail in bathtub No. 1, About 2 months use

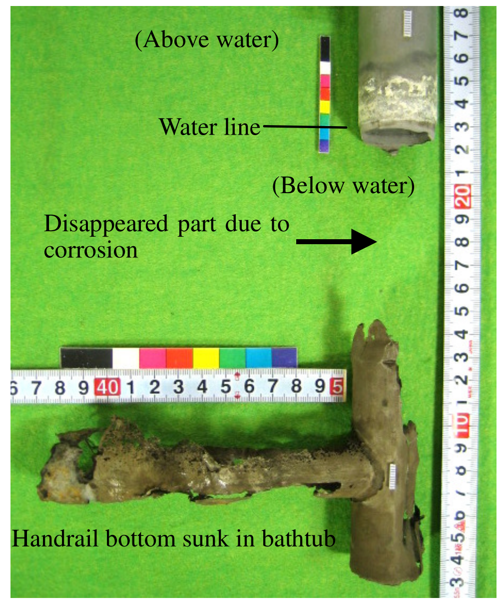

Figure 2 - State of corrosion of handrail in bathtub No. 2, About 8 months use

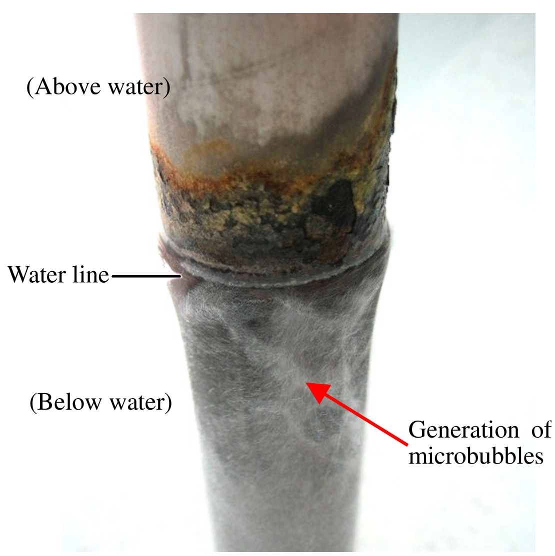

Figure 3 - State of active dissolution of handrail in bathtub No. 3, About 12 months use

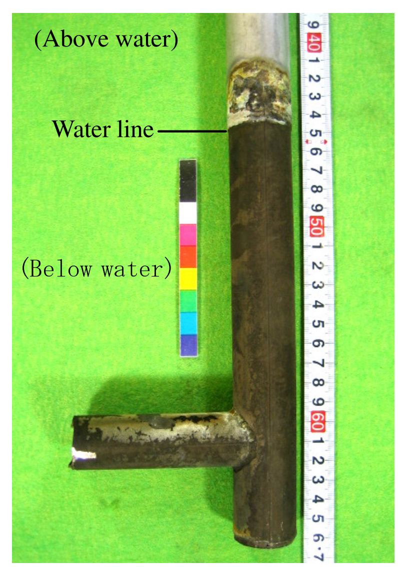

Figure 4 - State of corrosion of handrail in bathtub No. 3, About 12 months use

2.2 Analysis of corrosion products

Rust from the waterline of the handrail of bathtub No. 1 was scraped off, and the results of analysis by EDX (JEOL Ltd., JSM-6300) are shown in Fig. 5. Apart from the components of the material, S was strongly detected. Also, according to EPMA (JEOL Ltd., JXA-8100) analysis results for the cross-section of the rust layer shown in Fig. 6, S, O, Cr, Fe, and Ni are distributed throughout the whole layer. This infers that corrosion products of sulfide or sulfate of Fe, Cr, Ni were formed. From the analysis results of XRD (MAC Science MXP18 and Rigaku RU-2000) on rust samples from the handrails of the No. 1 and No. 3 bathtubs, only nickel sulfate was detected. In all cases the peak was broad, suggesting a compound with low crystallinity. In the case of non-crystalline rust, the state of the compound is estimated from the bonding energy, so state analysis was carried out by XPS (Shimadzu Corporation, ESCA-3200). The XPS analysis results for the rust from bathtub No. 3 are shown in Fig. 7. Figure 7 suggests the generation of sulfides FeS, FeS_2, NiS, sulfates $FeSO_4$, $NiSO_4$, oxides Fe_2O_3, Cr_2O_3, CrO_3, and hydroxides $Cr(OH)_3$, etc. Also, as shown in Figs. 5 and 7, small quantities of copper and its compounds (Cu_2S, $CuSO_4$) were detected. According to the water quality analysis results for the two source waters shown in Table 2, the concentration of copper in source A was less than 0.01 mg/L, and the quantity of copper contained in the SUS304 of the handrails was 0.3% (mass%, x-ray fluorescence analysis, Shimadzu Corporation, MFX2400), so it is considered that the copper originated from the handrail material (an impurity). The quantity of copper in the SUS304 is minute, but there is a possibility that it was detected due to being concentrated in the rust.

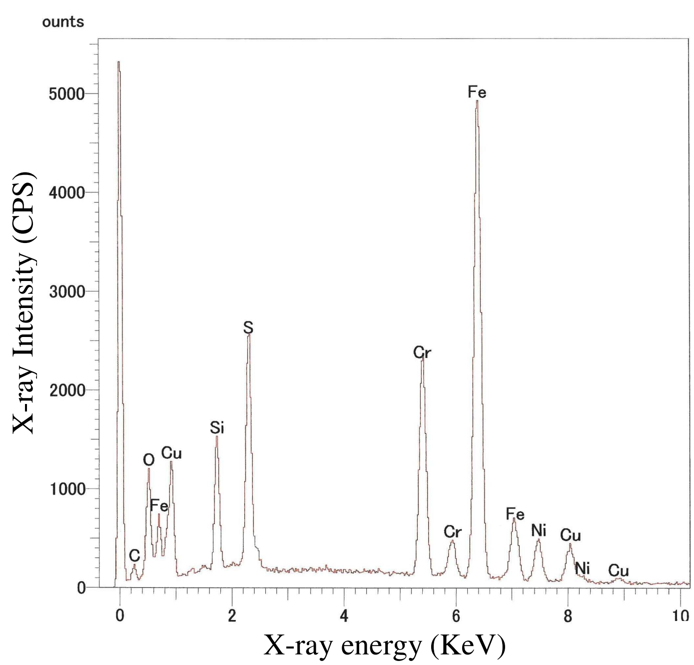

Figure 5 - Analysis result by EDX of corrosion products of SUS304 handrail in water line part

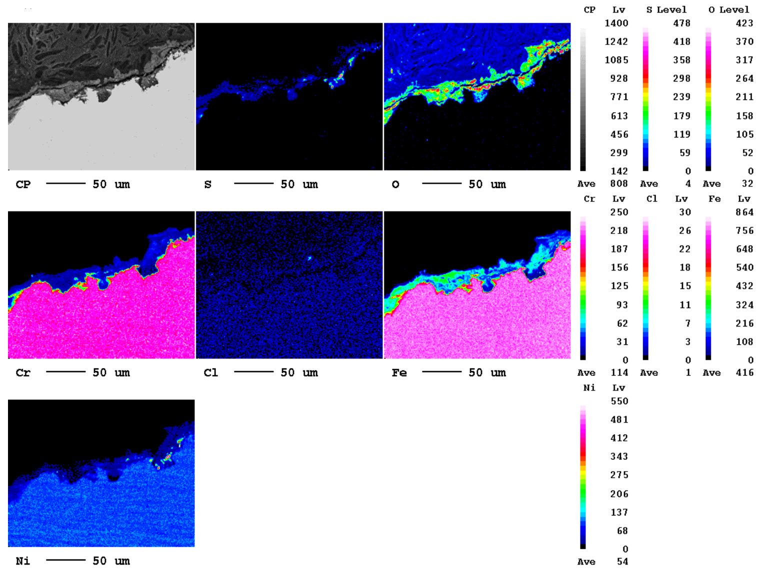

Figure 6 - Analysis result by EPMA of corrosion products of SUS304 handrail in water line part(bathtub No. 1)

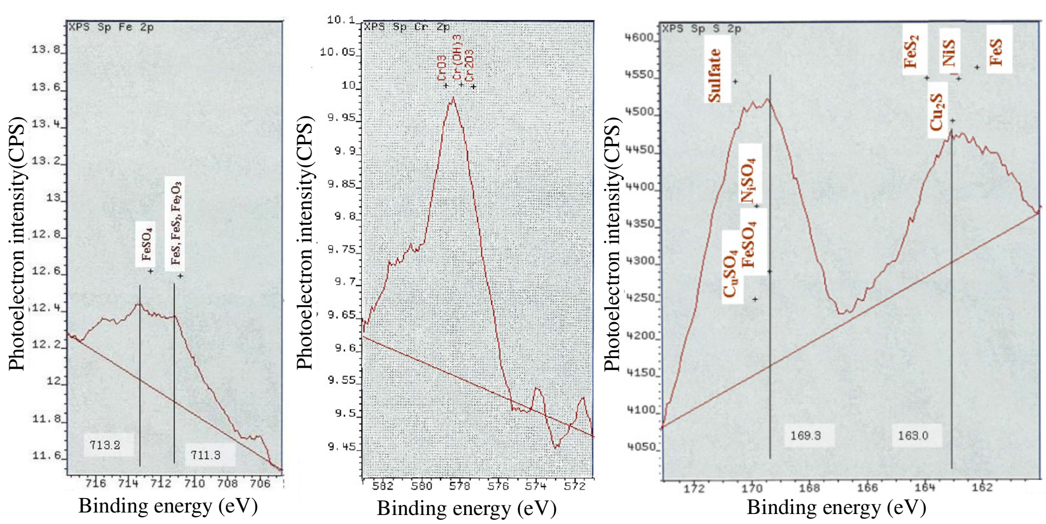

Figure 7 - Analysis result of corrosion products of SUS304 handrail by XPS in bathtub No.3

Table 2 Water quality of hot spring source

Water quality item	Unit	A	B
pH		1.9	1.7
Tuebidity	TU	2.0	$<$0.2
Color	CU	4.4	4.9
Conductivity	mS/m	559	1120
Ca-Hardness	mg/L as $CaCO_3$	172	229
Total-Hardness	mg/L as $CaCO_3$	304	423
Cl^{-}	mg/L	289	689
SO_4^{2-}	mg/L	848	1400
S^{2-}	mg/L	4.0	$<$0.1
$KMnO_4$ Consumption value	mg/L	21.2	9.6
Residue	mg/L	1940	3290
Soluble SiO_2	mg/L	168	361
Total SiO_2	mg/L	181	387
Fe	mg/L	12.7	4.09
Cu	mg/L	$<$0.01	0.01
Mn	mg/L	1.82	2.92
Na	mg/L	56.3	102
K	mg/L	27.9	50.8
Free H_2S *	mg/L	7.3	0..0

* Analysis value by Gunma environmental hygiene center

2.3 Water quality analysis

pH was measured on site, and the other water quality items were promptly analyzed after refrigerating the water and transporting it to the analysis laboratory. The analyses were carried out in accordance with test methods for industrial water analysis standard (JIS K 0101), wastewater analysis standard (sulfide ions only, JIS K 0102), and the analysis organization's standards. The water in each case had a pH of less than 1.9 indicating strongly acidic water, source A had a free hydrogen sulphide H_2S content of 7.3 mg/L, and source B had a free H_2S content of 0.0 mg/L. Source A had unmistakable odor of hydrogen sulfide. SO_4^{2-}, Cl^- were magnitude of several tens greater than for normal tap water in Japan, but the ratio SO_4^{2-}/Cl^- (mg/L) was 2.93 for source A, and 2.03 for source B, and in addition the quantity of SO_4^{2-} was high, indicating a tendency to inhibit corrosion due to chloride ions.

2.4 Measurement of corrosion potential of handrails and test specimens

The corrosion potential of the handrails was measured on site in the condition of use using an electrometer (Toho Technical Research, EM-02) using a saturated calomel electrode (SCE) as standard. The materials of the test specimens for measurement of corrosion potential were SUS304, SUS316, which had a square 10 mm × 10 mm with a wet No. 600 finish polished surface and a periphery that was covered with epoxy resin. Also, an SUS304 support rod (covered with epoxy resin including the soldered joint to the test specimen) was fitted for connecting the lead wires for measurement of the corrosion potential. Measurement of the corrosion potential of the test specimens was carried out by soaking each of the test specimens for 41.5 hours in each of the source waters (source A 46.2°C, source B 47.8°C) which constantly flowed into resin containers (665 × 425 × 75 mm), using an electrometer with a saturated calomel electrode (SCE) as standard. The potential was read after allowing the electrodes to stabilize sufficiently after soaking. Figure 8 shows a view of the measurement of the corrosion potential of the handrails.

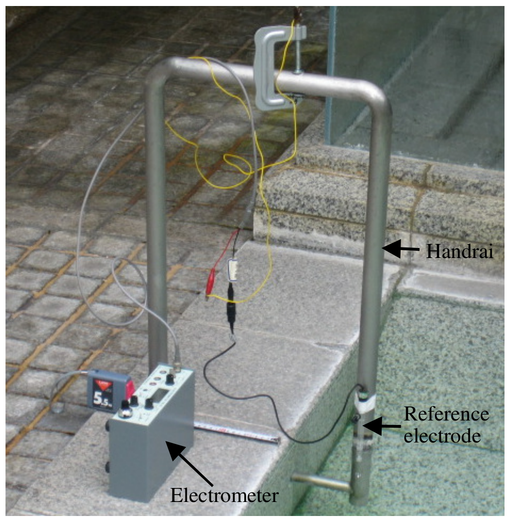

Figure 8 - Corrosion potential measurement of handrail

Table 3 Corrosion potential of SUS304 stainless steel in the two bathtubs with different sources (V vs.SCE, No. 3 and 4)

Bathtub No.	3	4
Corrosion potential	-0.494 (43.1℃)	-0.023 (43.1℃)

The measurement results for the corrosion potential of the handrails of bathtubs No. 3 and No. 4 are shown in Table 3. The corrosion potential of the SUS304 from the handrail of bathtub No. 3 with source A was -0.494 V (vs. SCE), which is significantly less noble potential so it is considered that it was de-passivated. On the other hand the corrosion potential of the handrail in bathtub No. 4 with source B was -0.023 V (vs. SCE), which was in the passivity state. The corrosion potential measurement results for each test specimen are shown in Fig. 9. The corrosion potential of the SUS304 test specimens in source A varied at a level that was close to that of carbon steel from the start of immersion. The SUS316 exhibited a similar less noble potential as that of SUS304 at the beginning, and thereafter became high potential to close to 0 V. However after 41.5 hours it became unstable becoming less noble again to -0.157 V. The corrosion potential of both SUS304 and SUS316 in source B varied close to 0 V, and the results showed that the SUS316 was several tens of mV more noble compared with SUS304. The surface condition of the SUS316 and SUS 304 test specimens after soaking in source A initially became black soon after immersion, and after completion of the test the color changed to a blackish brown color on all surfaces as shown in Fig. 10, but the color of the SUS316 was relatively lighter. In source B, no signs of corrosion were seen in both SUS304 and SUS316, and they retained their metallic luster.

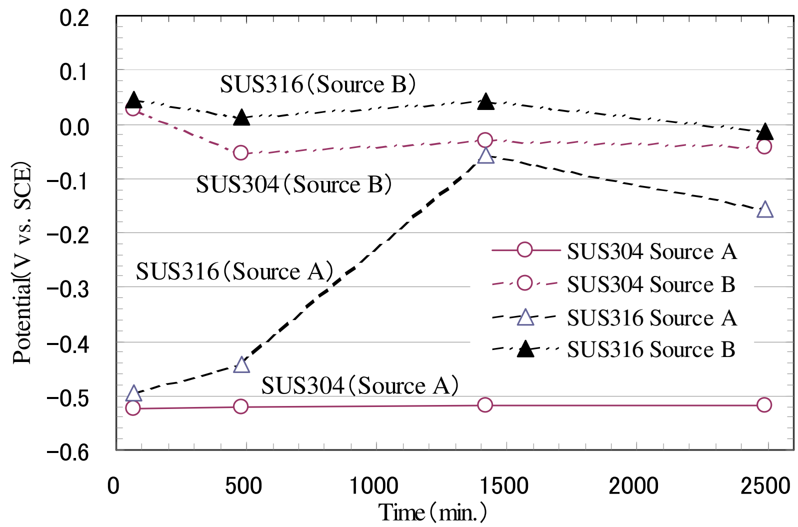

Figure 9 - Change over time on corrosion potential of SUS304 and SUS316 test pieces in hot spring source

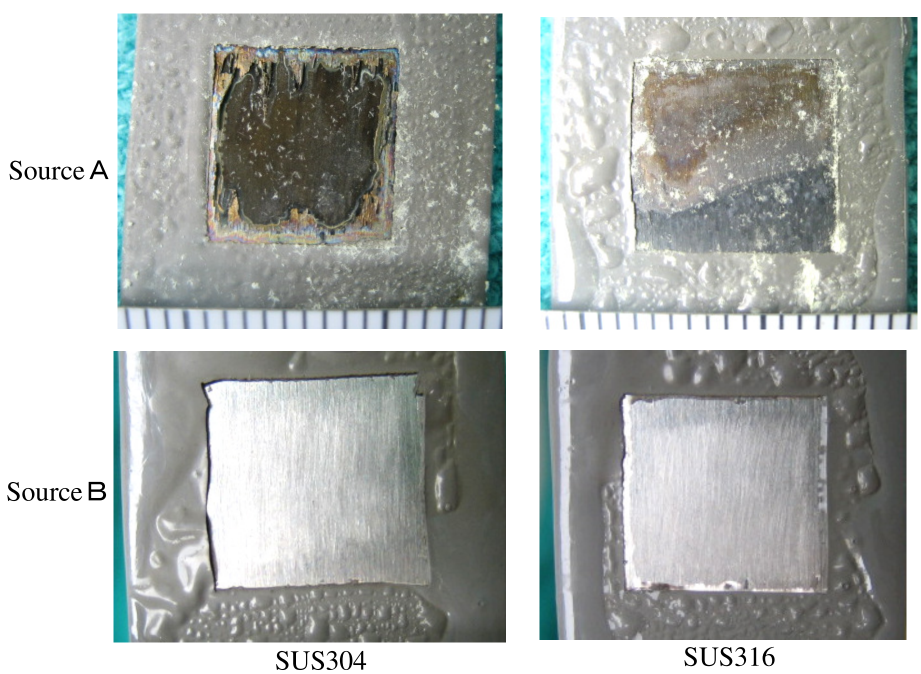

Figure 10 - Appearances of stainless steel test pieces in the hot spring source after 41.5 hours dipping

2.5 Discussion on cause of corrosion

Normally the depassivation pH (pH_d) of SUS304 and SUS316 is considered to be about pH 2 or less. In this case in source A with a relatively high pH SO_4^{2-}/Cl^- (mg/L) ratio and low chloride ion concentration, corrosion was generated progressively with time. Also the corrosion potential of the SUS304 handrail in source A was about -0.5 V (vs. SCE), and the SUS304 test specimens changed to a brownish color soon after immersion with a corrosion potential that was virtually the same (-0.525 V vs. SCE). Also it is suggested that sulfides of the elements that compose the SUS304 were generated as rust on the handrail in source A, so it is considered that the passive film broke down under the effect of the low pH of pH 2 or less and the free hydrogen sulfide. As a result, it is inferred that active dissolution occurred in the acidic spring water with many dissolved salts, and it is considered that the fine bubbles that can be seen in Fig. 3 is hydrogen generated by cathodic reduction reaction. In addition, corrosion dissolution only occurred in the handrail in source A whose pH was 2 or less and contained free hydrogen sulfide, so it is considered that the hydrogen sulfide in particular had a big effect on the degradation of the passive film. As shown below when hydrogen sulfide dissolves in water it forms dibasic acid and generates sulfide ions S^{2-}. The S^{2-} reacts with the components of the passive film to form sulfides and by degenerating the passive film it is considered that active dissolution accelerated. The reason dissolution of the handrails in each bathtub with source A occurred in a time sequence (No. 1 → No. 2 → No. 3) is considered to be because the water quality and the temperature conditions (No. 2 was outdoors so slightly lower) did not change so the corrosion was a probabilistic phenomenon.

[Dissociation of hydrogen sulfide]

$H_2S \rightarrow H^+ + HS^-$

$HS^- \rightarrow H^+ + S^{2-}$

[Generation of sulfides: iron sulfide (II)]

$Fe^{2+} + S^{2-} \rightarrow FeS$

Also in the past research, in an acidic aqueous solution that contains hydrogen sulphide H_2S (H_2S: 0-15ppm by mole, pH 3, 60°C), it was shown that the polarization resistance (Rp) of SUS304L was reduced, and the critical current density for passivation (i_{cr}) was greatly increased.[4)] This suggests that in an acidic aqueous solution that contains hydrogen sulphide H_2S, the resistance of the surface film of SUS304L is reduced, and passivation becomes difficult. In this case, iron disulfide FeS_2 and iron sulfide (II) FeS were detected as sulfides on the surface of the test specimens.[4)] From this fact also it is inferred that hydrogen sulfide affected the dissolution of the passive film. This indicates that in a multi-Pourbxi diagram FeS_2 can exist in the acidic region of pH 2 or less.[4)]

On the other hand, in source B that is acid sulfate-chloride spring water not containing hydrogen sulphide, the corrosion potential of the handrails and the test specimens were in the passive region, and in the measurements taken to date there have been no signs of overall dissolution. However, as the pH is 1.7 which is below the depassivation pH (pH_d), and examples of corrosion of stainless steel handrails in other facilities that use source B have been seen, it is considered to be a corrosive environment.

pH_d = about pH 2 is an important index for determining uniform corrosion of SUS304, but the corrosivity is also affected by the components dissolved in natural water such as salts, etc. The corrosion phenomena observed in two source waters at less than pH_d indicates that the effect of hydrogen sulfide was very large.

3 Countermeasures

The use of SUS316 and SUS329J4L or other materials were investigated as alternative materials to SUS304. However, in corrosion test results by Iino and others[2)] on welded members in an acidic sulfur – sulfate spring water that was similar to source A, uniform corrosion occurred in SUS316 and localized corrosion occurred near the waterline in SUS329J4L, so titanium was selected for its technical safety from the point of view of corrosion resistance to spring water and strength.

3.1 Results of external observation of titanium handrails

Figure11 shows the external appearance of the titanium handrails at No. 1 bathtub (source A) and No. 4 bathtub (source B) after about 18 months. As shown in Fig. 11, after about 18 months a white scale can be seen directly above the waterline in the handrails of both the source A and source B bathtubs, but discoloration with rust or local corrosion has not been generated either in the immersed portion or in the portion exposed to air.

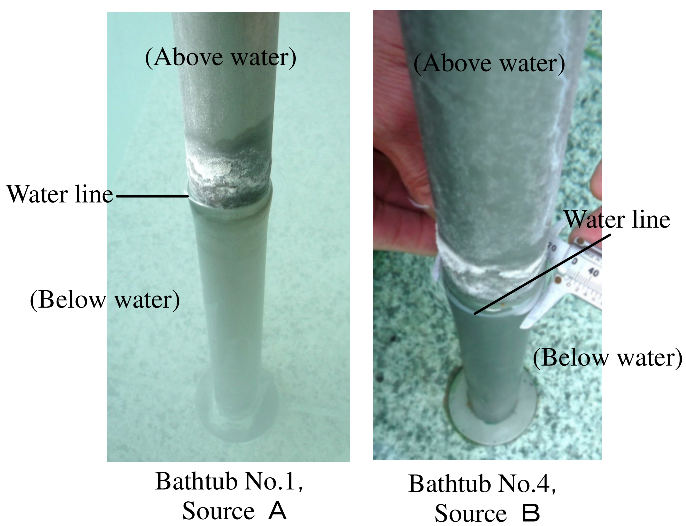

Figure 11 - Appearances of titanium handrail after about 18 months use

3.2 Titanium handrail corrosion potential measurement results

Figure 12 shows the corrosion potential of each bathtub immediately after installation and after about three months. It is considered that in all cases the potential is within the passive region of titanium. About three months of immersion, the potential in each bathtub became 0.3 to 0.5 V more noble compared with immediately after immersion. This infers that the oxide film of titanium surface increased with passage of time. Each of the potentials measured in source A are less noble compared with source B, so it is considered that the water quality of source A is affecting the surface oxide film of titanium.

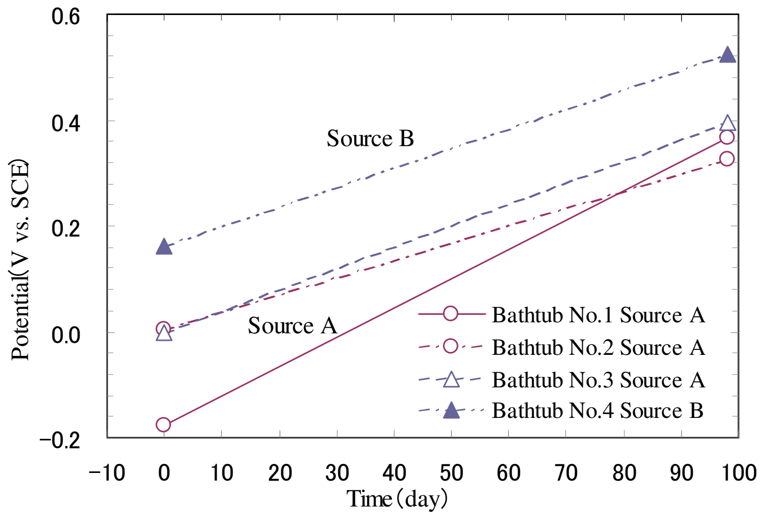

Figure 12 - Change over time on corrosion potential of titanium handrail

4 Conclusion

Observation of samples of corroded handrails, analysis of the corrosion products, analysis of the water quality, observation of the corroded state of handrails on site, and measurement of corrosion potential, etc., were carried out in order to determine the causes of and countermeasures against corrosion of SUS304 stainless steel handrails that occurred at Kusatsu Hot Spring in Gunma Prefecture. Also, a follow-up survey was carried out on the use of titanium as an alternative material as a countermeasure. The main results were as follows.

1) The corrosion potential of SUS304 handrails immersed in acid sulfate-chloride spring water containing hydrogen sulfide (source A: pH 1.9) became less noble significantly resulting in active dissolution with generation of hydrogen, so that the immersed portion was dissolved after about a minimum of two months.
2) On the other hand, the corrosion potential of SUS304 handrails immersed in acid sulfate-chloride spring water not containing hydrogen sulfide (source B: pH 1.7) was in the passive region after about 12 months and corrosion did not occur.
3) Discoloration with rust or local corrosion was not generated after about 18 months in either the immersed portion or the portion exposed to air of titanium handrails that were used in the two hot spring source waters as a countermeasure.

Corrosive environments containing hydrogen sulfide have long been known as sour environments, but the corrosion properties of stainless steel in strongly acidic environments containing hydrogen sulfide are not sufficiently known. In particular, for natural waters containing various types of ions such as hot springs there is academic data and indices for quantitatively evaluating uniform corrosion and local corrosion of stainless steels, but it is considered that it is not sufficiently known how well they correspond to actual corrosion phenomena in complex systems. In this paper one example has been introduced as a case study analysis of corrosion of SUS304 handrails at a hot spring having typical water quality, and discussed based on past research and measured data. In this case, titanium was selected as an alternative material based on its technical safety from the point of view of corrosion resistance with respect to the water quality and strength, which was required for urgent countermeasure construction. For the future it is considered that other metal materials, resins, or composite materials can also be considered from the point of view of cost performance with respect to corrosive water.

Acknowledgments

The authors would like to express their gratitude to Michiro Kanako of Nippon Steel Corporation and Tomoaki Saita of Nippon Metal Industry Co. Ltd., for their advice given during the course of this research, in particular regarding the countermeasures.

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The research on the corrective maintenance service for water supply and drainage system in high rise office building-taking one case as an example

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Abstract

In Taiwan, an average building lifecycle is approximately forty years old. The first high rise building was built in 1960s. At present, the extension of building lifecycle is getting a crucial issue in Taiwan. The building maintenance could be divided into three strategies: corrective maintenance, cyclical maintenance, and preventive maintenance. The maintenance area is separated into public and lessee area in an office building. The corrective maintenance in building facilities which included architectural hardware, mechanical electronics, air conditioning, water supply and drainage etc., is an essential requirement. This research aims at one case study which is a comparison between the realistic case and academic research in water supply and drainage system done by the previous research. The fault of the system during the operation which may caused by the behaviour of the user or the flaw of the system is going to be discussed. After clarifying the problem, the precaution and the cost of maintenance for the water supply and drainage system are proposed by this research.

Keywords

corrective maintenance; water supply and drainage system; facility management; high rise office building

1 Introduction

A building lifecycle takes the plan, design, construction, installation, commissioning, operation and decommission phases into account. Building usage highly demands both optimum operation and appropriate maintenance of facilities. Building facilities including architectural hardware, mechanical electronics, air conditioning, water supply and drainage and so on are the crucial factors that extend the building lifecycle. The research shows the building facility degraded its function after 10 to 15 years (Cheng, 2001). At present, the extension of building lifecycle has been getting an crucial issue in Taiwan since the first high rise building was built in 1960s.

The building maintenance could be divided into three strategies: corrective maintenance, cyclical maintenance, and preventive maintenance. This research focuses on the "corrective maintenance" of water supply and drainage system. The service area is separated into public area and lessee area in an office building. In academic, building drainage system, the phoneme of water discharge and air pressure have been discussed widely (Cheng, 2008). Therefore, this research aims at a comparison between the realistic case and academic research in water supply and drainage system based on a case study. The corrective maintenance service including costing, hours, problem solving and profit will be discussed.

2 Literature review

2.1 Building Drainage

Building drainage was influenced by water discharge location, floor height, discharge volume and air volume in pipe etc. These factors could cause the extreme fluctuation of positive or negative air pressure which induces the failure of the water trap on sanitary appliance. (Figure1). In Taiwan, the double-pipe system was put into practice which can be able to release the air pressure caused by instant water discharge (Figure 2). The risk analysis and improvement of the detecting infection were proposed (Cheng, 2008). Based on the previous research, this paper tries to clarify the fault of the system contributed by the user behaviour or system design.

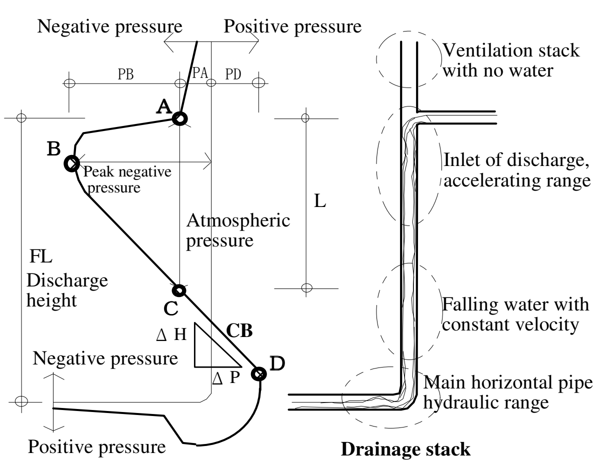


Figure 1- Air pressure distribution zone profile in a drainage stack

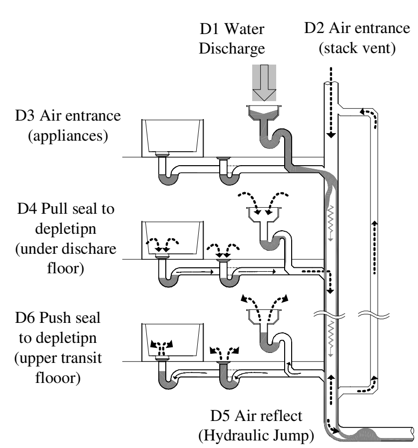


Figure 2- Air flow in double-pipe drain

2.2 Property and Facility management

Building Facility indicates that a building and its components support the whole user sources. To adapt the rapid development of the society, the buildings tend to be large-scaled. Also, the requirement of building utilities and function turn to be complicated. International Facility Management Association, IFMA, had defined" Facility management is a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology". According to The Charted Institute of Building, CIOB, the Strategies of building maintenance was divided into corrective maintenance, cyclical maintenance and preventive maintenance (Spedding, 1995). (Table 1)

Table 1- Strategies of building maintenance

Terms	Definitions (IFMA)
corrective maintenance	Maintenance activities performed because of equipment or system failure. Activities are directed toward the restoration of an item to a specified level of performance. Sometimes called "breakdown maintenance.
cyclical maintenance	Maintenance that can be predicted and performed on a regular basis (cycle).
preventive maintenance	Planned actions undertaken to retain an item at a specified level of performance by providing repetitive scheduled tasks which prolong system operation and useful life; i.e., inspection, cleaning, lubrication and part replacement.

In a forty-year building facility life, the cost of operation takes up to 70% of the building life cycle cost (LCC) and 30% of construction cost (Flangan, 1995). It shows that the cost of operation could be decision of audit and costs of administration. In order to discuss the corrective maintenance, the building components were divided into six items: architectural hardware system, water system, HVAC system, fire and safety system, electrical system and human resource (Cheng, 2012) shown as Table 2.

Table 2 - The six general attributes of building components

Category	The scope of the items
Architectural hardware system	malfunction devices such as, door closer, wall painting, curtain, cabinet and lock
Water system	leaking, drainage pipe blocking, toilet blocking, drinking fountain, floor drain, low water volume, urinal blocking
HVAC system	temperature too high or too low, Fan coil leaking, odour, no air-conditioning, low air supply
Fire and safety system	Power indicator malfunction, valve malfunction, sensor malfunction,
Electrical system	Error sign of power, no power, Error sound of power, power overloading, including devices which require electric support of all other systems
Human resource	Increasing power supply, furniture moving

Also, the two types of service process of the corrective maintenance are shown in Figure 3. The main difference between the two types is that the tenants go through the property management directly or indirectly.

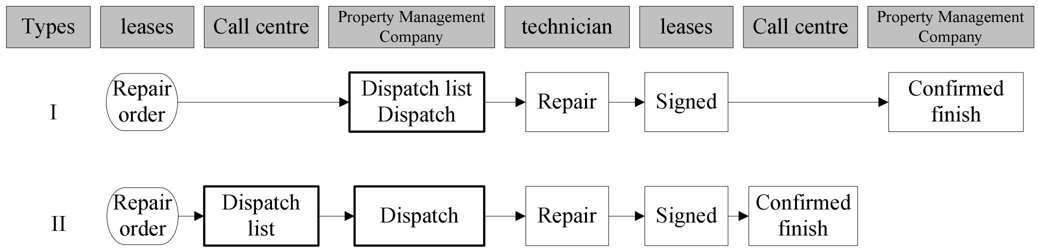


Figure 3- Two types of corrective maintenance service process

3 Case study

3.1 Data

In Taiwan, the architecture regulation defined a high rise building is the one which is above sixteen stories or fifty meters height. This building is operating within 8 years, and its cost of construction is 58 billion NT dollars. The monthly management fee for property management company is 85NT/m^2. Figure 4 and Figure 5 show a simple water supply and drainage riser diagram.

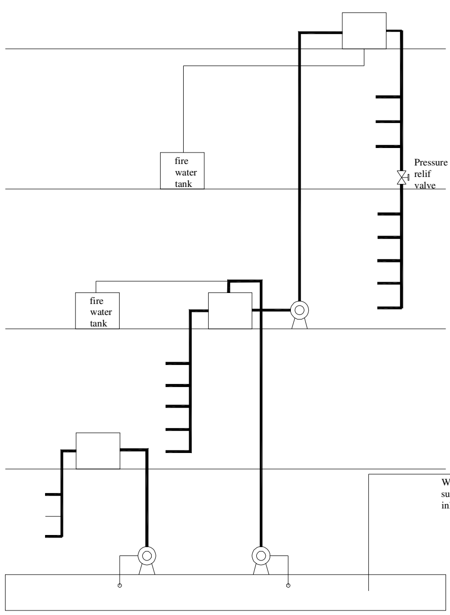


Figure 4 - water supply riser diagram

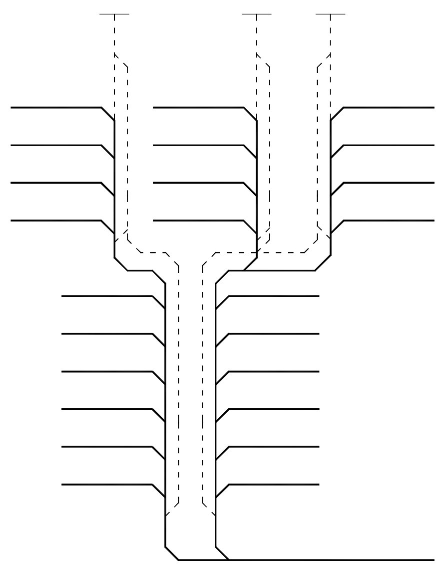


Figure 5 - drainage riser diagram

3.2 Scope of water system

Water supply system: all the water supply utilities, including water tank, water supply pipe, air relief valve, appliance and so on, the back part of the water meter from the government.

Drinking water system: Tap water system, water heater and the related equipments for the systematic pipings and fittings, daily and regular maintenance and the related troubleshooting measures.
Drainage system: Reclaimed water, waste water, sewage water and rain water including the drainage on double wall for basement, and the related maintenance of the systematic pipings and fittings
Mechanical room: for all system pump, water filter above.

Table 3 shows the periodical schedule of water supply and drainage system

Table 3 - the periodical schedule of water supply and drainage system

Water system	Description	Periodical schedule
Energy consumption	water and electricity daily usage (water meter and electricity meter)	daily(at night)
	water volume consumption of tenants	month
Water supply system(incl. mechanical area)	lift pump equipments for tap water	daily/month/season
	cistern inlet valve equipments	season
	water tank and feng-shui ball fountain (landscaping)	year
	automatic faucet filter clean	half year
	fountain filter clean of fountain equipments	month/season
	pump of fountain equipments	season
	feng-shui ball fountain and backflow filter clean	daily
Drinking water(incl. mechanical area)	all Drinking water systematic equipments	daily
	hot tap water system clean	3times/year
Drainage system (incl. mechanical area)	sewage, waste and rain water pump /distributor	daily/month
	Reclaimed Water lift pump	daily/month/season
	Drum Screen for Reclaimed Water clean	twice/day
	Checking and maintenance of drip irrigation equipment for garden	week/month
	drainage for double-wall in basement	season
	drainage for mechanical floor	half year
	floor drain of balcony and terrace	3times/year
Others	Leaking water detecting system	half year

4 Analyses and Discussion

4.1 Rating of Crucial corrective maintenance

Table 4 shows the rating of crucial corrective maintenance (include number and hours in tenant area and public area). In 2010 and 2011, the number of corrective maintenance for tenants is 2,842 which take 27% of total 10,535 cases. The corrective maintenance hour is 9,964 which take 42% of total 23,892 hours. In public area, the number is 7,693 (73%) and 13,928 hours (58%).

According to data shown on table 4, electricity system is the first in the rating of the corrective maintenance, including the numbers and hours in both tenants and public area. The factors for this rating include the large amount of light, special light device and electronic ballast system. In addition, it redistributes the three-phase A.C. voltage regulating circuit, also the circut checking when overloading.

Architectural system is the second in the rating of corrective maintenance for the numbers of dispatched order in tenant area as well as public area. However, it rates the fourth for the total repair hours since it focuses on easy maintenance, such as replacing door lock and curtain.

The water system rates the second in the corrective maintenance hours for public area. The main difference of water system between the tenant area and the public area in terms of dispatched numbers and repair hours is toilet unblocking in public area, together with unblocking and recovering devices.

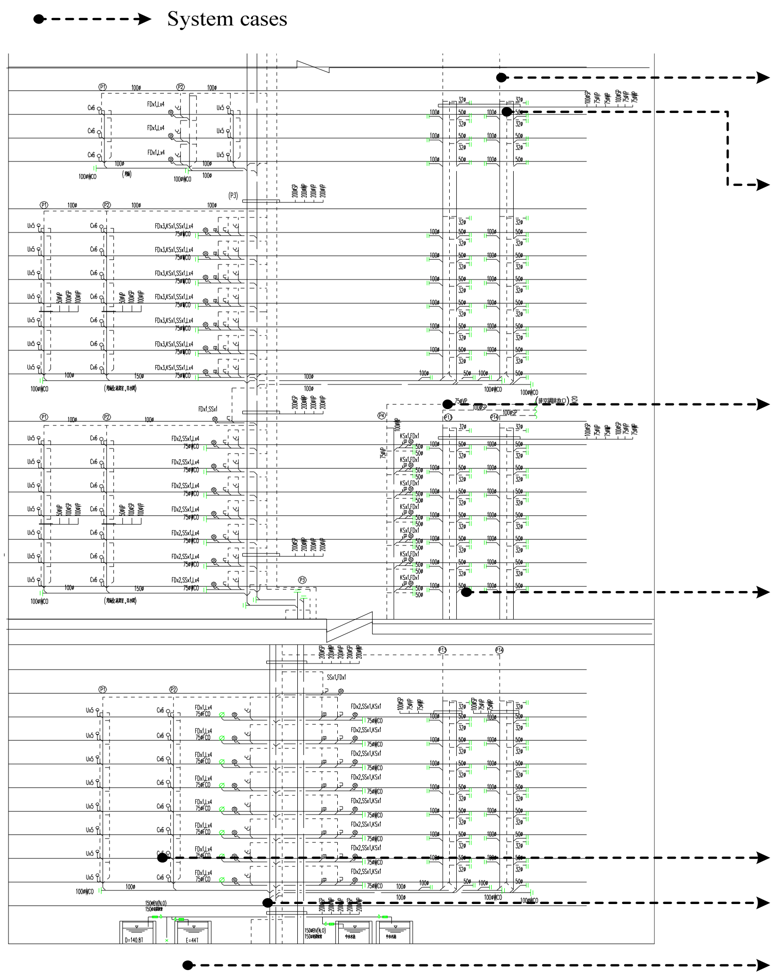
Table 4 - Rating of Crucial corrective maintenance (include number and hours in tenant area and public area)

2011and 2010	Total Dispatched (number)	Total repair (hours)	tenant area		Public area	
			Dispatched order (number)	repair (hours)	Dispatched order (number)	repair (hours)
Architectural system	2 (1,978)	4 (2,431)	2 (644)	3 (567)	2 (1,334)	3 (1,864)
Water system	3 (722)	3 (3,081)	4 (275)	4 (286)	3 (447)	2 (2,795)
HVAC system	4 (426)	2 (4,720)	3 (390)	2 (3,672)	4 (36)	4 (1,048)
Fire and safety system	5 (260)	5 (1,178)	5 (71)	5 (427)	5 (189)	5 (751)
Electrical system	1 (6,989)	1 (11,734)	1 (1,418)	1 (4,795)	1 (5,571)	1 (6,939)
Human resource	6 (160)	6 (748)	6 (44)	6 (217)	6 (116)	6 (531)
Total	(10,535)	(23,892)	2,842 (27%)	9,964 (42%)	7,693 (73%)	13,928 (58%)

4.2 Comparison between the realistic case and academic research in water supply and drainage system

This building was recorded 738 data of dispatched list on water system for two and half year of operation (58 cases for tenants' area).

Table 5 shows the representative case for water system condition in the building.



phenomenon	Description
Low water volume of faucet	On the building top area Pressure pump added
pipe blocking / Low water discharge voulme	Three water drainage pipe joint together with high water discharge volume Periodical Oil Water Separators and pipe clean
White bubble out from drainage pipe of drinking fountain	Oil and coffee grounds block between vertical pipe and branch pipe White bubble was cleaner
Odor from Kitchen	Drinking fountain install without trap
Toilet comes out water	Positive Air Pressure (Lowest floor in one drainage system) trap install
Positive pressure fluctuation	Positive Air Pressure. Attenuator *4
Basement pipe blocking	Periodical Oil Water Separators and pipe clean

Table 5 – the main reason and problem solving

4.3 Cost of maintenance

The corrective maintenance service of tenant area and administrate fee of public area are the two main revenues for Building Management Committee. In table 6, it shows that the water system in the corrective maintenance of tenant area was the second lowest one; however, in public area, it cost 11.7% of corrective maintenance cost, which is the second highest one in the maintenance cost of the public area. It also indicates that the water system and electrical system in public area was the major corrective maintenance. The cost of corrective maintenance which is charged from tenant area is to multiply the cost of maintenance per hour for technician by the total repair hours. In pubic area, the cost of corrective maintenance is mainly counted by administrate fee. By a simple comparison on tenant area and public area, in table 6, the cost for public area is also charged by multiplying by the cost of maintenance per hour for technician by the total repair hours.

Table 6 – corrective maintenance of six building components in 2010 and 2011

	tenant area		Public area		total	
	NT$	(%)	NT$	(%)	NT$	(%)
Architectural system	198,450	2.4	652,400	7.8	850,850	10.2
Water system	**100,100**	**1.2**	**978,250**	**11.7**	**1,078,350**	**12.9**
HVAC system	1,285,200	15.4	366,800	4.4	1,652,000	19.8
Fire and safety system	149,450	1.8	262,850	3.1	412,300	4.9
Electrical system	1,678,250	20.1	2,428,650	29.0	4,106,900	49.1
Human resource	75,950	0.9	185,850	2.2	261,800	3.1
Total	3,487,400	42	4,874,800	58	8,362,200	100

Figure 6 shows the five-year budget for preventive maintenance. The water system was budgeted 11,428,000NTdollars in 5 years. Figure 7 shows the five-year budget for cyclical maintenance, and water system was budgeted 5,398,419NTdollars. The difference between figure 6 and figure 7 is that the contract had been signed for cyclical maintenance to make sure the normal function of all the systems;moreover, the architecture hardware was excluded. In water system, the cyclical maintenance was less maintained.

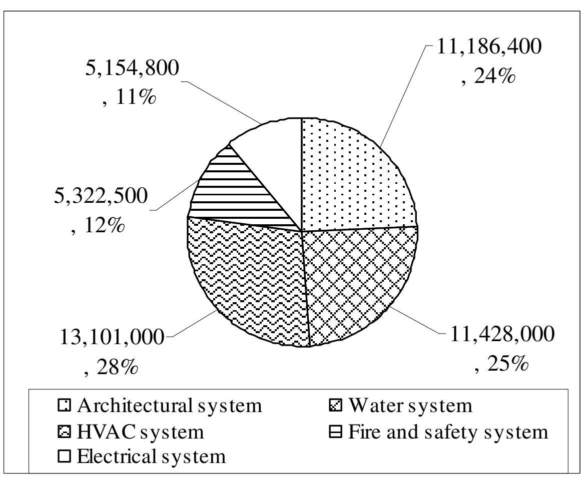


Figure 6- the five year budget of preventive maintenance (2007-2011)

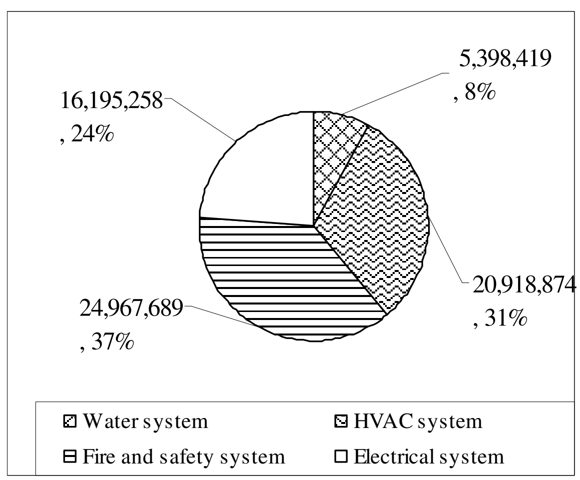


Figure 7- the five year budget of cyclical maintenance (2007-2011)

In figure 8, it was the cost of maintenance, which is the sum of preventive maintenance and cyclical maintenance. It could clearly show the percentage of water system (8%), HVAC system (31%), fire and safety system, (37%) and electrical system (24%).

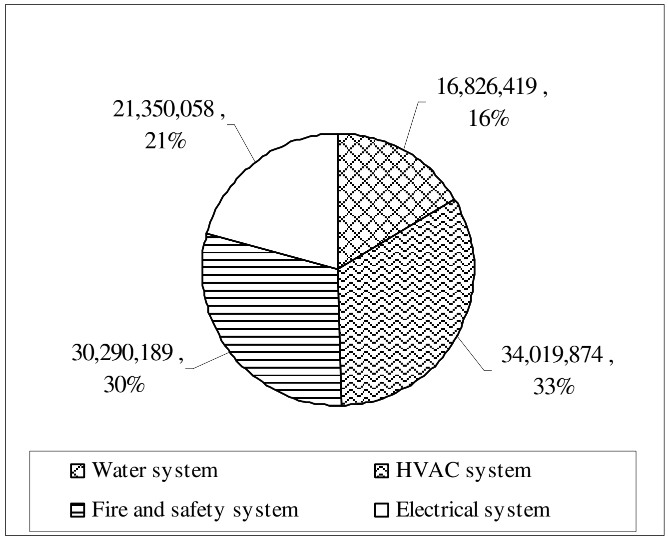


Figure 8 – the five year cost of maintenance

5 Conclusion

In water system, the most common conditions are toilet blocking by tissue paper, pipe blocking by unclassified solid, low water volume, water leaking and water economizer damage. It is important to clarify the crucial factors for corrective maintenance which enables to improve the quality of tenants' satisfaction.

In corrective maintenance, water system rated in the third position for all building system, which refers to the commission for the technician will be taken from electrical, HVAC, architecture hardware to fire and safety system in sequence. This research can further discuss the relation between outsourcing and back charge system. It can also provide the service income from tenants and profession commissioning.

The construction cost of the case building is about 58 billion NT dollars. Considering the cost of the life cycle, the operation of the cost of the building has run for 8 years. Although the life cycle cost could be continuous, the initial cost of maintenance is 3.6 billion NT dollars which takes of 0.62% of construction cost. The corrective maintenance is about 0.07% of cyclical maintenance.

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Separate water installations inside buildings in Slovak and Czech conditions

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Abstract

The professional teams from Czech and Slovak republic deal with the theme of reuse of rainwater/ grey water as a part of storm water management. Taking into consideration all facts (climate changes, droughts, rising of the sea level and urbanization) we decided to concentrate on a wide range of storm water management methods and grey water reuse that will contribute to significant cost savings in potable water and sustainable design.

In this article we will present our results of volume flow measurements in installations inside buildings and peak flow-rates in installations inside buildings. It is focused on peak flow-rates in separate water installations which supply WC-cisterns, WC and urinals flush valves. The design flow rates set by the different methods are generally higher than the measured peak flow rates. It will therefore be necessary to carry out another measurement and the calculation method.

Key words
Design flow-rate, peak flow rate, draw-off flow-rate, simultaneous use, measurements

1 Introduction

Facilities are a great opportunity for water conservation and water use efficiency. There are numerous retrofits available for the water-using equipment and fixtures within the building complex. Developing a water use profile often leads to short payback periods for retrofits.

It is important to calculate properly design flow rates of supply pipes for the dimensioning water installations inside buildings. There are used various calculation methods in different countries. These methods are based on probability theory or measurements of the peak flow rates in the pipeline. Both methods may be mutually combined that allows to complete missing information or comparison of the results.

2 Methods for calculation of design flow rate in supply pipes for water installations inside buildings

An important quantity for determination of design flow rate is draw-off flow-rate called in the Slovak and Czech Republic „nominal flow rate“. Comparing design flow rates in accordance with the standards and to the values measured by authors is referred to in Table 1. Another important indication is the simultaneous use of taps which is different in various types of buildings. It is possible to determine calculated design flow rates in supply pipes of installations inside buildings with the knowledge of draw-off flow rate and the simultaneous use of taps. Methods of calculation for design flow rate shall be based on probability theory and/or the measurements of peak flow rates in the pipeline. There is a simplified method for the certain calculation methods, such as [1] taps (draw-off points) characterised by loading units (LU).

2.1 Method based on probability theory

A calculation method of design flow rate based on probability theory was dealt with by Roy B. Hunter in the US, who published it in the year 1940 [6]. The result of calculations was the total number of taps, which are used simultaneously and depends on:

- the total number of taps (fixtures) supplied by a particular pipe;
- the average duration of flow for a given kind of fixture for one use;
- the average time between successive operations of any given fixture of a particular kind.

On the basis of fixtures (taps), which are used simultaneously and the flow rate Hunter estimated weight in pipe flow-rate expressed in FU (fixture units). Hunter took into account less simultaneous use of fixtures, which was started up in residential buildings caused by their location in bathrooms used as a general rule by one person only, by setting FU value for bathroom group composed of such as water closet, washbasin and bath or shower head. The FU value for bathroom group is equal to total of FU fixtures, which are in it and divided by two. Later FU values were re-evaluated and adjusted [7].

2.2 Method based on measurements

The method based on the measurements of peak flow rates from the year 1989 is used in Germany. This method consists in the systematic measurement of flow rates in the different buildings (residential buildings, office buildings, hotels, schools, etc.). The measured peak flow rates in the buildings with different number of fixtures drawn in the graph are then doing curve, which expresses dependency of design flow rate on total flow rate (Figure 1). The curves were adjusted [2] in the recent revision of the German standards.

Table 1 Comparison of draw-off flow rates in accordance with various standards and measurements

Draw-off point	Draw-off flow-rate Q_A (l/s)in accordance with various standards and measurements							
	EN 806-3 [1]		DIN 1988-300 [2]		STN 73 6655 [3]	ČSN 75 5455 [4]	Measurement of draw-off flow rate	Notes on measurements
	Only cold or hot	Loading units LU	Only cold or hot	Draw-off flow rate				
WC-cistern	0,10	1	0,13	0,13	0,10	0,15	0,05 to 0,15	--
Washbasin DN 15	0,10	1	0,07	0,14	0,20	0,20	0,10 to 0,14	--
Domestic kitchen sink DN 15	0,20	2	0,07	0,14	0,20	0,20	0,20	running sink
Bath domestic DN 15	0,40	4	0,15	0,30	0,30	0,30	0,40	--
Shower head DN 15	0,20	2	0,15	0,30	0,20	0,20	0,20	--
Urinal flush valve DN 15	0,30	3	0,30	0,30	0,15 to 0,25	0,15 to 0,30	0,15 to 0,30	In accordance with product norms
WC flush valve DN 20	1,50	15	1,00	1,00	1,20	1,20	1,0 to 1,3	In accordance with product norms [5]

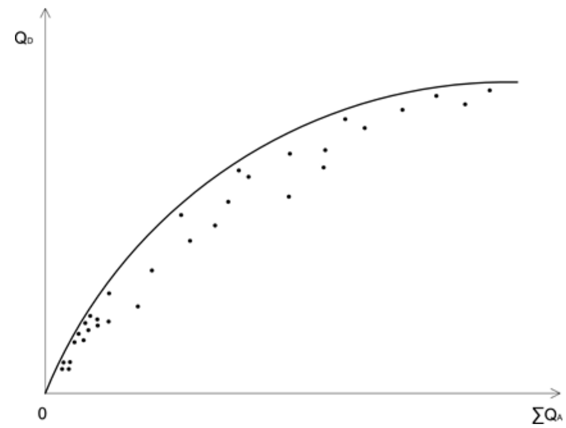

Figure 1 – Dependency curve of design flow-rate Q_D on total flow-rate $\sum Q_A$ in accordance with measurements of peak flow rate highlighted by dots

Dependency curves of design flow-rate on *total flow-rate* have the equation:

$$Q_D = a \cdot (\sum Q_A)^b - c \quad (1)$$

Where Q_D is design flow-rate (l/s);

Q_A – draw-off flow-rate (l/s);

a, b, c – the constants dependent on the type of buildings.

The constants *a, b, c* have values specified in Table 1 and processed in accordance with [2].

Table 2 Constants *a, b, c* for various buildings

Type of building	Constants		
	a	***b***	***c***
Residential houses	1,48	0,19	0,94
Hotels	0,70	0,48	0,13
Schools or office buildings	0,91	0,31	0,38

2.3 Method in accordance with the Slovak and Czech standards

The method of determining design flow-rate in accordance with the Slovak [3] and the Czech Standard [4] was introduced in the early 60´s of the 20th century in the former Czechoslovakia, and after certain adaptations it is still used in Slovakia and in the Czech Republic. This is the method of calculation, which is based on the measurements and analyses obtained by empirical and static methods and experience. Relation (2) is based on the method published in the [8].

The method used in Slovakia and in the Czech Republic is simple by calculated dependency of design flow rate on the number of taps (draw-off points) with certain values of draw-off flow rates. The pipes of uniform installations with dimensioned design flow rates, and set out in accordance with this method always safeguarded faultless water supply and the experience of using this method was good.

Design flow rate Q_D (l/s) in supply pipes shall be determined in accordance with relations:
a) for family houses, residential houses, administrative buildings, the individual stores (with equal collection of water only for personal hygiene of employees and cleaning) and sanitary facilities for a hotel room

$$Q_D = \sqrt{\sum_{i=1}^{m} \left(Q_{Ai}^2 \cdot n_i\right)} \qquad (2)$$

b) for the other buildings with a predominantly equal collection of water, such as hotels, restaurants, commercial houses and day nurseries according to the Slovak standards [3]

$$Q_D = \sum_{i=1}^{m} Q_{Ai} \cdot \sqrt{n_i} \qquad (3)$$

c) for the other buildings with a predominantly equal collection of water, such as hotels, restaurants, commercial houses and day nurseries according to the Czech standards [4] (the adjustment of the previous relation (3))

$$Q_D = \sum_{i=1}^{m} f_i \cdot Q_{Ai} \cdot \sqrt{n_i} \qquad (4)$$

d) for building or group fixtures, for which the mass and the one about use of taps (draw-off points) are predicted, for example sanitary facilities, industrial plants, public spa

$$Q_D = \sum_{i=1}^{m} \varphi_i \cdot Q_{Ai} \cdot n_i \qquad (5)$$

Where

Q_A - draw-off flow-rate (l/s) according to the table 1;

f - coefficient of flow rate according to the table 3;

φ - coefficient of simultaneous water collection according to the table 3;

n - the number of draw-off points of the same type;

m - the number of the types of draw-off points.

Table 3 Coefficients of draw-off point and coefficients of simultaneous water collection

Draw-off point	Coefficient of draw-off point 1		Coefficient of simultaneous water collection φ
	For one draw-off point	For two or more draw-off points	
WC-cistern	0,7	0,7 2)	0,2 až 0,3
Washbasin, handbasin, wash through	0,65	1	0,8
urinal with siphonic action	1	0,75	0,2
WC flush valve DN 20	0,85	0,85	0,1
Shower head	1	1	1
1) For not given draw-off points *f* = 1 2) Only for pipes supplying WC-cisterns *f* = 1			

Design flow-rate determined in accordance with relations (3) and (4) is given by the total of sub-design flow-rates for the various types of draw-off points. From the comparison between the (2) relation and (3) and (4) it is evident that, determining the design flow-rate for draw-off points of the same type and with coefficient of flow rate *f* = 1, the value of design flow rates referred to in relations (3) and (4) are the same as referred to in the (2), which may cause sub-dimensioning pipes (simultaneous use of draw of points like in residential houses). This is the case that may occur at the separate pipes supplying WC-cisterns. Also, in the design flow rate calculated in accordance with the (5) for the pipes, which supplies only WC-cisterns, may be sub-dimensioning.

2.4 Method in accordance with the European Standard

Since 2006 in Slovakia and in the Czech Republic the European Standard [1] has also been valid which enables the design flow-rate for so-called standard - installations, which are in accordance with national foreword installations in family houses, residential houses and office buildings. The design flow rate is determined according to loading units (LU) and the highest individual values of loading units.

3 Measurements of peak flow rates in supply pipe installations inside buildings

In the project TAČR TA01020311 and another research peak flow rates were measured in the different buildings. The measurements were carried out for the period of 14 or more days and the flow rate was read every second. For the measurement Axial turbine flow meter for liquids AHLBORN Type FVA915VTH25 embedded in the pipeline was used and connected to the measuring switchboard AHLBORN ALMENO 5690 2M. The measurements and their comparison with design flow rates determined in accordance with the various standards are referred to in Table 4. Samples flow rates measured in the course of the day are set out in the figures 2, 3 and 4 (zero flow rates were deleted from the graphs). The figure 3 is clearly visible for implementation of the individual WC-cisterns.

Table 4 shows that:
- The design flow - rate of [1], [3] and [4] is not considered with separate water installations (it results from a low design flow-rate);
- The calculated relation in accordance with [2] provides good results for separate taps;
- Pipes in restaurants cannot be dimensioned in accordance with [1] (according to the Slovak and Czech National Foreword to this standard it is not permitted);
- design flow rates according to the cancelled standard [9], which were in force in the years 1933 and 1955, when the separate water installations were normally established in the former Czechoslovakia, seemed to be taken into account the specifications of separate water installations, but were too high. This is the old calculation method, which expected a high draw-off flow rates.

3.1 Comparison of design flow-rates in supply pipe supplying only WC-cisterns

In the separate water installations it is necessary to determine design flow-rates in pipe supplying only WC - cisterns. As can be seen from Table 5, design flow-rates in residential houses which were determined in accordance with the various standards are different. The nearest fact is when design flow-rates, in our view, are determined in accordance with standard [2]. In the other buildings with equal water collection this comparison was carried out with Hunter method [6] (Table 6). Design flow-rates in accordance with standards [3] and [4] compared with Hunter´s assumptions are significantly lower. The question is whether Hunter method gives good results for the large number of WC - cisterns.

3.2 Comparison of design flow rates in pipe supplying only WC flush valves

WC flush valves are in operation only for a short period of time and "are a burden on "pipe installations inside buildings with a high flow-rate. Therefore, it is necessary, in particular in the pipes of separate installations, to determine as precisely as possible design flow-rate in pipe which supplies the toilet flush valves. In Table 7 design flow rate using Hunter method [6] is set out, and it is compared with design flow rate in accordance with the (4). The table shows that the formula for design flow rate referred to in (4) is comparable to

Hunter method and for WC flush valves gives good results as well as for the greater number (if it is thought the flow through WC flush valves QA = 1,0 to 1,3 l/s). When the flow rate calculated in accordance with the (2) the number of WC flush valves is considering compared with actual number of half.

Table 4 Measurements of peak flow rates in different buildings and their comparison with design flow rates in accordance with various standards

Building	Types and number of draw-off points	Max. measurement of peak flow rate (l/s)	Design flow-rates (l/s) in accordance with various standards				
			EN 806-3 [1]	**ČSN 75 5455** [4]	**STN 73 6655** [3]	**Cancelled ČSN 1099** [7]	**DIN 1988-300** [2]
Residential house "J"	5 x VA 5 x DJ 5 x WCNS 5 x AP	0,61 1)	0,90	0,98	0,95	1,98	0,82
Residential house "Š"	6 x DJ	0,24 2)	0,42	0,49	0,49	1,20	0,31
Residential house "K"	5 x WCNS	0,40	0,30	0,33	0,22	0,70	0,42
Office building with restaurant	15 x WCNS 8 x U 2 x UEO 9 DJEO 2 x PM	0,86	0,86	0,97	0,87	2,25 3)	1,15
Restaurant night-time operations	3 x WCNS 3 x U 2 x PM	0,62	0,50	0,73	0,73	0,87 3)	--

Notes:
1) Cold water flow rate (central preparation of hot water).
2) Hot water flow rate (central preparation of hot water).
3) The method is not intended for other than residential buildings.

The explanatory notes for abbreviations:
AP – washing machine, DJ – domestic kitchen sink, DJEO – domestic kitchen sink with a tankless electric heater, PM – urinal flush valve manually operated, U – washbasin, UEO – washbasin with a tankless electric heater, VA – bath (domestic), WCNS – WC-cistern.

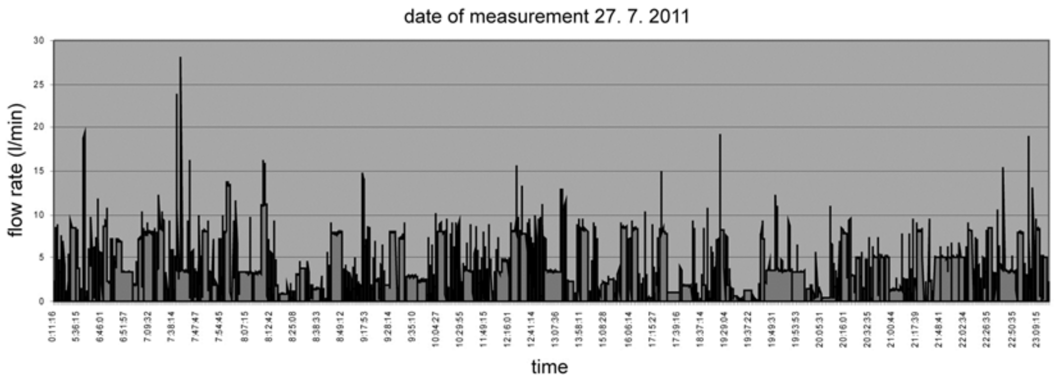

Figure 2 – Flow rates in rising pipe in residential house "J" measured in the course of day

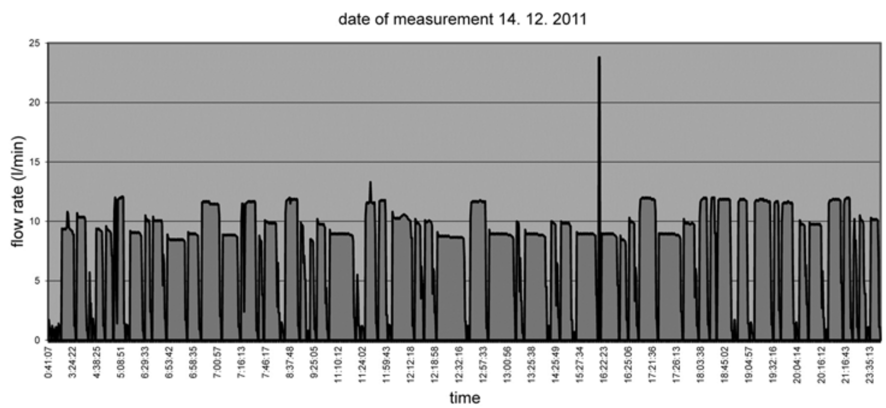

Figure 3 - Flow rates in rising pipe to WC -cisterns in residential house "K" measured in the course of day

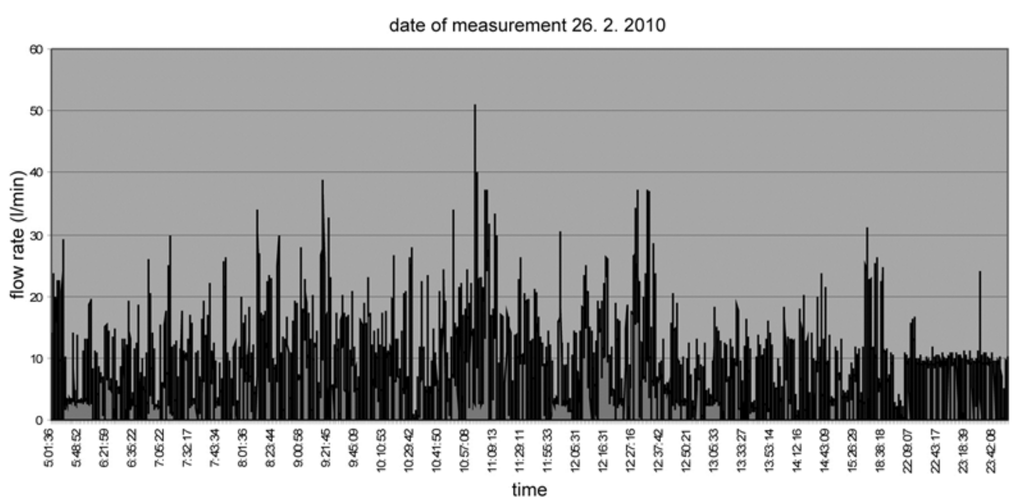

Figure 4 – Flow rates in header pipe in administrative building with restaurant measured in the course of day

Table 5 Design flow rate in pipe supplying WC-cisterns in residential house

Number of WC-cisterns n	Design flow rate Q_D (l/s) in accordance with:			
	DIN 1988-300 [2] (relation (1))	EN 806-3 [1]	ČSN 75 5455 [4] (relation (2))	STN 73 6655 [3] (relation (2))
3	0,30	0,24	0,26	0,17
5	0,42	0,30	0,33	0,22
7	0,51	0,34	0,40	0,26
9	0,58	0,38	0,45	0,30
15	0,74	0,46	0,58	0,39
25	0,91	0,57	0,75	0,50
40	1,08	0,70	0,95	0,63
64	1,27	0,87	1,20	0,80
132	1,60	1,20	1,72	1,15
240	1,90	1,50	2,32	1,55
305	2,04	1,70	2,62	1,75

Table 6 Design flow rate in pipe supplying WC-cisterns in other buildings with equal water collection

Number of WC-cisterns n	Number of WC-cisterns, which are operating simultaneously according to Hunter [6]	Design flow rate Q_D (l/s) in accordance with:			
		Hunter [6], pro Q_A = 0,15 l/s (cistern of the volume 9l	Hunter [6], pro Q_A = 0,1 l/s (cistern of the volume 6l)	ČSN 75 5455 [4] (relation(4))	STN 73 6655 [3] (relation (3))
3	2	0,30	0,20	0,26	0,17
5	3	0,45	0,30	0,33	0,22
7	4	0,60	0,40	0,40	0,26
9	5	0,75	0,50	0,45	0,30
15	7	1,05	0,70	0,58	0,39
25	10	1,50	1,00	0,75	0,50
40	14	2,10	1,40	0,95	0,63
64	20	3,00	2,00	1,20	0,80
132	36	5,40	3,60	1,72	1,15
240	60	9,00	6,00	2,32	1,55
305	74	11,10	7,40	2,62	1,75

Table 7 Determination of design flow rate in pipe, which supplies WC flush valve according to Hunter method and its comparison with relation (4)

Total number of WC flush valves *n*	Number of WC flush valves, which are operating simultaneously according to Hunter [6]	Design flow rate considering simultaneous demand according to Hunter and with an assumption that the flow rate by one WC flush valve is 1,3 l/s (l/s)	Design flow rate in accordance with ČSN 75 5455 [4] (relation (4)) (l/s)
6	2	2,6	2,5
16	3	3,9	4,1
30	4	5,2	5,6
47	5	6,5	7,0
66	6	7,8	8,3
85	7	9,1	9,4
107	8	10,4	10,5
151	10	13,0	12,5
199	12	15,6	14,4

4 Conclusions

The design flow rates set by the different methods are generally higher than the measured peak flow rates. Except for the pipes of separate installations supplying only WC - cisterns, where calculation method in accordance with the Slovak [3] and the Czech standards [4] and the method in accordance with the European Standard [1] does not provide good results. It will therefore be necessary to carry out another measurement and the calculation method in accordance with the Slovak [3] and the Czech standards [4] edit.

Acknowledgements
Contribution is processed in the framework of TAČR TA01020311 Reuse of rainwater and grey water in buildings. This work was also supported by the Slovak Research and Development Agency under the contract No. SUSPP-0007-09.

5 References

[1] European standard EN 806-3 Specifications for installations inside buildings conveying water for human consumption - Part 3: Pipe sizing - Simplified method

[2] German standard DIN 1988-300 Technische Regeln für Trinkwasser-Installationen – Teil 300: Ermittlung der Rohrdurchmesser; Technische Regel des DVGW (Codes of practice for drinking water installations - Part 300: Pipe sizing; DVGW code of practice)

[3] Slovak standard STN 73 6655 Výpočet vodovodov v budovách (Calculation of water installations inside buildings)

[4] Czech standard ČSN 75 5455 Výpočet vnitřních vodovodů (Calculation of water installations inside buildings)

[5] European standard EN 12541 Sanitary tapware - Pressure flushing valves and automatic closing urinal valves PN 10

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6 Presentation of Authors

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Comparative evaluation of the hot water-saving effect of hot water-saving single-lever faucets with different operating methods

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Abstract

This study aims to quantitatively understand the hot water-saving effect of various types of single-lever kitchen faucets which have been developed with the intention of saving hot water. This report presents a quantitative understanding of the hot water-saving effect and energy-saving effect of single-lever faucets, along with consideration for usability, which was acquired from experiments on two types of single-lever faucets with different types of control levers.

Keywords
single-lever faucet, hot water-saving effect, unintentionally used hot water

1 Background
This study was carried out, with the main focus on different types of single-lever kitchen faucets which have been developed for the purpose of saving hot water, with the

aim of understanding quantitatively the hot water-saving effect of the faucets. Experiments were carried out on two types of single-lever faucets each equipped with different types of control levers, i.e. the vertical type and the lateral type. The experiments involved subjects and were conducted through a summer period, an intermediate period (autumn) and a winter period. The previous reports[1)2)] described experiments on hot water-saving single-lever faucets provided with a mechanism in which a control lever is operated in the vertical direction to adjust the flow volume of water and turn off the water (Photo 1 (1), “the vertical type” hereafter), and the hot water-saving effect of the faucets was clarified when the faucets were used, by subjects, in real houses, in washrooms of business facilities, and in laboratories.

This report evaluates the hot water-saving effect of kitchen faucets of a different type from the ones in the previous reports, i.e. the faucets are equipped with a lateral single-lever (“the lateral type” hereafter). As shown in Photo 1 (2), the lateral type is equipped with a control lever positioned on the side thereof, providing better design than the vertical type by securing more space around the water outlet, thus, making it easier to do washing activities in the sink. This report describes the hot water-saving effect of the lateral type, along with the usability thereof, in comparison with the vertical type, which was evaluated through experiments with subjects.

(1) Vertical type single lever

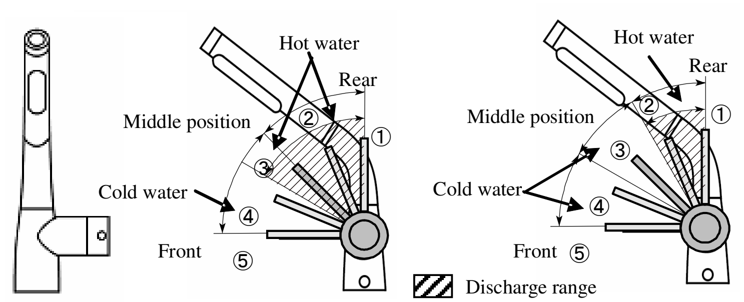
(2) Lateral type single lever

Photo 1:Space around the water outlet provided by two different types of single levers

2 Experiment overview

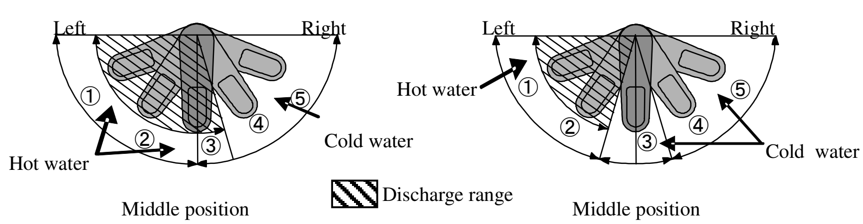
The experiments involved subjects and were carried out in the kitchen of a meeting room on the third floor of the Faculty of Engineering building, Kanto Gakuin University. The faucets used for the experiments were of two types, i.e. the vertical type and the lateral type, and because of the difference in discharge range, the vertical type and the lateral type were each divided further into a conventional faucet (“the conventional type” hereafter) and a hot water-saving faucet ("the hot water-saving type" hereafter). In the experiment, the subjects were asked to do washing-up at the sink in sets of four times.

Fig. 1 shows the front view of the lateral type and the side view of the conventional type and the hot water-saving type with different discharge ranges. Meanwhile, Fig. 2 shows the vertical type faucets with different discharge ranges. With the control lever of the lateral/conventional type in the middle position (Fig. 1 (1) ③), hot water and cold water are discharged together more or less in the same amount, but the lateral/hot water-saving type (Fig. 1 (2) ③) discharges cold water only with the control lever in the middle position. Generally speaking, users of single-lever faucets have a tendency of automatically setting the control lever in the middle position, thus, using hot water unintentionally even when hot water is not needed. With the control lever in the middle position, conventional type faucets discharge lukewarm water, the temperature of which is very close to that of cold water, and it is often unnoticed that users are actually using hot water. By discharging cold water only, when the control lever is set in the middle position, hot water-saving type faucets prevent the wasteful discharge of hot water and actually save hot water.



Front view (1) Conventional type (2) Hot water-saving type

Fig. 1 Lateral-type single lever faucets



(1) Conventional type (2) Hot water-saving type

Fig. 2 Vertical-type single lever faucets

The experiments involved the same subjects who used the lateral type faucets and the vertical type faucets, and the hot water-saving effects of both types were compared. The experiments were scheduled to be carried out on four types of faucets, i.e. the vertical types (conventional and hot water-saving types) and the lateral types (conventional and hot water-saving types), in a sequential manner throughout a day. Incidentally, the subjects were not informed in advance that the hot water-saving type faucets would not discharge hot water when the control lever was set in the middle position.

Table 1 Experiment overview

Experimental period	Summer		Intermediate		Winter	
Duration of experiment	2011 8/3-9/29		2011 10/5-11/30		2011 12/01-2012 2/21	
Subjects (No.)	Housewives 0	Students 12	Housewives 12	Students 18	Housewives 20	Students 4
Avg. age	-	21.9	49.5	22.6	49.6	21.0
Activities involved	Wash plates and cutleries using the vertical-type and lateral-type faucets (each type includes conventional and hot water-saving types)					
Water heater temperature setting	60°C					
No. of activities	Wash 44 items** (11 items/person) twice, using the conventional type and hot water-saving type faucets					
Room temperature setting	Approx. 26°C		Approx. 22°C			
Items to wash	Large, medium and small plates, rice bowls, soup bowls, tumblers, green tea cups, spoons, forks, knives, chopsticks, 11 items/person, 44 items** in total					

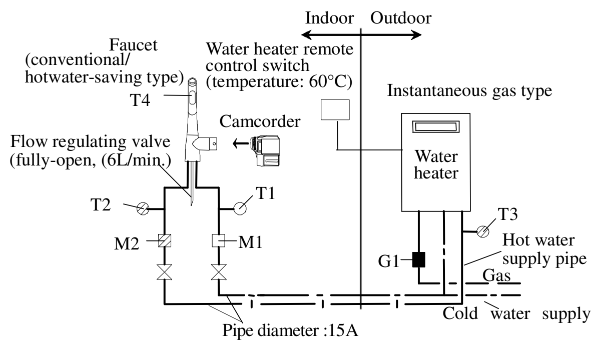


Table 1 shows the overview of the experiments. The experiments involved a total of 66 subjects; 34 students (27 males and 7 females) and 32 housewives. Fig. 3 shows a water supply system set up for the experiments, and Table 2 lists items to measure and measurement intervals. Here, "supplied hot water volume" and "supplied cold water volume" must be clearly defined. With reference to Fig. 3, "supplied hot water volume" means the volume of hot water which is passed through the hot water supply pipe and discharged from the water outlet, and "supplied cold water volume" means the volume of cold water which is passed through the cold water supply pipe and discharged from the water outlet.

Fig. 3 Water supply system for the experiments

Table 2 Items to measure

Symbol		Term	Measurement interval
M	1	Water supply flow [L/min]	1[sec]
	2	Hot-water supply flow [L/min]	
G	1	Gas flow [m^3/h]	
T	1	Water supply temperature [°C]	
	2	Hot-water supply temperature [°C]	
	3	Hot-water supply temperature of the faucet [°C]	
	4	Hot-water supply temperature of the water heater [°C]	
	5	Inside temperature [°C]	1[min]
	6	Outside air temperature [°C]	

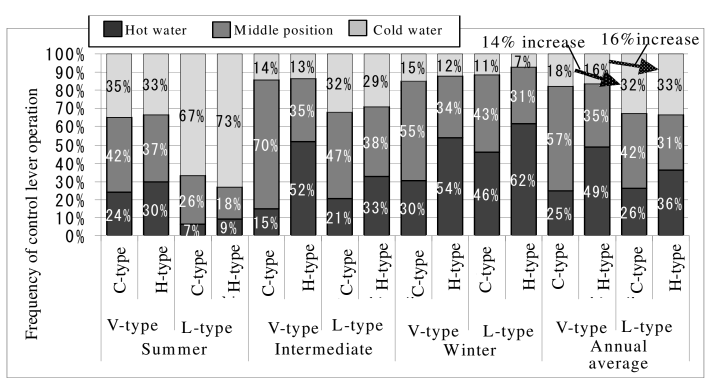
The flow regulating valve (Fig. 3) of each faucet was set to allow the maximum flow volume of 6[L/min] (cold and hot water combined) with the control lever in the fully-open position, and the subjects were asked to keep the control lever in the fully-open position at all times in order to ensure the consistency of the flow volume. As for the washing method, the subjects were instructed to do washing-up as they would normally do in their own homes and finish at the point when they thought all the plates and cutleries had been washed clean.

For the experiments, the temperature on the remote control of the water heater was set to 60°C. In addition, the hot water supply pipe was filled with hot water at the beginning of the experiments so as to prevent any cold water being discharged and wasted before hot water reaching the outlet of the faucets. This condition was set in order to eliminate the influence of the piping condition between the water heater and each faucet. The progress of the experiments was recorded on a camcorder while the lever control was observed. After the experiments, a questionnaire was given to each of the subjects to confirm how frequently they did washing-up and how they used the lateral type faucets. The results of the experiments on each of the faucets, i.e. the vertical types (the conventional type and the hot water-saving type) and the lateral type (the conventional type and the hot water-saving type) are as described below.

3 Experimental results and discussion

3.1 Comparison of frequencies of control lever operations

Fig. 4 shows the frequency of control lever operation in percentage per faucet and per period for comparison. Fig. 4 indicates that when comparing the conventional type faucets and the hot water-saving type faucets, the frequency of control lever operation in the middle position was reduced on the hot water-saving type faucets. This implies that the subjects actively operated the control lever on the hot water-saving type faucets when hot water was needed. This leads to a suggestion that compared to the conventional type faucets, the amount of unintentionally used hot water is less with the hot water-saving type faucets with the lever in the middle position. Furthermore, when comparing the vertical type faucets and the lateral type faucets, the average frequency of control lever operation on the cold water side per year is increased by 14% with the conventional type faucets and a 16% increase with the hot water-saving type faucets, i.e. the lever operation frequency is



C-type:Conventional type, H-type:Hot water-saving type, V-type:Vertical type, L-type: Lateral-type

Fig. 4 Frequency of control lever operation per

greater with the lateral-type faucets than the vertical type faucets , and the annual average frequency of control lever operation on the hot water side is increased more or less the same as on the cold water side with the conventional type faucets and a 13% increase with the hot water-saving type faucets; slightly less than the increase on the cold water side. This implies that on the lateral type faucets, it was easier for the subjects to set the control lever to cold water by moving the lever towards them than setting the lever to hot water by moving the lever away from them, and this light awkwardness in operating the control lever may have made the subjects more aware of how they were using hot water, hence the results obtained.

3.2 Comparison of supplied hot water volumes and supplied cold water volumes

Fig. 5 shows the volume of supplied hot water and the volume of supplied cold water per faucet for comparison. Fig. 5 indicates that when comparing the total amounts of hot water supplied to the vertical type faucets and the lateral type faucets, approx. 42[L/washing-up] was consumed during the summer period and approx. 50[L/washing-up] during the intermediate (autumn) period and the winter period on both types, i.e. 40-50[L/washing-up] was consumed on both types during each period. This rightly suggests that the prerequisites for the comparison of the vertical and lateral type faucets were more or less consistent. Therefore, it is considered that the experimental conditions for examining the hot water-saving effect of the faucets of both types were each within a constant range. Fig. 5 shows the comparative evaluation on the faucets of both types used by both the students and the housewives combined. In reality, however, housewives are more likely in charge of doing washing-up than anyone else in their homes, and therefore, the experimental results involving the housewife subjects only will be discussed later.

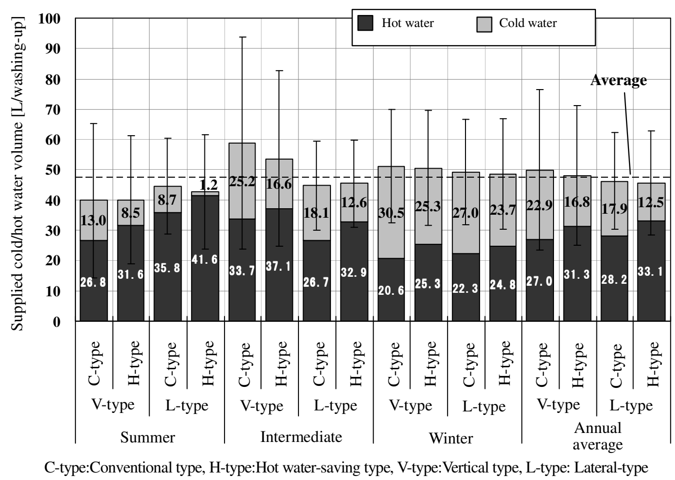


Fig. 5 Supplied cold/hot water volume per faucet

3.3 comparisons of supplied hot water volumes

Fig. 6 shows different volumes of hot water, which is supplied through the hot water supply pipe, compared by experimental period. Fig. 6 indicates that between the vertical type and the lateral type, the supplied hot water volumes are smaller with the lateral type than with the vertical type, not matter whether it is the conventional type or the hot water-saving type. Similarly to 3.1, this suggests that the opposition and operability of the lever of the lateral type made the subjects aware of how they were using hot water. Furthermore, when comparing the lateral/conventional type and the lateral/hot water-saving type, the supplied hot water volumes are smaller with the hot water-saving type than with the conventional type in each experimental period, which clarifies how much hot water can be saved by the hot water-saving type. The annual average volume of hot water saved by the lateral type is 504[L/washing-up] and 6.1[L/washing-up] by the vertical type. Moreover, the hot water-saving efficiency, using a formula; ((hot water volume supplied to the conventional type –hot water volume supplied to the hot water-saving type)/ hot water volume supplied to the conventional type) ×100[%], is approx. 26.6[%] by the vertical type and approx. 30.2[%] by the lateral type. This suggests, although there may not be enough supporting examples, that using the lateral/hot water-saving type increases the hot water-saving efficiency by approx. 3.6[%], compared to the vertical/hot water-saving type.

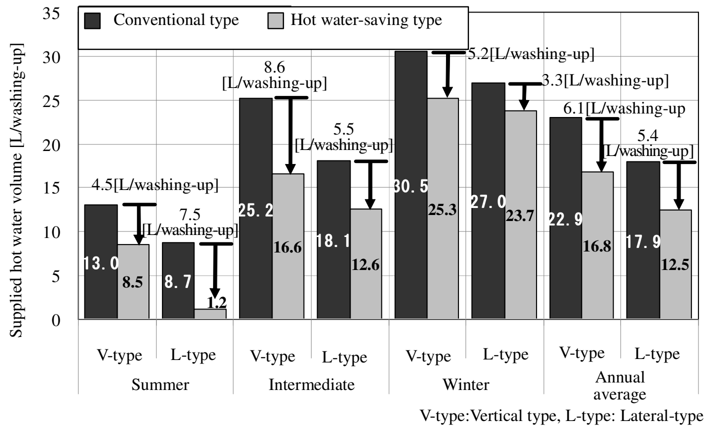


Fig. 6 Supplied hot water volumes by experimental

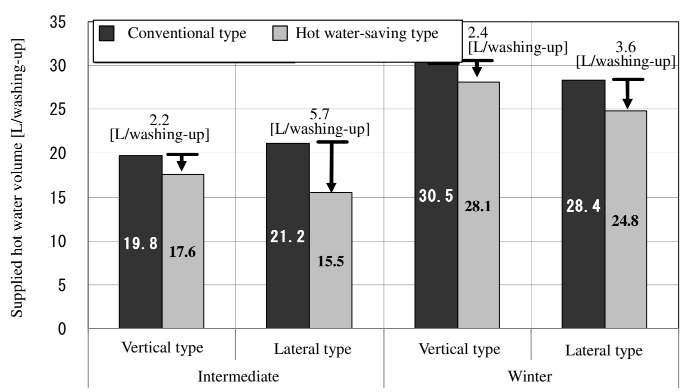


Fig. 7 Supplied hot water volumes by experimental period (housewives only)

Fig. 7 shows different supplied hot water volumes in different experimental periods for comparison, but this time involving the housewife subjects only. It is as evident as when the vertical type and the lateral type were used by both the students and the housewives (Fig. 6) that hot water was supplied to the lateral type in smaller volumes than to the vertical type. As for the hot water volume saved by the housewives using the lateral type in each experimental period, it is 5.7[L/washing-up] in the intermediate period (autumn) and 3.6[L/washing-up] in the winter period. These figures more or less correspond to those shown in the intermediate and winter periods in Fig. 6, when involving both the students and the housewives, and therefore, it is assumed that more or less the same hot water-saving effect would be found with the lateral type used only by the housewives in the summer period as the lateral type was used by both the students and the housewives in the summer period, as shown in Fig. 6.

3.4 Comparison of supplied hot water volumes at a converted temperature of 40°C

Table 3 Calculation of supplied hot water volume (40°C conversion) and supplied hot water heat load

40°C conversion	$Q_{40} = Q \times \frac{(T_h - T_c)}{(40 - T_c)}$ …(1)	Q_{40}: Supplied hot water volume at 40°C Q: Supplied hot water volume[L/min] T_h: Supplied hot water temperature[°C] T_C: Supplied cold water temperature[°C]
Supplied hot water heat load	$H = C_P \times Q \times (T_h - T_c)$	H: Supplied hot water heat load [KJ/S] CP: Specific heat of water [4.186 KJ/(Kg・)] Q: Supplied hot water volume[L/min] T_h: Supplied hot water temperature[°C] T_C: Supplied cold water temperature[°C]

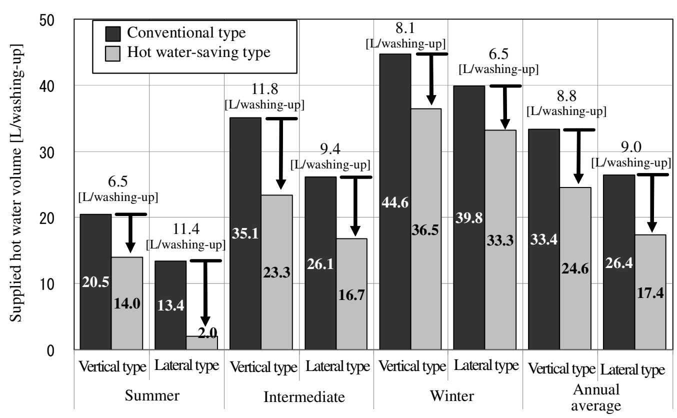


Fig. 8 Supplied hot water volumes at a converted temperature of 40°C

The temperature on water heaters is commonly set to 40°C. Fig. 8 shows supplied hot water volumes in different experimental periods when the temperature used for the experiments is converted to 40°C by using equation (1) of Table 3. In relation to Fig. 6, Fig. 8 indicates that hot water was supplied in large volumes to both the vertical type and the lateral type, and it is particularly noticeable in the winter period. The annual average volume of hot water saved by the lateral type is 9.0[L/washing-up], and 8.8[L/washing-up] by the vertical type. The hot water-saving efficiency is the lateral type 34.1% and the vertical type 26.3%, i.e. the lateral type is more efficient than the vertical type. Moreover, Fig. 9 shows the results of experiments which involved the housewife subjects only.

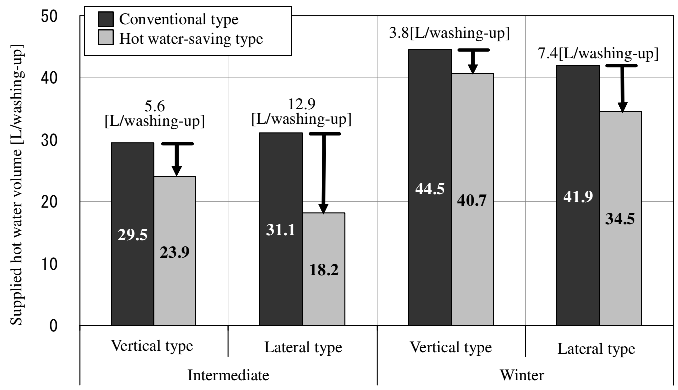


Fig. 9 Supplied hot water volumes at a converted temperature of 40°C (housewives only)

Fig. 9 indicates that the volumes of hot water saved by the lateral type are 12.9[L/washing-up] in the intermediate (autumn) period and 7.4[L/washing-up] in the winter period, and the volumes of hot water saved by the vertical type are 5.6[L/washing-up] in the intermediate (autumn) period and 3.8[L/washing-up] in the winter period. In reality housewives are more likely in charge of doing washing-up than anyone else in their homes, and using lateral type faucets is considered to contribute to saving large amounts of hot water.

3.5 Supplied hot water heat load

Fig. 10 shows heat loads generated by hot water, which were calculated using equation (2) of Table 3. The annual average amount reduced by the lateral type is 0.8[MJ/washing-up] and 0.6[MJ/washing-up] by the vertical type, and compared to the vertical type, the lateral type makes an annual average reduction of 29.6[%] according to the calculation using a formula, ((conventional type, supplied hot water heat load/hot water-saving type, supplied hot water heat load)/ conventional type, supplied hot water heat load)×100[%]). In addition, Fig. 11 shows heat loads obtained from the experiments which involved the housewife subjects only. Fig. 11 indicates that the reductions achieved by the lateral type are 1.2[MJ/washing-up] in the intermediate (autumn) period and

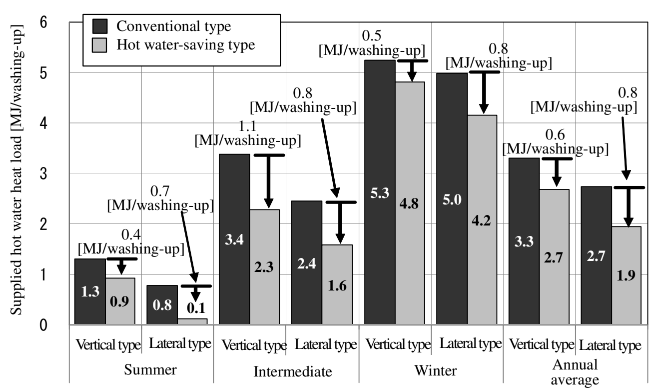


Fig. 10 Supplied hot water heat loads by experimental period

0.8[MJ/washing-up] in the winter period, whereas the reductions achieved by the vertical type are 0.5[MJ/washing-up] in the intermediate (autumn) period and 0.5[MJ/washing-up] in the winter period. Compared to the vertical type faucets, the lateral/hot water-saving type achieved a 40% reduction in the intermediate (autumn) period and a 16% reduction in the winter period.

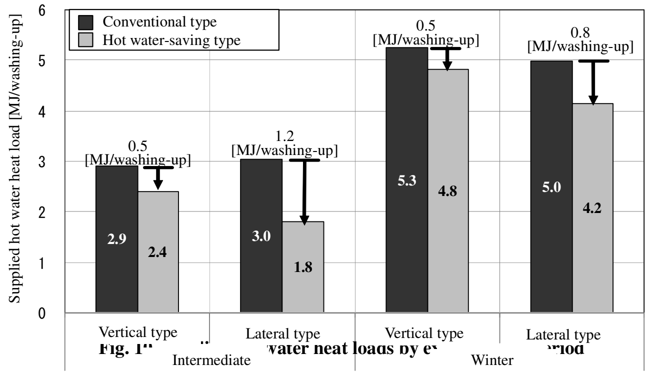
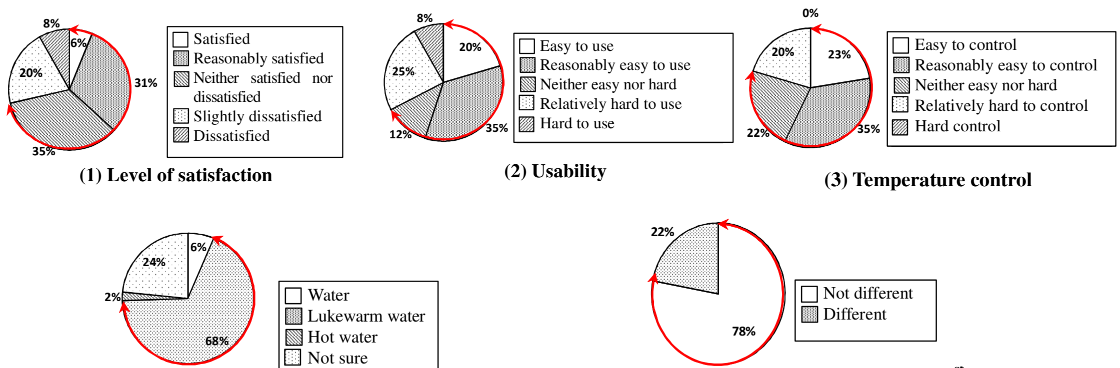


Fig. 11 Supplied hot water heat loads by experimental period (housewives only)

3.6 Questionnaire survey results

Subsequent to the washing-up experiments, a questionnaire survey was conducted with the subjects to find out how often they normally do washing-up and how easy they found it to use the lateral type faucets during the experiments. Fig. 12 shows responds from subjects (78% of the subjects) who are currently using single-lever faucets in their own homes, which are sorted in the form of pie chart. According to Fig. 12, in (1) Level of satisfaction, approx. 70% of the respondents said that they were either “satisfied” or “neither satisfied nor dissatisfied” with the lateral type, and in (2) Usability, approx. 70% of the respondents felt that the lateral type was “easy to use”. In (3) Temperature control, approx. 80% of the respondents said either “easy to control” or “neither easy nor hard”. Furthermore, no one said “hard to control” bufaucetprox. 20% of the respondents thought “relatively hard to control”, and it is thinkable that the lateral type may not be immediately user friendly to first-time users. In (4) Water discharge with the lever in the middle position, approx. 70% of the respondents said that lukewarm water (hot water and cold water mixed together) was discharged when the control lever of the lateral type faucets was set in the middle position, and approx. 20% of the respondents said they were not sure. As for the vertical type faucets, the approx. 70% of the respondents also said that lukewarm water was discharged. In (5) Difference in lever control between the first washing-up using the conventional type and the second washing-up using the hot water-saving type, approx. 80% of the respondents said that there was no difference. This suggests that the lateral/hot water-saving type can provide a hot water-saving effect without most users experiencing too much difference in lever control from the conventional type.



(1) Level of satisfaction

(2) Usability

(3) Temperature control

(4) Water discharge with the lever in the middle position

(5) Difference in lateral lever control between the 1st washing-up(the conventional type) and the 2nd washing-up(the hot water-saving type)

Fig. 12 Some of the questionnaire survey results

4 Summary

Table 4 summarises the hot water-saving effect of the vertical and lateral type singe lever faucets which were evaluated through the experiments. The over all result is that the vertical type and the lateral type both provide the same level of hot water-saving effect. In terms of usability, some subjects found it less easy to use the lateral type, in response to which further evaluation will be implemented with increased parameters.

Table 4 Hot water volume and supplied hot water heat load reduced per person

Subject		Summer	Intermediate	Winter	Annual average
Vertical type	Supplied hot water volume [L/washing-up]	4.5 (34.6%)	8.6 (34.1%)	5.2 (17.0%)	6.1 (26.6%)
	40°C conversion [L/washing-up]	6.5 (31.7%)	11.8 (33.6%)	8.1 (18.2%)	8.8 (26.3%)
	Supplied hot water heat load [MJ/washing-up]	0.4 (30.8%)	1.1 (32.4%)	0.5 (9.4%)	0.6 (18.2%)
Lateral type	Supplied hot water volume [L/washing-up]	7.5 (86.2%)	5.5 (30.4%)	3.3 (12.2%)	5.4 (30.2%)
	40°C conversion [L/washing-up]	11.4 (85.1%)	9.4 (36.0%)	6.5 (16.3%)	9.0 (34.1%)
	Supplied hot water heat load [MJ/washing-up]	0.7 (87.5%)	0.8 (33.3%)	0.8 (16.0%)	0.8 (29.6%)

5 Acknowledgements

For its excellent environmental performance, the vertical/hot water-saving type kitchen faucet, the hot water-saving effect of which was quantitatively evaluated and reported in the previous reports, won the Environment Minister's Award, one of the best awards given at the 8th Eco-Products Awards (Dec. 2011). The author wishes to thank those from Kanto Gakuin University, Tokyo Gas, and TOTO Ltd., who contributed themselves to the winning of the award.

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7 Presenter of the report

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A Study on the Best Design of Water Supply System in the Multiple Dwelling Houses Corresponding to the Variety of Life-Styles

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Abstract

Japan has become a rapidly aging society with low birthrate as a serious problem in various fields. In addition, under the influence of the family number of people, family constitution, changing life-styles and water saving appliances, water supply demand and water use patterns have changed greatly in the recent multiple dwelling houses. And it is very important that the designers predict the water supply demand of buildings appropriately at the design stage while promoting resource saving and energy saving. Particularly the establishment of the design of water supply system corresponding to the variety of life-styles has become the urgent business in the present age. Against this background, the authors analyzed the water supply demand of recent multiple dwelling houses and examined the optimization of the water supply demand basic unit standard. Study has been done with the contents of following three steps.

1st. step: Building a standard model for the water supply population and a standard for quantity of water use by dwelling unit type.

2nd. step: Building a calculated model of probable peak flow rate of water supply by an appropriate safety factor using Gumbel distribution.

3rd. step: Inspecting the validity of this standard model that the authors built this time in real multiple dwelling houses and demonstrated the effect.

As a result, it is thought that the authors were able to build a standard model for water supply demand at present conditions by leading a decision process of water supply demand. In the future, the authors will establish the best design of water supply system in the multiple dwelling houses corresponding to the variety of life-styles by leading a decision process of the water distribution system.

Keywords

Water supply system; Multiple dwelling houses; Life-styles

1. Introduction

In the city in Japan, multiple dwelling houses stood in a row and it became the rate that multiple dwelling houses has 40 percent or more of housing starts of the Japan whole country, in 2003 and afterwards. It is expected that urbanization progresses and it continues to be expected that the construction ratio of multiple dwelling houses continues increasing. Moreover, an urgent aging society with low birthrate is greeted, a life-style is also diversified with changes of a time, and people's life pattern has been presenting various aspects(1). In Japan, the procedure of design of the water supply system in multiple dwelling houses assumes the personnel from water supply load specific productivity first. Next, the method of computing one-day planned anticipation water supply and the instant maximum anticipation water supply from the personnel who assumed, and choosing a water supply system according to a scale or location is common. Typical design standards of the water supply system have design standards of the Ministry of Land, Infrastructure, Transport and Tourism(henceforth: MLIT design standards), design standards of the Society of Heating, Air-conditioning & Sanitary Engineers of Japan(henceforth: SHASE design standards), etc.

Authors have so far verified many things to the conventional water supply system design standards based on a measurement survey result. And the water supply load specific productivity standard corresponding to the present diversified life-styles was improved, and it has been shown clearly that it is necessary to reconstruct design standards of the water supply system(2)-(4). In this paper, in order to consider it as general design standards, water supply load specific productivity which was the conventional fixed mount type is made into a change system, and the result of having drawn the calculation process of the water supply system is reported.

2. The design flow of the water supply system in multiple dwelling houses

The design flow of water supply system in multiple dwelling houses by the design standards of the MLIT is shown in Figure 1. Although the procedure of water supply system design was classified into two steps, the calculation process of water supply quantity, and the determination process of a water supply system, it examined the optimum calculation process of water supply as first research stage in this paper. In the stage of the calculation process of water supply until it determines a water supply system, two items of "assumption of water supplied population" and "anticipation of water supply" become important especially. Moreover, in this paper, since it aimed at becoming a guideline the design standards of the water supply system in prospective multiple dwelling houses, the design standards of the water supply system were reconstructed in the form adapted to the present design flow, without building a new design flow.

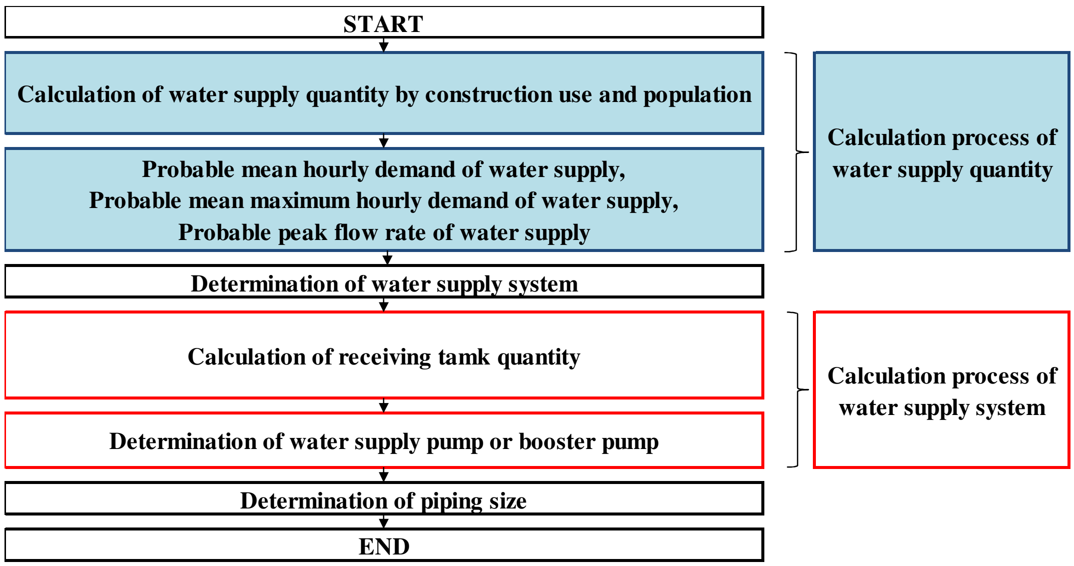

Figure 1 - The design flow of water supply system in multiple dwelling houses by the design standards of the MLIT

3. Construction of the design standards of the water supply system in multiple dwelling houses

3.1 Dwelling unit classification water-supplied-population conversion standard which considered factor of safety

Authors proposed the dwelling unit classification parameter conversion standard that accuracy can predict design population supplied highly very much, in past research[(2)-(4)]. However, since actual design population supplied was always accompanied by change, when design population supplied greatly exceeded a predicted value, short supply may have happened in the direct connection water supply system without a buffer. In order to consider it as a flexible design manual based on these, it decided to build the design standards which considered the factor of safety in consideration of increase or decrease and the local characteristic of prospective design population supplied. This time, comparison of design population supplied conversion standard in the design standards which performed construction, and each conventional design standards is shown in Table 1, and the safety factor of the conversion standard of each design standards is shown in Figure 2, respectively.

Table 1 – The design standard of dwelling unit classification design population supplied conversion

(Person/House)

	1R・1K etc.	1DK・1LDK etc.	2DK・2LDK etc.	3DK・3LDK etc.	4DK・4LDK etc.	5LDK over
Design standards of the MLIT	2	2	3.5	3.5	4	4.5
Design standards of the SHASE	1	2	2.5	3.5	4	5
Design standards of parameter conversation	1	1.5	2	2.5	3.5	4.5
Proposal design standards	1	1.5	2.5	3	4	4.5

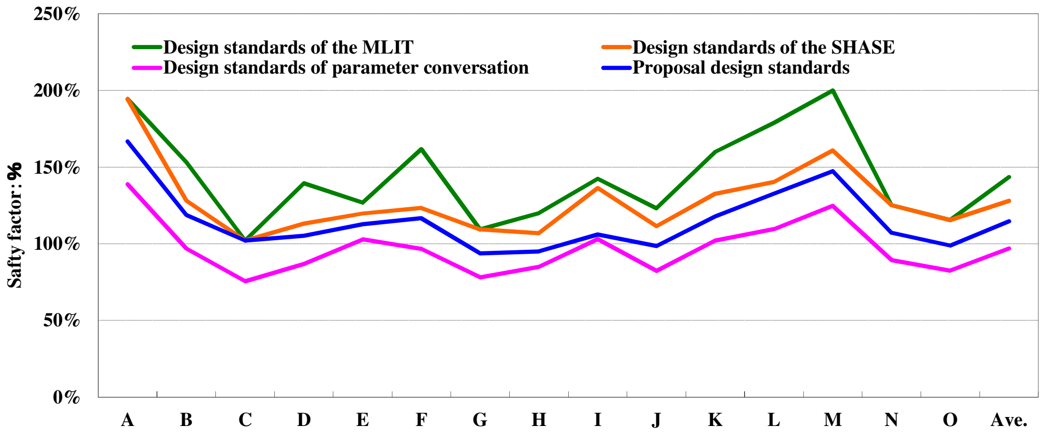

Figure 2 – The safety factor of the conversion standard of each design standards

As compared with the conventional parameter converting method design standards, the design standards of design population supplied built in this paper were par, and increased by about 19%. Moreover, although some which were less than 20% had the minimum on the parameter converting method standard, the minimum in this design standards became about 6% of decrease. This is considered to be a standard which can be used as design standards of a direct connection water supply system without creating danger. Furthermore, in the design standards of SHASE, since design population supplied doubled rather than the actual condition according to the scale of the building, distribution of the assumed design population supplied was very large. It is thought that correspondence of the design standards built in this paper is possible even when dwelling unit classification is diversified, since it was not based on the scale of the building, and there is little distribution.

3.2 Water consumption conversion standard by change system specific productivity

Authors built the water consumption conversion standard by dwelling unit classification in past research[(2)-(4)]. However, since this design standard was a standard in consideration of the maximum of water consumption, and distribution, they brought a result as which planned anticipation water supply will be greatly calculated a little rather than the conventional standard value. There is the purpose of computing planned anticipation water supply in water supply system design in order to calculate the water tank capacity represented by prediction of the water supply supplied to the whole building, and the pressurization water supply system. The capacity which will store water in 4/10 - 6/10 of planned anticipation water supply is decided in the stage of design, and the water tank has become a thing with the role of the buffer in the tank itself. Moreover, in the latest multiple dwelling houses, since the saved type instrument of water is used for most sanitary fixtures, the consumption amount of water in a home is reducing rather than before. Therefore, by water supply system design standards, it is thought suitable to adopt not the maximum of water consumption but the average value only in consideration of the distribution at the time of the use in a residence of water consumption. This time, the safety factor of the calculation water consumption according the built water consumption conversion standard to change system specific productivity to Table 2 is shown in Figure 3, respectively.

Table 2 – The design standard by change of dwelling unit classification design population supplied conversion

Dwelling unit classification	Area of dwelling unit (㎡/House)	Design supplied population (Person/House)	Average of water consumption (L/day・person)
1R・1K etc.	37.0 following	1	285
1DK・1LDK etc.	43.0 grade	1.5	270
2DK・2LK・2LDK etc.	55.0 grade	2.5	255
3DK・3LDK etc.	65.0 grade	3	240
4DK・4LK・4LDK etc.	83.0 grade	4	225
5LDK over	98.0 above	4.5	225

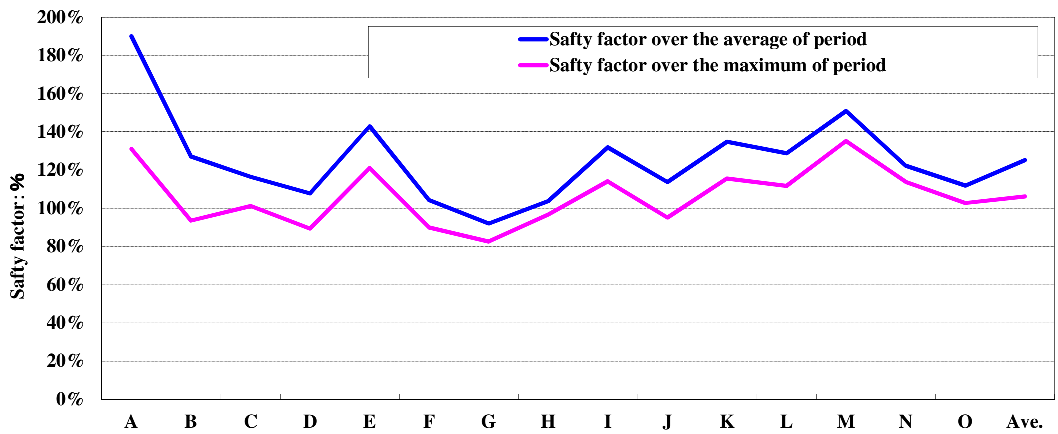

Figure 3 – The safety factor of design standard by change of dwelling unit classification design population supplied conversion

On being based on par water consumption, water consumption decreased by about 5% as compared with the result built by past research. Moreover, the safety factor of the calculation water consumption by change system specific productivity had increased by about 6% to the maximum to period average rates as compared with the actual measurement during increase and the period about 25%. All have been improved as compared with the conventional calculation formula, and it was not less than the actual measurement. Therefore, it is thought that the standard suitable for the design standards of the water supply system which use a water tank has been built by combining a change system specific productivity water consumption conversion standard with a dwelling unit classification conversion standard.

3.3 Design standards of the instant maximum anticipation water supply which considered factor of safety

The design standards of the MLIT by a proportional expression and comparison of the instant maximum anticipation water supply calculation formula of the concurrent use flow by logarithm approximation are shown in Figure 4. In the proportional expression, bordering on 170 persons, when the number became fewer, water supply became small, and when the number increased, water supply had become large. Building as an actor the water supply system which uses a water tank is raised with a proportional expression as a reason. When calculating the capacity of a tank, it is satisfactory at a proportional expression, but since a concurrent use flow has influence greatly on the occasion of selection of a pump, or the determination of a piping caliber, it is thought desirable to use the calculation formula calculated from the concurrent use flow by logarithm approximation for calculation of the instant maximum anticipation water supply.

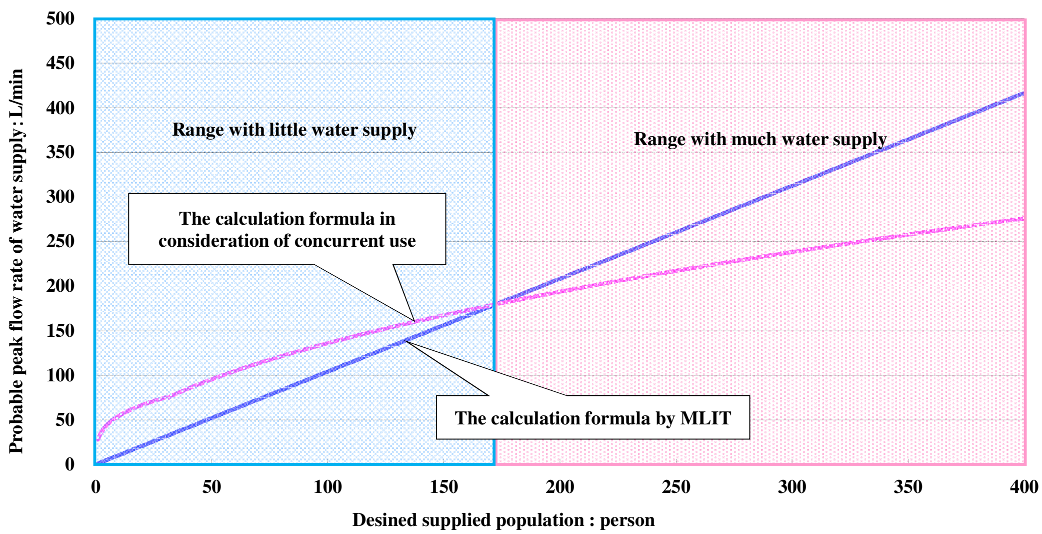

Figure 4 – The probable peak flow rate of water supply in consideration of concurrent use and MLIT

Next, in order to build the design standards of the instant maximum anticipation water supply, the Gumbel distribution which is one of the extreme value distributions currently used for meteorological data etc. is used as a probability distribution. An extreme value distribution gives the standard of the maximum in a long term about the strong phenomenon of random nature, such as abnormal weather which happens rarely. The factor of safety of the instant maximum anticipation water supply is examined supposing a long period using the Gun Belle distribution. The probability which may happen in a period the examination result by the procedure and estimated value which the Gumbel distribution which is one of the polar zone distribution applies to Figure 5 for three weeks over a long period of time to a standard value is shown in Table 3, respectively.

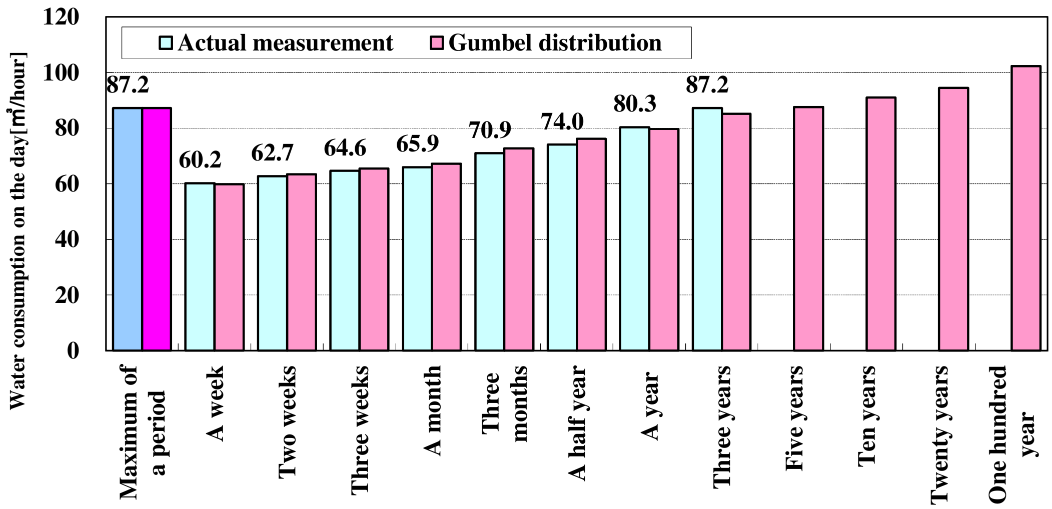

Figure 5 – The estimated value of water consumption on the day using the Gumbel distribution

Table 3 – The estimated value which the Gumbel distribution for three weeks over a long period of time to a standard value

(Probability: %)

	Once in a month	Once in three months	Once in a half year	Once in a year	Once in three year	Once in five years	Once in ten years	Once in twenty years	Once in one hundred year
Probability which happens to a standard value (three weeks)	3%	11%	17%	22%	31%	35%	40%	45%	58%

Became increase 11% once, it became increase 17% once in half a year, and the factor of safety over the probability which may happen to each of a period once on the basis of a value for three weeks in one month increased by 22% once a year in 3% and increase and three months. When determining the factor of safety of the instant maximum anticipation water supply, it is necessary to take into consideration comprehensively the factor of safety in assumption of water supplied population, and the factor of safety in piping and pump selection. The factor of safety in assumption of the water supplied population built in this paper turned into a factor of safety of the increase of about 15% on the average. Moreover, if it takes into consideration adopting the apparatus and piping size which exceeds a design standards value also in selection of a pump and piping, even if it is a case where a factor of safety is set to 0 in the instant maximum anticipation water supply, it will be thought that the factor of safety of 20% or more is secured in the design phase, but. An actual measurement is considered simultaneously with it with a possibility of being less than a design value stopping being 0.

The deployment to a local self-governing body was put into the view as design standards with consideration of local limitation of survey data, and flexibility, and it decided to select the factor of safety of the instant maximum anticipation water supply used as excessive design. When the factor of safety was examined in consideration of the seasonal variation based on the four seasons and an event day of Japan, it was thought desirable to adopt the safety factor of the probability once in half a year which may happen. In addition, also in Tokyo, the calculation formula in consideration of safety factor once in half a year is adopted. The calculation formula in consideration of the factor of safety which was proposed this time and which may happen once in half a year of the instant maximum anticipation water supply is shown in Table 4.

Table 4 – The calculation formula of peak flow rate of water supply (Once in a half year)

	n≦30	31≦n	Unit
The calculation formula by an actual measurement	$Q=28.0n^{0.29}$	$Q=13.0n^{0.51}$	n : designed supplied population (person) Q : peak flow rate of water supply (L/min)
The calculation formula in consideration of safetyfactor	$Q=26.0n^{0.30}$	$Q=15.2n^{0.51}$	

4. Verification of change system specific productivity standard

It verified about the validity of the calculation process of the water supply to water supply system determination based on the data which authors collected in past research about the change system specific productivity standard of having built in this paper. Comparison of the instant maximum anticipation water supply according comparison of the planned assumption number by a change system specific productivity standard and the real residence number to a change system specific productivity standard and the instant maximal flow of a survey period is shown in Figure 6 and in Figure 7, respectively.

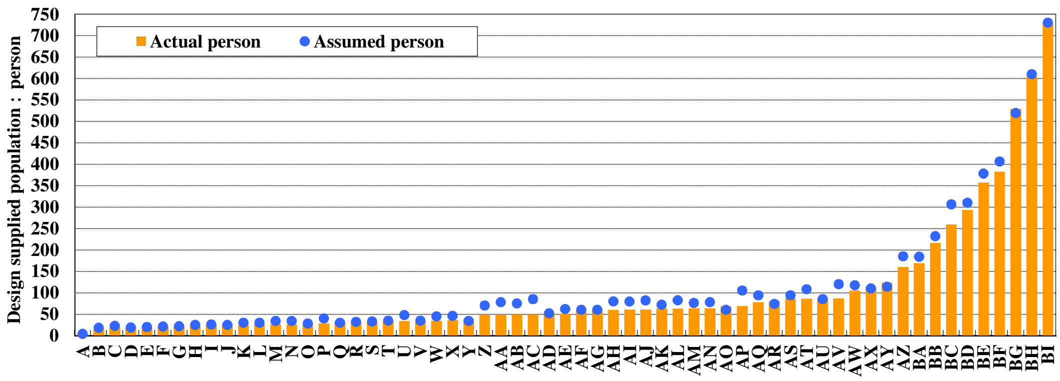

Figure 6 – The verification of design supplied population of the proposed design standards by the actual multiple dwelling houses

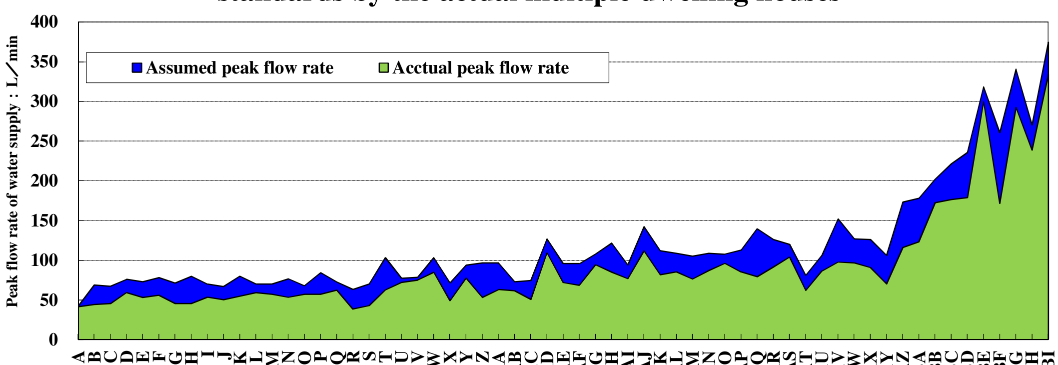

Figure 7 – The verification of peak flow rate of the proposed design standard by the actual multiple dwelling houses

As a result of verifying about the planned assumption person, a result of the design standards proposed in consideration of the safety factor and an almost equivalent result were brought. Design supplied population was par, and increased by about 15%, and there was no housing which is less than 5%. Moreover, distribution is not changed sharply, either, and it is not based on the scale or dwelling unit classification of a building, but it is thought that application to the real design housing of design standards built in this paper is useful.

A result of the design standards which also proposed the result of having verified, in consideration of the safety factor about the instant maximum anticipation water supply, and an almost equivalent result were brought. The housing with which the instant maximum anticipation water supply is less than the instant maximal flow of a survey period did not have one affair, either, was par and increased by about 20%. Moreover, I guess it also as the result of the safety factor by an extreme value distribution mostly, and think that the validity as design standards was shown. The calculation process of the water supply from the above result to water supply system determination is considered that the effect of adopting a change system specific productivity standard was shown as compared with the specific productivity standard of the fixed system to the former. Furthermore, it is thought that the change system specific productivity standard built by this research is possible not only for a direct connection water supply system but application to the water supply system which uses a water tank, and is a standard which gave flexibility in consideration of the factor of safety.

In future, I promoted verification of people's life pattern and a water supply load pattern, and think that the water supply load change of the multiple dwelling houses of the present age which the life style diversified will be analyzed. And I grasp the water use pattern of the multiple dwelling houses in the present age, and think that he would like to analyze about the source of variation. Furthermore, the relation of the rate of a peak of multiple dwelling houses and water supply load was considered, when performing water supply system design, the fundamental data which become useful were created, and I think that he would like to draw the determination process of a water supply system.

5. Conclusion

In this paper, it proposed about the dwelling unit classification water-supplied-population conversion standard of multiple dwelling houses of having balanced the life system which the present life-style diversified, water consumption conversion standard, the instant maximum anticipation amount of water design standards, and change system water supply system design standards. Furthermore, the knowledge acquired by performing verification with the real housing of design standards built in this paper is shown below.

1) It is thought that the dwelling unit classification design supplied population conversion standard of having taken the factor of safety into consideration is more exact than the conventional standard, and it can respond also when dwelling unit classification is diversified.

2) It is thought that it can respond also to the water supply system by a water tank by using the change system water consumption conversion standard which uses water consumption.
3) It is thought that it is effective to adopt as a safety factor the probability once in half a year which may happen in consideration of a seasonal variation, an event, regionality, etc. as for the instant maximum anticipation water supply which considered the factor of safety.
4) As a result of verifying a change system specific productivity standard, it is thought that validity was shown in the calculation process of the water supply to water supply system determination.

By promoting verification of the water supply system design standards of multiple dwelling houses, and also drawing the determination process of a water supply system from now on, the authors built the water supply system design standards corresponding to the life style which the present age diversified, and think that would like to aim at the establishment as a design manual.

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7. Presentation of Author

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Water efficiency intervention strategies for domestic buildings

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Abstract

Evidence shows that some parts of the UK are under considerable water stress. Various environmental problems, including water shortages, are partly rooted in human behaviour, and can thus be managed by changing perceptions and behaviour. Achieving domestic resource efficiency for water also requires an understanding of buildings and technological systems. According to the UN Environmental Program, buildings consume 20% of the world's available water and this continues to increase. Studies conducted in the UK and US report that on average, applying water efficient designs and products leads to 15% less water use, 10-11% less energy use and 11-12% reduction in operating costs. Yet, while technological advances permit increased efficiency of products, fittings and fixtures in buildings, the user's decisions and habits affect the water performance of the products. It is therefore beneficial to gain further understanding of customer behaviour and interpret this with existing knowledge of water saving technologies. This will serve as useful and rational means to understand, document and promote pro-environmental behaviours in building users and well as improve the water performance of buildings. This paper reviews water efficiency intervention strategies. It presents the various intervention strategies employed in environmental studies; then discusses the opportunities and constraints. To conclude, it establishes the argument for an integrated intervention strategy for water efficiency in domestic buildings.

Keywords

Domestic buildings; water efficiency; intervention strategies; user behaviour

1. Introduction

With projected increases in temperature compared to 1999 levels, it is likely that globally, many people will be exposed to increased water stress (Stern 2007). Based on current evidence, parts of the UK are already under considerable water stress (Defra White Paper 2011; EA 2011). This claim is further supported by the drought order that is still in place in South East England as this paper is being written.

Various environmental problems, including water shortages, are partly rooted in human behaviour, and can thus be managed by changing behaviour to reduce the environmental impacts (Steg and Vlek 2009; Gardner and Stern 2002). The production and use of buildings also consumes a significant amount of natural resources. Achieving resource efficiency in relation to water, energy and materials also necessitates an understanding of buildings and technological systems. Buildings are very complex systems because of the high degree of interaction with its surrounding environment such as bioclimatic architecture and service provisions (Casals 2006). According to the UN Environmental Program, buildings consume 20% of the world's available water and this continues to increase. This level of resource consumption in buildings has been attributed to technological development, economic growth, demographic factors, institutional factors and cultural developments (Abrahamse *et al.* 2005). To mitigate the water resource challenges, policy often commences with putting legal frameworks in place to dissuade resource waste and increase efficiency from supply, through to demand processes. Water efficiency policies, therefore, require an understanding of customer behaviour and water use, as well as encouraging the optimisation of building processes if water efficiency is to be improved across the spectrum (Defra White Water Paper 2011).

The need for consumer information and technological innovation to stimulate user behavioural responses in order to achieve the necessary improvements in water use is also increasingly recognised (Defra White Paper 2011; Defra 2008). For instance, design and engineering methods have the potential to assist in persuading or guiding users to operate products in a more sustainable manner, through *self-management* of resource consumption (Lockton *et al.* 2008). Technological solutions help to mitigate wasteful practises during daily processes; as simple e.g. washing of hands, or complex the activity may be. Studies conducted in the UK and US report that on average, applying water efficient designs and products leads to 15% less water use, 10-11% less energy use and 11-12% reduction in operating costs (Darby 2006; McGrawHill report 2009). While engineering advances permit increased efficiency of product operation, the user's decisions and habits ultimately have a major effect on the water resources used by the product (Lockton *et al.* 2008). Technological fixes alone are not enough (IPCC 2001) and technical efficiency gains resulting from water saving devices tend to be overtaken by consumption growth (Midden, Kaiser and McCalley 2007). Whilst information, technological and design interventions have all been undertaken by the private, public and voluntary sector as part of water efficient strategies (e.g. Darby 2010; 2000) knowledge and methodological gaps especially on how water consumption behaviour affects building water efficiency performance have been identified, even in government studies and reports (EA 2009). Indeed, it is clear that the methodological advances used to understand pro-environmental behaviours (Barr *et al.* 2011) and domestic energy efficiency (Abrahamse *et al.* 2005) have not been applied to understand domestic water use.

The primary aim of this paper is to review existing knowledge on how behaviour, information and technology affects the socio-psychological response of water users to efficiency measures in domestic buildings, thereby contributing to related theory and practice on implementing water efficiency interventions particularly in homes. To do this, the paper considers a range of behavioural and technological intervention strategies used to address a range of environmental issues including energy efficiency and waste and the advantages and disadvantages are examined. The paper concludes with a discussion on the benefits of an integrated approach to designing and deploying water efficiency interventions. It also highlights that monitoring, evaluation and feedback are crucial for the success of interventions and for achieving long term results.

2. Context of the study

The quantity of water used by households in the UK increased by 55% in the last 25 years (DEFRA, 2008a), although some of this increase has been attributed to population growth, the prevalence of domestic technologies such as washing machines, power showers among other factors. The average per capita consumption (PCC) in the UK is 150 litres per person per day (l/p/d). Comparatively, the average PCC in European countries is less than 130 l/p/d. In Belgium and the Czech Republic it is less than 110 l/p/d (Ofwat 2007). In the UK, the highest rates of consumption are in severe water supply areas in the South East of England where baseline figures of household water use for unmetered properties is more than 170 l/p/d (EA 2008b). It is currently difficult to determine actual consumption because only about 37% of properties are currently metered. In domestic buildings, metering is predominantly voluntary or enforced to high discretionary users, while business users are almost universally metered. Current projections suggest water savings of 10-15% through metering. With an average consumption of 13 per cent less in metered homes compared to unmetered homes (EA 2008a).

In addition to technological factors such as metering, socio-economic variables, cultural and religious practices are also known to influence water supply and demand. These factors influence the outcome of any demand management programmes which rely as much on changes in attitudes toward water use and in some cases cultural practices, as on technological advances. Consequently, PCC can vary significantly even within countries and regions (EA 2008b). Demographics and population concentration in urban areas has impacts of the demand and supply of water. The increase in population and the creation of urban conurbations and agglomerations due to the expansion of cities and commuter belts places a substantial amount of stress on water resources which in turn requires special considerations for water resource management (Williams, Walsh and Boyle 2010). The increasing trend of low occupancy households (Mitchell 2001) has also been highlighted has an important factor for the management of water resources. Single occupancy households are particularly on the increase. This places additional stress on housing supply and has consequences for energy and water consumption. Single occupancy households appear to consume more water per person than larger households with two or more occupants (Ofwat 2009).

Lastly, housing developers and providers must now comply with Building regulations, Part G requirements of not exceeding a design/specification target of 130 per capita (litres per person per day). In addition, housing associations homes must, as a minimum, achieve Level 3 of the Code for Sustainable Homes which has a target of 125 litres per person per day. Code levels 5-6 can be achieved with some degree of water recycling and reuse. However, few housing developments have ventured to meet the higher level targets due to insufficient evidence of the risk and accruable value of such provisions. In broad terms, this trend is in response to criticism that command-and-control policies constrain innovation in so far as companies pursue minimum compliance (Lu and Sexton 2011). Such regulations are, of course, only one form of intervention and are not aimed at the users of domestic properties. The next section considers the different interventions that have been designed to influence occupier behaviour in relation to a range of environmental issues in addition to water demand such as energy use and waste recycling.

3. Interventions

Interventions as a means to promoting pro-environmental behaviours serve as a tool for understanding consumption behaviours and behaviour change. Interventions serve as a useful source of evidence for building professionals, environmental strategists and decision makers to answer real and pertinent questions for implementing change. Interventions can also potentially contribute to a transparent, multi-stakeholder policy process in which participants gain an understanding of the complexity of the issues and the 'interconnections among actions and outcomes' (Beratan *et al.* 2004, p 184). This means that by recognising the importance of human experiences, it is then possible to reconnect the perception of space and comfort with the inclination to value nature and natural resources (Kellert 2005).

Interventions have been employed with varying degrees of success. Hence, an important first step in designing and implementing interventions aimed at reducing consumption among households is a thorough problem diagnosis (Geller 2002). In the building context, the goal of interventions should be to promote the adaptive capacity of users i.e. to prepare people to accept more responsibility for their role in resource management during their interaction with buildings and the built environment as a whole. Water users should be encouraged to achieve this through experiential knowledge rather than informed knowledge. 'Real' user-building interactions are often different to that proposed through design or assumed strategically. Drawing parallels from the energy efficiency debate, Leaman (1999) noted that occupants make decisions to use tools, switches or controls after an event has prompted them to do so, and even then, may wait for some time to take action. And even after then, most will take action only after reaching a crisis of 'discomfort', and despite this, some will operate the most convenient rather than the logically appropriate. Leaman concluded that placing the responsibility of change on building occupants or inhabitants is also insufficient in itself, but necessitates a shift in the quantity and quality of understanding and communication about the short term, as well as the long – term (positive) consequences of exerting environmental or resource control.

3.1 Intervention strategies

Literature including those outside built environment subject realms was reviewed in order to explore the different intervention strategies that could be relevant to domestic water users. The review scope included the following themes: environmental, social and economic psychology, consumer studies, product innovation and marketing, information sciences and systems etc. From this exercise, two broad classifications of intervention strategies were identified; behavioural, including information interventions, and contextual, including technological interventions.

3.1.1 Behaviour intervention strategies

In general terms, behavioural responses are divided into two categories: efficiency and/or curtailment behaviours (Gardner and Stern 2002). Efficiency behaviours are one-time actions, behaviours or responses that provide lasting impact e.g. buying water efficient washing machine: for this contextual interventions are generally applied (see next section). Curtailment behaviours involve forming new routines, or repetitive efforts to reduce consumption e.g. spending less time in the shower. There are varying opinions about the effectiveness of both efficiency and curtailment behaviour (Berkhout, Muskens and Veldhuijsen 2000; Abrahamse 2005; Gardner and Stern 2002). For homes, however, it is clear that those responsible for interventions must understand the environmental behaviours that they are trying to motivate and to design interventions around those behaviours (Froehlich et al. 2010).

The design of behavioural intervention strategies depends on whether strategies that influences users before (antecedent strategies e.g. incentives for conserving water) or after (consequence strategies e.g. penalties for not conserving water) they take action or 'behave' in a certain manner is required. Behaviour intervention strategies include:

- Commitment: A commitment is an oral or written pledge or promise to change behaviour or to behave in a specific way or attain a certain goal (Abrahamse *et al.* 2005; Froehlich 2010). The promise can be linked to a specific goal, for instance, to reduce water or energy use by a specified amount.
- Goal setting: Goal setting entails giving households a reference point, for instance to save 5% or 15% of total consumption. A goal can be set by the experimenters, or by the households themselves (Locke and Latham 2002).
- Information: This is where information is presented to consumers in order to induce or promote a response; to conserve water. An implicit assumption is that the presentation of information, particularly at a time of local decision making, is enough to provoke environmentally responsible behaviours (Froehlich *et al.* 2010).
- Incentives/ disincentives: Incentives have been used effectively to motivate a range of pro-environmental consumer behaviours. For instance, rebates for new energy-efficient home appliances. Incentives need not always be monetary; incentives associated with status or convenience may also have important effects on pro-environmental behaviour (Froehlich *et al.* 2010).
- Minimal justification/ 'foot-in the door' technique: This technique is based on the premise that if an individual is asked to comply first with a small request, he or she is later more likely to comply with a larger, more difficult (and generally related) target request (Freedman and Fraser 1966). For example, if filling out the questionnaire was to be considered the first request, then the target request may be asking subjects to comply with setting and reaching a water saving goal.
- Feedback: Feedback consists of giving households information about their consumption, or savings. It can influence behaviour, because households can

associate certain outcomes (e.g. water savings) with their behaviour. Ideally, feedback is given immediately after the behaviour occurs (Geller 2002).

- Rewards/ penalties: A review by Froehlich *et al.* (2010) found that people respond to rewards even if they are nominal in nature (e.g., an acknowledgement of positive behaviour) and that the reward should be linked as closely with the target behaviour as possible. Rewards strategies should be used with care, some studies (see: Abrahamse *et al.* 2005) report the effects of rewards to be short-lived.

3.1.2 Contextual intervention strategies

Contextual (technological) interventions start from the design phase of products, the features of a product, buildings, computer systems etc. which the user interacts with. The purpose is to encourage, guide, shape or regulate behaviour modification in ways that can be pleasant, attractive to the users and useful to improve the quality of daily life (Lockton *et al.* 2008; Arroyo *et al.* 2005). Contextual intervention strategies include:

- Affordances and constraints: Affordances (including perceived affordances) are the actions or functions which are offered or presented to users (or which they perceive are available to them) and the constraints or limits on their behaviour provided by the system (Lockton *et al.* 2008). For example; rationing where a user can only shower for 5 minutes or boil one cup of water at a time. It is worth highlighting that there is a tendency for users to find these interventions excessive, frustrating, limiting or unethical, therefore, combining affordance and persuasion techniques is beneficial (Lockton *et al.* 2008; Arroyo *et al.* 2005).
- Persuasion techniques: While many affordance and constraint-based techniques aim to ‘force’ user behaviour to conform to the designers’ intent, persuasive techniques, (e.g. those developed by Fogg 2003) can be employed to effect sustained behaviour change that users take with them beyond the point of interaction.
- Feedback/ Eco-feedback techniques: Similarly to behavioural feedback, contextual feedback can help users to develop more accurate mental models of how technological or design systems around them actually work (Lockton *et al.* 2008).
- Positive or negative reinforcements: Positive reinforcement is anything that a user desires and that occurs in conjunction with an activity. If presented at the time of an action, it tends to increase the likelihood that the action will be repeated. Negative reinforcement, on the other hand, is an unpleasant stimulus. Behaviour change can be elicited by providing negative reinforcement during undesirable behaviour and removing it when change occurs (Arroyo *et al.* 2005).
- Just-in-time prompts: Researchers from a wide range of fields have demonstrated the value of using “just-in-time” prompts to engage sustainable behaviour change regarding energy conservation (e.g. Intille *et al.* 2003). Many conservation programs use high-level written or verbal messages, or prompts, to promote conservation e.g. signs reading: “Use Energy Wisely”, “Turn off tap when not in use” (Arroyo *et al.* 2005; Froehlich *et al.* 2010).
- Value added design: One basic problem in water conservation is that modern plumbing makes clean water seem plentiful and inexpensive and serves up clean water as though it were effortless to produce and distribute. By applying the principle of "value-added design" to water, it may be possible to enhance the perceived value of this precious commodity and one can effect basic behaviour

change that makes the product seem more valuable and attractive to consumers (Arroyo *et al.* 2005).

- Adaptive interfaces: While constant reinforcement should be presented at the beginning stages of behavioural modification, once behaviour is established, they can become less effective and potentially annoying. Adaptive interfaces help to apply variable interval reinforcement. It is used to regulate the intervals, varying modality and frequency that cannot be readily predicted by users in order to be less annoying and more effective (Arroyo *et al.* 2005).
- Social validation or comparison: Social validation principles suggest that people determine what is correct based on what other people think is correct. In this strategy, behaviour change may then be effected by revealing the actions of others (Cialdini 2001). A comparison between individuals or groups is used to motivate action, particularly when combined with feedback about performance.

3.1.3 Opportunities and constraints of intervention strategies

The intervention behavioural and contextual intervention strategies enumerated above will not be applicable in all instances. The findings of studies above suggest effective interventions require a high degree of personalisation and efforts should be made to understand the water user; either through ethnographic studies or some degree of engagement or co-creation with the user.

It is worth highlighting that there are opportunities and constraints to deploying the fore mentioned intervention strategies. For instance, research suggests the goal setting strategy is best deployed in combination with other interventions, such as feedback (to indicate how households are performing relative to the goal), or as part of a commitment to conserve a certain amount (Abrahamse *et al.* 2005). Although by applying specificity, to focus the attention of the user, it is possible to ensure that the user expends more personal effort to attain the goal and increase performance (McCalley 2006). Prompt feedback, by making a particular goal more salient, is also recommended. This will attract attention and effort away from one goal at a particular level of the hierarchy and activate another at another level of the hierarchy (Kluger and DeNisi 1996). It is worth mentioning that previous studies show no significant difference emerged between participants who had been able to set a goal themselves and those with an assigned goal (McCalley 2006).

Findings also demonstrate that information interventions tend to result in higher knowledge levels, but not necessarily in behavioural change or yield substantial consumption savings. Rewards have effectively encouraged energy conservation, but with rather short-lived effects. Feedback has also proven its merits, in particular when given frequently (Abrahamse *et al.* 2005). Physical and technical innovations in itself imply behaviour changes because individuals need to accept and understand them, buy them, and use them appropriately (Steg and Vlek 2009). However, technological interventions have also yielded mixed results. McCalley (2006) argues that in order to successfully “harvest” the advantages of technological improvements, it is essential to understand the fundamental principles underlying the interaction between the user and the system through the careful development and use of appropriate theoretical frameworks. The copious energy feedback studies of the late 1970s and early 1980s stand as an example of how a general lack of cognitive motivation theory sustained a flow of research that often produced contradictory results (McCalley 2006) expand on this in what way contradictory??. Similar issues are now being experienced with the water resource, water efficiency trials and user engagement studies in the UK water sector.

Key findings of the studies reviewed showed that no singular intervention strategy for energy, waste or other environmental fields appeared to yield sustained results on its own. Combined or integrated interventions, designed and deployed with the user appeared to deliver the better results in the medium to long term.

4. Discussion – implications for interventions for domestic water consumption

Current water efficiency intervention strategies include information tools such as leaflets attached to water bills, low level technological interventions such as water hippos and shower times or retrofitting taps and showers, installing water meters or high level technological solutions such as rain or grey water harvesting systems.

Existing research suggests that water efficiency interventions are likely to be more effective if it targets behaviour determinants (Michie *et al.* 2008) rather than the behaviour itself. Learning derived from this literature review shows that in practical terms, intervention strategies are effective if they manage user expectations and preference particularly with regards to technological and product performance expectations (McCalley 2006). Physical and technical innovations in itself imply behaviour changes because individuals need to accept and understand them, buy them, and use them appropriately (Steg and Vlek 2009). It was also found that effective water efficiency interventions should promote user choice as an active, continuous process (Kellert 2005). The strategy employed should aim to fine-tune the approach to incentivising: people are in general more loss averse than motivated by gain and studies show that the effects of rewards can be short-lived (Abrahamse et al. 2005). Strategies should promote transparency, acting on information and feedback from all parties (IPCC 2001; Larson 2010). This is particularly important in England and Wales where the consumer has less choice of supplier and feels less empowered to influence change.

Importantly, findings suggest that an integrated approach to water efficiency interventions informed by a better understanding of water users yields the best results. Information, behaviour and technological interventions will be more effective than singular interventions deployed in a non-systematic manner. For example, a review of energy interventions conducted by Abrahamse *et al.* (2005) found that information proved to be more effective when used in combination with other interventions. However, the effects of information seem to depend largely on its specificity and tailoring. This study also reported that home energy audits and using tailored energy advice had positive effects on household energy use (curtailment behaviour) as well as the extent to which efficiency actions/ behaviours were taken. However, further studies are required to fully explore this in the context of water efficiency.

Additionally, there are two vital components to achieving effective interventions to influence domestic water use and behaviours; the availability and transparency of information from the key stakeholders in order to engage customers in the process of personalisation and, a holistic and non-compartmentalised approach to realising water efficiency objectives which is co-designed with customers (Adeyeye 2011). Two-way improved communication has an important role to play in facilitation of the changes in behaviours of individuals and other agents e.g. households, as changes in behaviours are more likely to occur when agents are able to translate the potential impact to their own situation, to understand how their own wellbeing would be negatively impacted if no change occurs and thus actively acquiesce to change in behaviour (Larson 2010). After all, technology, however functional in scientific terms, still relies on positive social interactions to be effective.

5. Conclusion

This paper set out to review existing intervention literature to promote resource efficiency and behaviour change. The aim is to contribute to existing knowledge and support best practise for water efficiency in domestic buildings. At the end of this exercise, it was found that interventions are likely to be more effective if they target determinants of behaviour and behaviour change i.e. cause, effect and response. From previous studies on domestic interventions in relation to energy, waste and other areas of environmental consumption, it was also found that resource efficiency interventions are most effective when they are designed to understand both causality and response by analysing the interconnections among information, actions and outcomes. Previous conceptual and empirical research also indicates that there are varied types of behavioural change made by consumers in response to intervention promoting household resource efficiency. Lastly, evidence was found to support the assertion that a combined or integrated approach to designing and deploying water efficiency interventions is more likely to support better outcomes i.e. sustained water efficiency in the home. The next stage of this study is to conduct further studies in order to develop a systematic approach to deploying water efficiency interventions in homes.

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Prof Andrew Church is a leading expert on water, politics and recreation. He will guide the social science aspects and methods of the proposed project. He was recently the lead author for the cultural services chapter in the UK National Ecosystem Assessment. He will also provide advice to ensure the project has a national impact based on his experience of undertaking a large number of funded impact oriented projects for Defra, Environment Agency, Forest Research and the private sector.

Water efficiency of products. Comfort limits.

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Abstract

Currently used in an unsustainably way, not only because of the exponential growth of the population on the planet, but mainly of the global model of economic growth that over-consumes the resources, fresh water is becoming a limited resource.

The first step to sustainability is the efficiency. In buildings, the use of efficient products should be considered a priority measure, among other measures applicable, as the use of grey water and rainwater and the reduction of losses and waste. With this objective, the ANQIP (National Association for Quality in Building Services), a Portuguese NGO dedicated to promoting quality and efficiency in building services, decided, in the end of 2008, to launch a system of voluntary certification and labeling of water efficiency products, aiming new construction and rehabilitation.

However, the reduction of the flow in the devices can have some constraints, at the level, for example, of the comfort of the users, of the drainage performance or even in terms of public health.

In this paper are referred some works developed by ANQIP in the field of the relation between the reduction of the flow in the devices and the user comfort, highlighting, in particular, the application of restrictors in faucets and showers. In the latter case, are presented the results of a study recently performed in a student residence at the University of Aveiro, in Portugal.

Finally conclusions are presented and several recommendations are made in the context of the relationship between minimum flows in devices and user comfort.

Keywords

Comfort limits, showers, taps, water efficiency.

1. Introduction

Nowadays, the water efficiency of the water using products (WuP) it's a matter of growing importance, due to the unsustainably use of the potable water at a global level, as a result of the exponential growth of the population on the planet and, mainly, of the global model of economic growth and resource consume.

In this sense, and among other measures applicable, as the use of grey water and rainwater or the reduction of losses and waste, the use of water efficient products should be considered a priority measure to increase the water efficiency in buildings.

With this aim, the ANQIP (National Association for Quality in Building Services), a Portuguese NGO dedicated to promote quality and efficiency in building services, decided in the end of 2008 to launch a system of voluntary certification and labeling of WuP, trying to provide consumers with information about the most efficient products.

This system has already been presented in a previous edition of the CIB W02 Symposium [1]. The ANQIP generic labels are presented in Figure 1.

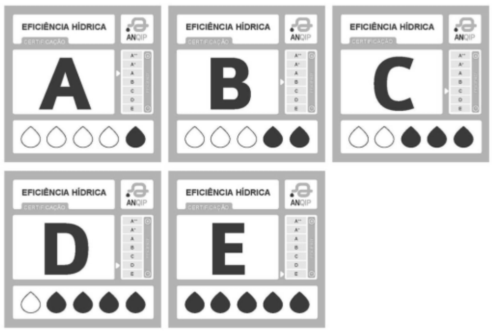

Figure 1 – ANQIP labels of water efficiency [1]

However, the reduction of the flow in the devices can have some constraints, at the level, for example, of the comfort of the users, of the drainage performance or even in terms of public health.

As regards the comfort, the reduction of flow in showers and taps could be more sensitive to the users. So, ANQIP has developed some studies in this field and the Portuguese system of labeling of water efficiency of WuP has created special labels for devices of small flow, requiring, in some cases, the application of specific solutions for the assignment of the label ANQIP.

2. Low flow taps. Problems and solutions

2.1. Description of the problem and typical solutions

Low flow taps are commercially available. Generally, manufacturers try to restore the feeling of comfort with appropriate solutions, such as the emulsion of air.

Regarding the taps with high flows, the reduction of the flow can be done, for example, applying on the tap a flow restrictor. However, in these cases the reduction in the flow may lead to a sensation of discomfort, particularly when the design of tap is not appropriate for low flow rates and can impart a feeling of lack of pressure or flow.

So, the flow restrictor to be used in these cases must be of special type, like aerators, sprayers or restrictors of laminated flux. [5]

The aerators consist of elements which restrict the flow without reducing comfort, thru the introduction of air into water flow (Figure 2).

Figure 2 – Aerator [2] [3] [4]

The spray tips (or sprayers) decreases the flow rate with a sprayed flow (Figure 3), producing a shower with multiple water jets. The shower effect broadens the radius of action of the jet, but keeping a reduced amount of water, due to its spray effect.

Figure 3 – Spray aerator [6]

There are also reducers that may function as an aerator or as a sprayer, being the user the one who choose the function by rotating the tip. Usually its installation occurs in kitchen taps (Figure 4).

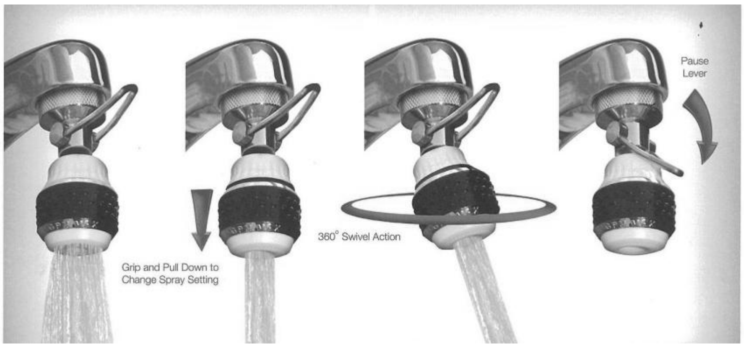

Figure 4 – Sprayer/aerator [7]

There are also restrictors with laminar flux (Figure 5) having a function identical to the aerators, without the introduction of air into the flow. This difference may cause a feeling of less comfort, since the rate of the flow is reduced, but the viewing of a body of water apparently abundant and a use without splashing reduces the discomfort. The laminar flow restrictors are appropriate for very frequent use, in public places and in all areas where there are concerns about public health due to contact air - water. [5] [8]

Figure 5 – Restrictor with laminar flux [6]

The restrictors have generally too low flows at low pressures and insufficient efficiency with high pressures. To overcome this problem, there are restrictors with a system of Pressure Compensating Aerator (PCA), which maintains a constant flow regardless of the pressure available on the water supply. This system increases the comfort with low pressures and maintains the efficiency even with high pressures (Figure 6).

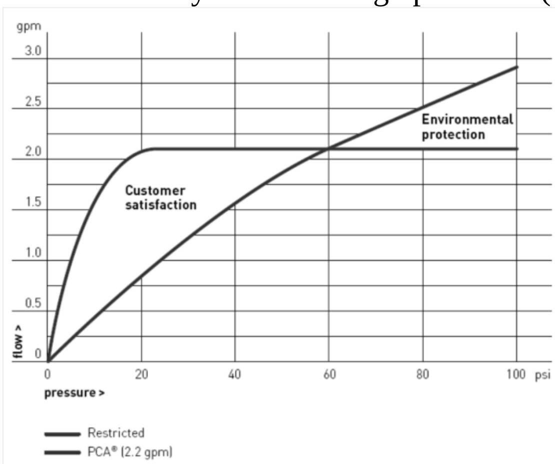

Figure 6 – Chart flow – pressure with PCA [6]

These systems exist in restrictors with aerated flux, pulverized flux and laminated flux. The flow regulation takes place independently of the supply pressure, because there are a membrane which restricts the flow in function of pressure.

Note that the taps with low flow (or the application of low flow reducers) may be inconvenient in some cases, because their reduced flow rates may not activate the devices for producing instant hot water.

2.2. The Portuguese system of water efficiency labeling of taps. Brief description.

According to the Portuguese system of certification and labeling of water efficiency (ANQIP), the assignment of labels to a given faucet is made according to the categories set out in Table 1, for lavatory taps, or in Table 2 for kitchen taps [5].

Table 1 – Conditions to assign water efficiency labels in lavatory taps (ANQIP)

Flow (Q) (L/min)	Lavatory taps	Lavatory taps with eco-stop or aerator (2)	Lavatory taps with eco-stop and aerator (2)
$Q \leq 2,0$	A+	A++ (1)	A++ (1)
$2,0 < Q \leq 4,0$	A	A+	A++
$4,0 < Q \leq 6,0$	B	A	A+
$6,0 < Q \leq 9,0$	C	B	A
$9,0 < Q \leq 12,0$	D	C	B
$12,0 < Q$	E	D	C

Notes: (1) It is not considered of interest the use of eco-stop in these cases.
(2) The use of sprayers or restrictors of laminate flux is considered equivalent to the use of aerator

Table 2 – Conditions to assign water efficiency labels in kitchen taps (ANQIP)

Flow (Q) (L/min)	Kitchen taps	Kitchen taps with eco-stop or aerator (2)	Kitchen taps with eco-stop and aerator (2)
$Q \leq 4,0$	A+	A++ (1)	A++ (1)
$4,0 < Q \leq 6,0$	A	A+	A++
$6,0 < Q \leq 9,0$	B	A	A+
$9,0 < Q \leq 12,0$	C	B	A
$12,0 < Q \leq 15,0$	D	C	B
$15,0 < Q$	E	D	C

Notes: (1) It is not considered of interest the use of eco-stop in these cases.
(2) The use of sprayers or restrictors of laminate flux is considered equivalent to the use of aerator

Regarding the low flow taps, the system requires, for reasons of comfort, that the labels A and A^{+} apply to taps with a flow equal to or less than 4.0 L/min, in the case of lavatory taps, or 6.0 L/min, in the case of kitchen taps, have associated the words "Recommended the use with aerator", as shown in Figure 7. The use of sprayers or laminated flux restrictors is considerer equivalent to the use of aerators. In the case of the taps A^{++}, the assigning in this category already requires the existence of aerator.

Figure 7 – Special A and A$^+$ labels for taps [5]

3. Showerheads and shower systems with low flow

3.1. Comfort factors

The comfort in the use of showers depends on several factors, but are not known, however, many studies on this issue. WaterSense, for example, considers essentially, as factors of comfort, the strength of the spray and the coverage of the spray, by setting the performance to be followed in each of these parameters on the basis of user data.

For the first factor, WaterSense considers that the strength of the spray should not be less than 0.56 N to a residual pressure of 140 kPa, defining specifications for the tests to evaluate this performance. In relation to the spray cover, the spray should not be too concentrated in the center or in the periphery. The test methods are defined considering a set of rings (maximum 10) spaced of 2" and a distance of 18" to the shower, and should not be concentrated in the two central rings more than 75% of the volume collected. Also the three central rings should not receive less that 25% of the volume collected.

Other studies [9] refer comfort parameters such as the spray pattern (spray distribution), the water temperature (vertical temperature profile), the skin pressure (velocity of the spray), the effectiveness in washing away the soap and shampoo and the controllability.

3.2. Current solutions

As in the case of taps, there are in the market various types of low-flow showers, with different solutions to reduce the discomfort resulting from low flow rates.

The most common solutions are the emulsion of air (Figure 8), the use of different types of spray (Figure 9) or the use of a small turbine vane (Figure 10).

The use of flow restrictors is possible in existing showers to reduce the flow rate, but, in this case, can occur a discomfort in the use of the shower, if it has not been designed to operate at low flow rates. The restrictors are usually placed immediately before the showerhead or in the connection between the tap and the hose. These devices have an internal membrane which limits the flow, by applying a head loss (Figure 11).

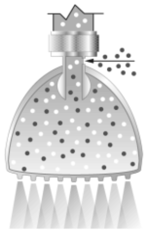

Figure 8 – Shower with emulsion of air [10]

Figure 9 – Shower with different types of spray [11]

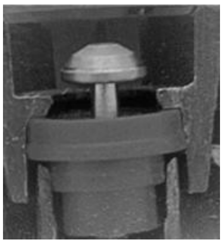

Figure 10 – Shower with a small turbine vane [12]

Figure 11 – Flow reducers [3]

It should be noted that, in the showers of low flow, variations in the flow of hot or cold water can result in sensitive variations of temperature, increasing the risk of scalding. This aspect was considered in the Portuguese system of certification and labeling of water efficient products (ANQIP), as it is mentioned later. [8]

As in the case of taps, the application of low-flow showerheads or reducing devices may be inconvenient in some cases, because their low flows may not activate the devices for producing instant hot water. In the case of electrical showers, the application of restrictors may result in overheating.

3.3. The Portuguese system of water efficiency labeling of showers and shower systems. Brief description.

3.4.

There are considered in the Technical Specification ANQIP which establishes the conditions for labeling showers and shower systems, the following types of products:

- Showerheads (showers), alone;
- Shower taps equipped with hose and removable or fixed showerhead (shower systems).

The assignment authorization of labeling of a product of these types is made in accordance with the categories established in Table 3. [8]

The labels A and A^{+} applicable to showers with flow equal to or less than 7.2 L/min and should be associated with the indication "Recommended the use with thermostatic taps", as shown in Figure 12. The use of automatic valves for compensation pressure is considered equivalent to the use of thermostatic valves.

Table 3 – Conditions for water efficiency labels in showers and shower systems (ANQIP)

Flow (Q) (L/min)	Showerhead	Shower system	Shower system with thermostatic tap or eco-stop	Shower system with thermostatic tap or eco-stop
$Q \leq 5$	A+	A+	A++ (1)	A++ (1)
$5{,}0 < Q \leq 7{,}2$	A	A	A+	A++
$7{,}2 < Q \leq 9{,}0$	B	B	A	A+
$9{,}0 < Q \leq 15{,}0$	C	C	B	A
$15{,}0 < Q \leq 30{,}0$	D	D	C	B
$30{,}0 < Q$	E	E	D	C

Note (1): is not considered of interest using the eco-stop in these cases

Figure 12 – Special labels for showers with low flow [8]

3.5. Comfort in showers. ANQIP study

In order to measure the effect of flow restrictors in existing showerheads, ANQIP lead a study in a student residence at the University of Aveiro, looking to know the minimum flow for comfort, relating to gender of users and duration of the bath. The study involved other less relevant parameters (age of student participants, etc.), that are not developed in this communication. The study did not involve, however, temperature measurements of the shower. As is evident, the results of this study cannot be extrapolated in general, as they are function of the type of existing showers and of its characteristics (spray coverage, etc.).

The study involved 16 persons, 8 males and 8 females, and each user was asked to record the flow that use commonly for showering (Q_{usual}) and to carry out a progressive reduction (around one liter per minute and per day) of the flow rate on subsequent days, until it finds a minimum value of comfort ($Q_{min.comf.}$). To this end it has been provided a simple flow meter. The data collected are summarized in Table 4.

Table 4 – ANQIP study. Data collected

Person	Age	Sex	Q_{usual} (L/min)	Duration (min)	$Q_{min\cdot comf.}$ (L/min)	Duration (min)
1	22	F	11	4	7	5
2	23	F	10	15	5	13
3	22	F	10	9	6	8
4	24	F	9	10	5	12
5	21	F	8	7	4	8
6	20	F	9	8	6	7
7	19	F	10	5	7	6
8	23	F	10	8	7	10
9	20	M	11	5	8	6
10	22	M	12	4	7	6
11	23	M	10	6	6	5
12	21	M	9	7	6	6
13	19	M	10	5	7	7
14	22	M	11	8	9	7
15	24	M	8	4	6	7
16	23	M	10	6	7	9

The average values obtained are presented on Table 5. The mean values obtained for the duration of the shower are slightly below the values obtained by other entities, such as Waterwise (9 minutes, on weekdays, for persons under 35 years) or the American Standard Group (8 minutes for a typical shower).

However, the most important result of the study is the fact that, from a certain value, the duration of the shower increases with the reducing of the flow rate, what means that the reduction in the water volume used on the shower does not follow the reduction of the flow, so that the savings may not be as significant as expected, and also leading to the conclusion that, for each type of shower, exists probably a "break point", i.e. a point at which the flow rate reduction is not translated into water efficiency.

Table 5 – ANQIP study. Averages

		Q_{usual} (L/min)	Duration (min)	$Q_{min.conf.}$ (L/min)	Duration (min)
Averages	F	9,625	8,25	5,875	8,625
	M	10,125	5,625	7	6,625

From the analysis of Table 5 it can be concluded that is the male that usually uses a higher flow in the shower and that also requires a greater flow of comfort. In terms of duration of the shower, the values are higher for females in any case.

It may be noted (from Table 4) that, for female, the minimum average flow of comfort required in the shower was 4 L/min and, for males, was 6 L/min, although these values does not satisfy all individuals, as is clear in the following figures (Figures 14 an 15), which indicate, for males and females, the duration and the flow used in the shower.

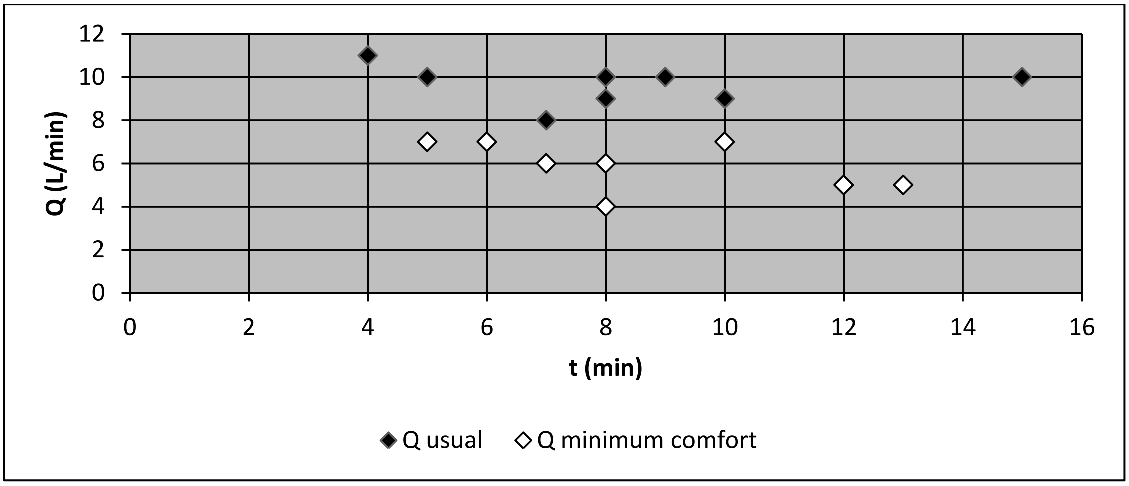

Figure 14 – Relations flow - duration of the shower (female)

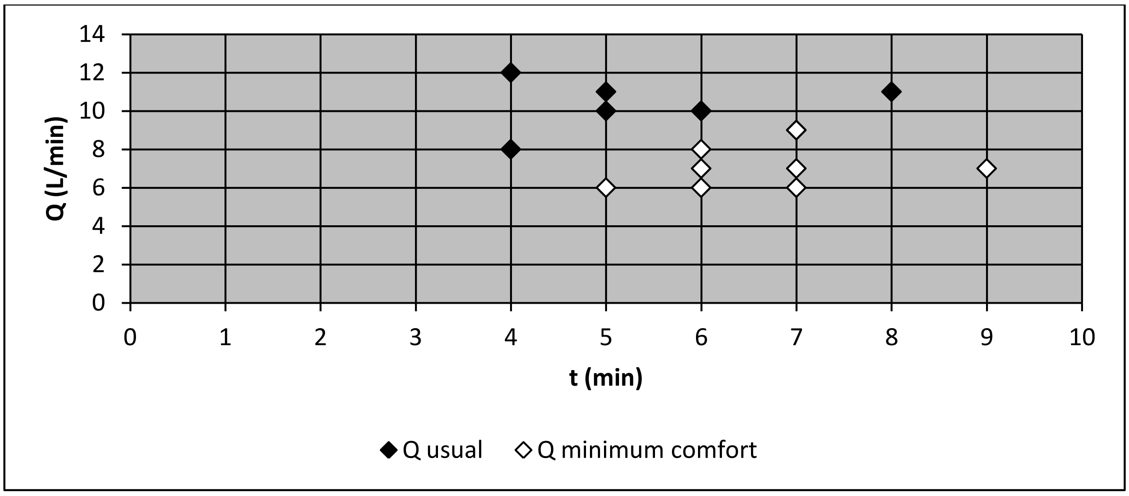

Figure 15 – Relations flow - duration of the shower (male)

In terms of consumed volumes (flow x duration of showering) the Table 6 presents the usual volumes and the volumes of minimum comfort for each person.

Looking at the Table it can be seen that the minimum and maximum usual volumes used by females are, respectively, 44 L and 150 L. In respect to the volumes of minimum comfort considered, the minimum value is 32 L and the maximum is 70 L.

Linking these two analyzes, it can be noted that it is the female who consume more water in showers. In any case, the reductions are significant because, in females, the average volumes fell from 80 L/shower for 50 L/shower (37.5% decrease) and, in males, decreased from 57 L/shower to 46 l/shower (reduction of about 20%).

Overall, the usual shower corresponds to an average of 68.5 L/shower and the minimum comfort value corresponds to 48 L/shower, which translates into an effective reduction potential of 30%.

Table 6 – Volumes consumed in shower (usual and min. comfort)

Person	Age	Sex	V_{usual}	$V_{min.conf.}$	Person	Age	Sex	V_{usual}	$V_{min.conf.}$
1	22	F	44	35	9	20	M	55	48
2	23	F	150	65	10	22	M	48	42
3	22	F	90	48	11	23	M	60	30
4	24	F	90	60	12	21	M	63	36
5	21	F	56	32	13	19	M	50	49
6	20	F	72	42	14	22	M	88	63
7	19	F	50	42	15	24	M	32	42
8	23	F	80	70	16	23	M	60	63

4. Conclusions

The demand for higher water efficiency in buildings cannot be realized without considering other factors such as user comfort, the performance of the drainage system or public health aspects.

The aspects of comfort are very relevant, as they can lead to the rejection of the efficiency measures or to changes in user habits, nullifying partially or totally the benefits of increasing the efficiency of the products (for example, the increasing of the duration of showering for low flows).

However, it is still scarce the number of studies performed in this field and the number of parameters usually analyzed seems insufficient. Thus, the evolution and improvement of systems of labeling of water efficiency requires greater attention to these aspects and the promotion of further studies in this area.

With regard to the parameters of comfort, specifically, it is noteworthy that, being concerned subjective parameters, the results may not be extrapolated to countries or populations with different habits, requiring more localized analyzes.

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6. Presentation of the Authors

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A simplified method for determining the value of water saving retrofits in schools

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Abstract
In recent years, the government's water policy has focussed on consumer education as well as the adoption of technological innovation, particularly in buildings. Schools, on one hand, provide opportunities to educate the future generations about water conservation. In addition, the need for high quality school facilities combined with budgetary challenges encourages school to be efficient in all aspects of operation and management. This is to ensure that sustainability standards are achieved without value compromises.

The aim of this study was to develop a simplified method to determine the feasibility of water saving retrofits in schools. In addition to assessing point-source water consumption, the method also assesses the effectiveness of various water saving solutions; including the cost savings and operational benefits. The simplified method was utilised to ensure usability and accessibility to key staff; bursars, business managers, premises officers, head teachers and teachers, responsible for making day-to-day value judgements and operational decisions as well as engaging and educating pupils at the school.

The paper starts by establishing the context of the study, then reviewing existing water efficiency assessment methods. It then presents the approach to developing the assessment method. Following this, the method and approach used to evaluate and revise the assessment method is then presented. The paper concludes by discussing the transferability of the assessment method and identifies areas for further work.

Keywords:

School buildings, value and payback, water efficient technologies, water saving retrofits.

1 Introduction

The need for improved and efficient water management in the UK is well documented. According to the Environment Agency, there is a predicted rise in individual water use that most water companies have not addressed to the full potential of the consequences (Environment agency 2004). This is still the case in an updated report by the environment agency stating that water resources will become more stressed in the future and that careful planning will be critical to ensure sustainable water supplies (Environment Agency, 2011).

In addition to the increasing demand, climate change will impact on future water availability. One consequence is the increased frequency of extreme weather events; excessive rainfall or droughts in the UK (Met office, 2010). These issues have in recent years gained increased policy attention. The government's water policy and strategies include improving consumer education for behaviour change and encouraging the adoption of technological innovation, particularly in buildings. One area for significant savings and mass education is public buildings, including school buildings. Schools provide not only a good opportunity for using water more efficiently, but serves as a useful platform to promote the positive water consumption behaviours and adoption of technologies especially if included in the school curriculum. Educating pupils on the merits of sustainable behaviour is a good long term strategy for encouraging the general public in reducing future personal water consumption.

Table Error! No text of specified style in document.**: Recommended minimum water storage (CIBSE 2004)**

Type of building/occupation	Minimum storage
Hostel	90 litres/bed space
Hotel	135 litres/bed space†
Office premises:	
— with canteen facilities	45 litres/employee
— without canteen facilities	40 litres/employee
Restaurant	7 litres/meal
Day school:	
— nursery	15 litres/pupil
— primary	15 litres/pupil
— secondary	20 litres/pupil
— technical	20 litres/pupil
Boarding school	90 litres/pupil
Children's home or residential nursery	135 litres/bed space
Nurse's home	120 litres/bed space
Nursing or convalescent home	135 litres/bed space

† There will be significantly greater demand in a luxury hotel than in a budget hotel.

The research focuses on schools as they provide not only a good opportunity of using water more efficiently, but also as a platform to promote the water efficient technologies as part of the curriculum for the school. Water in school buildings serves various uses; cleaning and washing, flushing toilets and meal preparation. The use and size of the building(s) affects the overall amount of water consumed in the building. For instance, according to the *CIBSE guide for public health engineering: water supplies*, a 200-pupil primary school would use 3,000 litres a day whilst a 200-pupil secondary school is likely to consume 4000 litres a day (CIBSE, 2004). Data taken from CIBSE Guide G2 is shown in Table 1.

The aim of this study was to propose a simplified water assessment approach or method for schools which can be used to facilitate value decisions when considering water efficiency strategies and solutions. The objectives were to:

- Review existing literature on water efficiency assessment methods currently used in industry
- Develop a simplified method for assessing the feasibility of using water efficient technologies to reduce the schools water consumption
- Evaluate the simplified approach and make recommendations of further improvement and application.

This paper starts by examining the water consumption in buildings, with specific attention to schools. It also presents a brief review of existing water assessment methodologies or tools with the view to justify the need for this study. The paper then proceeds to discuss the development and evaluation of a simplified method for determining the value of water saving retrofits in schools (henceforth referred to as the simplified approach). Current water saving technologies and their suitability within the school environment as well as available water assessment methods are reviewed to justify the development of the simplified approach. The paper concludes with a reflection on findings and recommendations for future work.

1.1 Research Methodology

This research utilises the exploratory approach based on three research methods; literature review, desk study and case study. A desk-based review of the available water efficiency technologies and currently available water use assessment methods was carried out to provide background knowledge and understanding. From the desk study findings, the initial content and structure for the simplified approach was developed. This output was then evaluated using a case study school in East Sussex.

2 Current water consumption assessment methods

The need to reduce water consumption, caused by increasing demand and climate change, has according to Brewer in (2001), led to the adoption of water conservation measures to reduce mains water use. It has also created a demand for assessment and feasibility models to aid householders, business owners as well as design and building professionals to reduce water consumption in buildings. There are many methodologies currently available to assess the water consumption and potential value of offsetting the water consumption of buildings with alternative water supply. This research initially focussed on the assessment methods for alternative water systems and various versions of the building regulations water calculator. Findings were then used to develop the research output: a simplified water technology feasibility method for schools.

In 2005, CIBSE (Charted Institute of Building Services Engineers) published as part of its knowledge guide an outline to reclaimed water including guidance on how rainwater and greywater systems work, as well as guides to how to assess the potential for the implementation of these technologies (Parsloe, 2005). The rainwater and greywater assessment methods covered in the knowledge guide provide a methodology for calculating the water that could be yielded from the system, the amount of water that could be used and the suitable storage size. The *CIBSE knowledge guide: Reclaimed water* provides a robust methodology for the calculation of the potential water yielded from rainwater harvesting and greywater reclamation systems. Although the methodology is robust, the only criticism is that a rainfall factor needs to be added to the equation as this methodology does not cover rainwater availability in the catchment area. The methodology only provides the annual yield of the systems. Schools are often used seasonally and monthly data is more beneficial for more effective planning and determining value and cost benefits. Furthermore, a crucial factor for public buildings is the payback period and the potential savings accessible from the system. This will largely depend on the billing method used by the building; all these factors should be included in any credible methodology.

In 2007 the Market Transformation Programme (MTP) with BSRIA (BSRIA, 2007) produced a series of documents examining rainwater and grey water technology. The guide for specifiers of the same series covers a model for assessing the potential yield for water technologies and covers some design considerations, including tank size, tank location and collection surface. The MTP report (BSRIA, 2007) provides a calculation method of water yielded from rainwater and grey water reclamation systems, as well as covering the technological requirements. Although the methodology provides a good basis for understanding the effectiveness of these systems, it fails to include the economic assessment of the system.

The building regulations Part G: Sanitation, hot water safety and water efficiency (Building Regulations Part G, 2010) has laid out a methodology to assess domestic water consumption. The methodology includes a “water calculator” which consists of a series of checklists that calculates the water consumption of the given dwelling. This methodology provides a good understanding of the methods used to calculate water consumption. The layout of the report is easy to follow and the process of completing the assessment methodology is straightforward. There have been some criticisms of the typical use factors. This water calculator also fails to include the economic assessment of the system. It also does not cover a financial assessment method. Instead it presents a basic understanding of how the financial details can be considered.

The Waterwise water calculator (Waterwise, 2012) is an online tool based on the building regulations water calculator. Anyone can use the calculator to work out the consumption of potable water of a domestic dwelling in litres per person per day. The water calculator also helps by showing both the values required to comply with building regulations as well as the different levels of the code for sustainable homes. The Waterwise water calculator is very similar to the one supporting the Building Regulations: Part G. However, the layout of the report is easy to follow and methodological for the process of completing the assessment. Primarily because it is also web-based, hence a more accessible form of the building regulations water calculator. Some criticisms however would be that the water calculator only accounts for residential buildings and whilst the use of standard fittings used where available, there did not appear to be an option for other fittings not in the list. Furthermore, whilst the calculator allowed for fittings to be varied and the difference observed, the average user could use a direct comparison page to highlight the differences more clearly.

In summary, methods and tools already exist for calculating mains water consumption and the potential savings derivable from water saving technologies and products. However, this brief review shows that none of the existing methods provide a robust value feasibility of any of the systems, considered beneficial to schools and funding authorities. The industrial standard appears to be the building regulations water calculator which is implemented in other voluntary tools such as the Code for Sustainable Homes (CSH). This approach is primarily designed for professionals. However, it serves as a useful basis for developing a simplified approach for use by non-professional school personnel. Lastly, it was identified that any solution proposed should be adaptable as schools often vary in size, scale and use. This will significantly affect the results of any feasibility method.

3 Case Study Findings

The development of the simplified approach for determining the value of water saving retrofits in schools was based on four work stages; literature review/desk study to develop the initial content and checklist, data collection, where data on site constraints and water consumption was collected. Data analysis, where the data provided was analysed to calculate what savings could be made in the school and any potential offsetting that could be achieved by the installation of a greywater or rainwater harvesting system. The final section then evaluated the potential savings and made recommendations for possible savings in water consumption.

This section sets out to discuss the results found from evaluating the assessment model on a school. The purpose of the evaluation is to investigate any areas missing from the simplified approach and the suitability for untrained staff using it within a school environment.

As presented in the preceding section, the primary aim was to provide a school with a simple and easily method to assess the water consumption of their school. The objective of this approach was to provide a simple, easy to use tool for making initial value and investment decisions by the school management team. It is worth highlighting that the simplified approach is not designed to provide detailed technical assessments as this would render it unusable for non-technical school personnel.

A number of factors were considered during development. This includes:

- Ease of use by non-technical personnel such that anyone can carry out the assessment
- Flexibility and adaptability to allow for the varying designs of school
- Compact and time saving to avoid time being taken away from other tasks and to further encourage the use of the tool.

3.1 Desk study findings

Cost information is often required in order to determine the value of an intervention. Therefore, it is useful to collate billing data and source information such as: Metering; type(s), location, number; Sewage charge percentage; The cost of supply both per unit and standing charge; the cost of sewage both per unit and standing charge; the cost of any standing charges for highway or surface drainage; and the frequency of billing.

A scaled site plan was then used to identify spatial provisions and relationships, building location and orientation, to calculate the floor and roof area etc. This data also provided useful knowledge of the site constraints. Table 2, displays the data capture form used and expresses the reasons behind the data collection in italics. An estimation of the current water consumption is also required so that the model can provide an estimate of both the potential reduction in water consumption and cost savings. The variability of design, buildings etc. in schools is crucial and needs to be captured. The model reflects this with separate tables for individual WC blocks, catering facilities, external uses and staffroom facilities. These tables can be duplicated to allow for several fittings in several locations. For each fitting, an estimation of the water consumption was calculated using the benchmark data provided by Welsh Water (Welsh water, 1997).

Separate fittings will have separate recommendations; this allows a degree of flexibility and the savings are represented as percentages. Certain assumptions are also inevitable. For instance, the assumption that each fitting has an equal percentage of use and the variation is in the frequency of use. A long term study is required to better calculate these values and this was not possible within the limits of this study. Therefore, it was proposed that the water savings are calculated in two stages with each fitting type calculated singularly by first dividing the total number fitting type by the overall consumption of each fitting, then calculating the saving per use based on a single unit use. This was then applied to the saving of each fitting as previously calculated showing the overall percentage of savings available. This approach is similar to the process laid out in the building regulations water calculator (BRE, 2009).

The resulting equation was:

(Current consumption/number of units) X (current size/suggested size X 100) X number of this fitting type.

Findings for potential water offsetting savings will be discussed in the following case study section using the two water reuse technologies covered in this study which were greywater and rainwater harvesting systems. Rainwater harvesting was assessed using a similar method to that laid out in the building regulations water calculator, with the potential demand being the value of the total water consumption used for WC's. Whilst the possible 'collection' factor was calculated using the adjusted rainwater collection equation, thus;

> *Collection area X Yield Co-efficient X Rainfall = potential collection*

Where yield co-efficient is given by the equation;

> *Yield co-efficient = Run off co-efficient X Fractional collector efficiency X shading factor X collection factor*

Where data is available for rainfall, the data will be given in monthly values to aid budgeting. However, where this is not possible an annual data option was provided. Greywater harvesting was also calculated using an adaptation of the building regulations water calculator method. Instead of individually calculating the potential demand for water, the total WC water consumption was taken except where for logistical reasons, where it is not possible to supply the greywater to certain WC blocks, it was calculated on limited WC's. The potential collection was calculated in a similar manner to rainwater harvesting with the assumption that any possible supply source would be connected and added to the potential collection volume, except where logistical reasons would limit the ability to connect the collection source to the greywater system.

3.2 Case study findings

3.2.1 The School

The case study is a Middle school in East Sussex serving children between the ages 11-16. The survey took place during the Easter break. The site and building data was collected during a preliminary conversation with the school's Bursar. The school has 1165 students and approximately 132 members of staff, of which some work part-time. The school building is occupied for 39 weeks of the year. Maintenance activities primarily take place during the holidays to minimise disruption. The school is of brick construction with a mixture of pitched and flat timber frame roofs, the school was constructed, 1937. The school buildings have had a few alterations during its lifetime which is detailed in Table 2. The school is billed quarterly according to readings from two water meters, with a 95% sewage charge. The school recently had some adaptations to two of its toilet blocks where new WC's and taps where installed. The first block was updated in 2009 and the second in 2010.The intention was to update the third block however this is currently being reviewed, hence the proposed simplified model to aid this decision making process.

Table 2 the site and building data

<table>
<tr><th colspan="12">The site constraints</th></tr>
<tr><td>Number of pupils:</td><td colspan="11">1165</td></tr>
<tr><td>Number of staff:</td><td colspan="11">Approximately 132</td></tr>
<tr><td>Billing method:</td><td colspan="11">Metered 2 Meters 95% sewage charge</td></tr>
<tr><td>Bill available:</td><td colspan="11">Yes</td></tr>
<tr><td rowspan="5">Term time hours:</td><td></td><td colspan="2">Mon</td><td colspan="2">Tues</td><td colspan="2">Weds</td><td colspan="2">Thurs</td><td colspan="2">Fri</td></tr>
<tr><td>Caretaker</td><td>6:30</td><td>10</td><td>6:30</td><td>10</td><td>6:30</td><td>10</td><td>6:30</td><td>10</td><td>6:30</td><td>10</td></tr>
<tr><td>School day</td><td>8:30</td><td>3:15</td><td>8:30</td><td>3:15</td><td>8:30</td><td>3:15</td><td>8:30</td><td>3:15</td><td>8:30</td><td>3:15</td></tr>
<tr><td>Teachers</td><td>8:00</td><td>5:30</td><td>8:00</td><td>5:30</td><td>8:00</td><td>5:30</td><td>8:00</td><td>5:30</td><td>8:00</td><td>5:30</td></tr>
<tr><td colspan="11"></td></tr>
<tr><td>Outside term use:</td><td colspan="11">Only maintenance</td></tr>
<tr><td>Building construction type:</td><td colspan="11">Brick typical of 1930s construction</td></tr>
<tr><td>Roof construction type:</td><td colspan="11">Timber frame, mixed flat roofs and pitched</td></tr>
<tr><td>Year school Built:</td><td colspan="11">1937</td></tr>
<tr><td>Extensions:</td><td colspan="11">1992- School refurbished,2006- Dining room extended,2007- Music block added 2009- Dance studio added,2011- Ovesco solar panels (currently in planning)

Water specific: 2009 and 2010 some WC's upgraded to new standard.</td></tr>
</table>

3.2.2 Water consumption

The water consumption for the period 29th January, 2011 and 25th January 2012 was 4,411.2m3. This value is utilised as the annual consumption for the school. Water consumption in the school during this period was from a number of outlets: WC's, urinals, sinks, cleaning and canteen. Although, there was also an external hosepipe, anecdotal evidence suggests this is used very rarely used if at all. The Welsh Water benchmark data which detailed water consumption breakdown for schools (Welsh water, 1997) was adapted for the purpose of this survey as there was also evidence that water was being used for educational purposes for science, art and DT food. It is considered that the water consumption from these sources would be irregular and limited. Hence, the overall percentage usage of 2% was taken, due to the limited use, offset from the consumption from the WC's. A full breakdown of the estimated water consumption can be found in Table 3**Table** .

Table 3 Water consumption on site

Water consumption on site		
Annual consumption:	*4,411.2m^3*	
Uses of water	Estimated consumption (%)	Estimated consumption (m^3)
WC's	*41%*	*1808*
Urinal flushing	*20%*	*822*
Washing	*27%*	*1191*
Cleaning	*1%*	*44*
Canteen use	*9%*	*397*
Educational	*2%*	*88*

3.2.3 Potential water savings

In order to propose potential water savings, a survey of the overall water consuming fittings and appliances in the school was undertaken. From the site survey, it was found that the school has 59 WCS; 20 for staff and 39 for students; 18 urinals, 60 sinks and 18 taps used for educational purposes. All the fittings surveyed are shown in Table 4.

It was also observed that whilst 20 of the WC's in the school had been changed from the original 6 litre cisterns to 4.5 litre cisterns the other 39 remained as 6 litre flushes. This was considered an example of where changes can be made to improve water consumption performance of the building. It was further observed that the sinks have been changed. However, none of the new or old fittings where aerated. This alteration could provide up to 30% water saving. Furthermore, it was observed that the new taps installed in the 2010 renovation work which had timers, still ran for a long time. This was also noted for possible savings by reducing the runtime by half.

Table 4 Water fittings on site

Water use on site		
WC's		
Type	No	Notes
6 Litre flush	*16*	*Student- PE changing room + Opposite PSE office*
4.5 Litre flush	*20*	*Student recently changed toilet blocks*
6 Litre flush	*20*	*Staff toilets*
6 Litre flush	*3*	*Music block toilets*
TOTAL	*59*	
Urinals		
Individual low flush	*8*	*In new toilet blocks*
Trough urinals	*10*	*Mostly in older fitted toilet blocks*
TOTAL	*18*	
Sinks		
Older fittings	*22*	*Not aerated, instant off*
New 2010 fittings	*14*	*Not aerated, long run time*
New 2009 Fittings	*18*	*Not aerated, better run off*
TOTAL	*54*	
Education use		
Normal taps in food tech	*≈8*	*Unavailable on survey*
Science taps	*10*	*Specified for science use*
Canteen		
Taps for sink	*6*	*Standard kitchen taps*
Dishwasher	*1*	*Industrial use (Hobart)*

Although the initial study focus was on high level technological interventions such as rain and grey water harvesting systems. The calculations summarised in Table 5, indicate that the school could also make some savings from other low level solutions such as altering tap run-time settings and replacing WC's and aerated taps.

Table 5 Potential savings from fitting alterations

Savings from fitting alterations				
WCS				
Total consumption			*1808m³*	
Consumption attributable to students			*1624m³*	
Consumption attributable to staff			*184m³*	
Consumption per student unit			*42m³*	
Consumption per staff unit			*9m³*	
Savings				
Recommendation	Attributable use	No	Saving (%)	Saving (m³)
6 Litre Student	*672m³*	*16*	*25%*	*168*
6 Litre Staff	*180m³*	*20*	*25%*	*45*
Total	*852*	*36%*	*25%*	*213*
Sinks				
Total consumption			*1191m³*	
Savings				
Recommendation	Attributable use	No	Saving (%)	Saving (m³)
All fittings aerated	*1191m³*	*60*	*30%*	*396*
New 2010 fittings	*277m³*	*14*	*50%*	*138*

3.2.4 Rainwater harvesting

The potential for installing a rainwater harvesting system was examined for the north roof of the main school building since detailed drawings of this building was made available to the researcher. Other roofs where not considered due to site constraints. For example, the use of the southern wing would prove difficult to find a location for the rainwater harvesting tanks other than in the ground which is currently used for a soak away. The rainfall data was obtained from the Met office, using the historic rainfall data for 2011 for Eastbourne, the nearest weather centre. Table 6 shows the calculations for this part of the model.

Table 6 Rainwater harvesting

Rainwater collection													
Collection area:	*539m²*												
Run off coefficient	*0.8*												
Fractional collector efficiency	*0.9*												
Shading factor	*1*												
Collection factor	*345*												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall	*86*	*58*	*22*	*11*	*11*	*38*	*45*	*79*	*31*	*16*	*37*	*193*	*627*
	x	x	x	x	x	x	x	x	x	x	x	x	x
	388	*388*	*388*	*388*	*388*	*388*	*388*	*388*	*388*	*388*	*388*	*388*	*388*
Yield	*33*	*23*	*9*	*4*	*4*	*15*	*17*	*30*	*12*	*6*	*14*	*74*	*243*

3.2.5 Greywater harvesting

The potential for the installation of a greywater system throughout the school was also examined. The objective was to explore whether this could be used to offset the water consumption from WC's and Urinals. It was proposed that the greywater is sourced from sinks in the toilet blocks, the catering facilities and all the water consumed for cleaning the school. While some educational consumption could be possible to use, it is considered this could potentially could contain contaminants, which could be hazardous to health. Table 7 shows the calculations done to evaluate the potential installation of a greywater system. As there was no metered data for the point source consumption, a conservative estimate of 80% reusable water to supply WC's and Urinals was utilised as it has been difficult to ascertain the exact consumption. This percentage could be replaced in the calculation page when more accurate data is available. It was found that with this estimated value, a saving of 1305m^3 approximately was possible which will offset up to 50% of the total WC demand.

Table 7 Greywater harvesting system

Greywater system	
Greywater demand:	*2630m³*
Maximum recyclable (%):	*80%*
Washing collection	*1191m³*
Kitchen collection	*397 m³*
Cleaning collection	*44 m³*
Potential offset	*1305m³*
Likely offset	*1305m³*

4 Discussion

Overall, the simplified method proved to be successful to provide sufficient analysis and expected water savings to support value decisions by the school. Whilst the recommendations included replacing WC cisterns, fit aerated taps and install rainwater and greywater system, other operational savings were also identified. For instance, it was observed that some of the trough urinals were left running during the Easter break. Therefore, it was recommended that the school facilities team should consider switching this off overnight and throughout periods where the school is not in use as this would help reduce unnecessary water consumption.

The evaluation of the simplified approach using this case study revealed some necessary improvements, starting with the consumption estimations of each fitting. For example, the actual flow rate of taps, cisterns and other fittings could be, where possible, measured to enable a more accurate estimation of the cistern size, where manufacturer data is unavailable. The same could be done for automatic shutoff valves where the water flow time could be timed. These tests could be easily carried out by the school's maintenance staff. The current model relies on abstractions and it was also found that if more accurate and refined data would make analysis more precise. An improved consumption breakdown could also provide a more accurate methodology of calculating savings accruable from rain and grey water recycling or reuse. The overall consumption breakdown and potential offsets will also be much improved. The installation of point-source meters was therefore recommended. An alternative may be to qualitatively document the use patterns by monitoring zones or individual fittings where possible.

The best method for providing accurate water consumption would be to run a full analysis of the school to provide a full breakdown of how often each space is used and perhaps even down to individual fittings. This comprehensive data could then be used to both provide more accurate water consumption saving estimates as well as allowing the school to prioritise the alterations based on the maximum likely saving. However, this approach would require employing consultants and may be time and cost intensive. These costs may also far outweigh its benefits. This simplified approach provides a means for the schools to conduct a basic study of their water consumption and possible solutions with which they can then make value decisions on which solution warrants further investigations by a professional. In addition to the simplified model, it was recommended that the school consider installing point-source meters for example at each toilet block. This will provide a more accurate consumption data in zoned areas on the premises. With this it will be possible to use the proposed simplified approach to develop a more accurate profile of use patterns and frequency.

5 Conclusion

This study achieved its aim of developing a simplified model for evaluating the potential for water savings in schools in order to make value decisions for investments. The evaluation of the simplified model also found that savings on water consumption can be made within the School. During evaluation, it was found that the model was easy to use for non-technical school personnel. The model also provides flexibility for varying designs and building composition of schools as sections of the model can be duplicated as required so that the school can accurately examine its water consumption and provide the most suitable alterations. The model is quick and easy to complete as it avoids all unnecessary data. Although the model provides a standardised and simplistic approach to the feasibility of water efficiency measures within schools, it can be improved by: Improving the data collection methods, and, improving the cost estimation process. Lastly, deploying this simplified approach in a pre-programmed toolkit would further reduce human errors and increase usability. The following areas have been identified as areas for future research:

- Monitoring and benchmarking a series of schools over a period of time to fine-tune the calculation factors and coefficients for improved results.
- Integrating assessment findings and observed socio-occupancy factors with a learning to support the teaching curriculum
- Implement the recommendations using this model with a school and monitor the reduction in water consumption, to further evaluate its effectiveness.

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7 Presentation of Authors

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Reconsideration of the "Conduit Header System" in the Cold and Hot Water Supply Piping System.

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Abstract

In recent years, environmental problems such as global warming and depletion of natural resources are becoming increasingly serious, examination has been carried out in various fields. In the field of building service, various techniques to reduce environmental impact at the time of new construction or renewal have been studied.

In the field of cold and hot water supply system, water heaters and water-saving equipment to reduce the impact of the environment have been developed up to the present. On the other hand, the study of cold and hot water supply piping system has lagged behind, that is demanded to review.

Since 1989, in our country, adoption of the "Conduit header piping system" in the multiple dwelling houses with plastic pipe has begun. This system, to improve the workability of pipe in the dwelling unit and to make it easy updating the plumbing, was an innovative method in those days. However, in the current twenty years have elapsed since the adoption of such method, the following problems have been pointed out.

(1) To understand the reality of current situation of this method.
(2) To accommodate for the newly developed equipment.
(3) To respond to changes in lifestyle.
(4) Study of method and pipe diameter considered reduction of the environmental impact.

To clarify these points, research project was established from 2011 in TMU (Tokyo Metropolitan University). In this project, we intend to do a field study, verification experiment, and so on. This paper report results of the investigation of the standards related to this research project, simulation results of waiting time of hot water and the heat radiation from the hot water piping associated with the downsized diameter piping, and overview of the planning of this research.

Keyword

Water supply piping system, Plastic pipe, Downsizing diameter

1. Introduction

In recent years, environmental problems such as global warming and depletion of natural resources are becoming increasingly serious, examinations have been carried out in various fields. In the field of building services, there are strongly demands for flexible response to update of the equipment and renovation of the building. Also, in the field of cold and hot water supply system, various technologies to reduce the impact of the environment have been developed : water-saving equipment and high-efficiency water heaters, and so on. On the other hand, the study of cold and hot water supply piping system has lagged behind, that is demanded to review.

Since 1989, in Japan, adoption of the "Conduit header piping system" in the multiple dwelling houses with plastic pipe has begun. This system, to improve the workability of pipes in the dwelling unit and to make it easy updating the plumbing, was an innovative method in those days. However, recently adoption of systems that do not use the conduit pipe has been increasing. In addition, the update of plumbing has been rarely carried out. From the situation like this, in the current twenty years have elapsed since the adoption of such method, the following problems have been pointed out.

(1) To understand the reality of current situation of this method.
(2) To accommodate for the newly developed equipment.
(3) To respond to changes in lifestyle.
(4) Study of method and pipe diameter considered reduction of the environmental impact.

Furthermore, there was a demand, about shrinking the pipe diameter, among designers in Japan for a long time. In this study we examined the possibility of using a smaller diameter plastic pipe for a piping system that can be contributing to a reduction of environmental impact while taking various advantage of the header piping system. It is considered below as an effect of using a small diameter piping.

(1) Reduction of initial cost.
(2) Shortening of the waiting time of hot water and reduction of wasted water.
(3) Improvement of workability.
(4) Energy conservation.
(5) Possibility of flex respond to refine the existing building stock.

This paper describes that the numerical results for the items which should be considered to apply a smaller diameter pipe for a piping system.

2. Overview of the consideration.

When the downsized diameter plastic pipe adapt to the water supply piping system, some problems will be assumed. We considered about the following items: the effects of flow velocity and reduction of energy.

For the effects of flow velocity, we examined the rise of the flow velocity in the case of using the narrower pipe. In addition, from the viewpoint of prevention of corrosion and water hammer, standard value of flow velocity has been set at SHASE-S 206 in Japan.

We compared calculated results with this standard. And we calculated the maximum water hammer pressure that occurs suddenly closed water faucet. Also we confirmed the pressure loss from the flow rate chart.

About the reduction of energy, we examined temperature change in the pipe and heat radiation for each pipe diameter. The rise of the flow velocity results in a shortening of arrival time of hot water until the equipment from water heater ("the waiting time of hot water"). From this shortening of time, it is expected that the water-saving effect by reducing water to be drained without being used until the hot water from the faucet (wasted water). We also examined the amount of the reduction of energy associated with the shortening of the waiting time of hot water.

3. The effects of downsizing the plastic pipe diameter.

3-1. Examination of the flow velocity.

Figure-1 shows the flow velocity and the waiting time of hot water per unit length for each flow rate and pipe diameter. Provided that the waiting time of hot water is a simplified value obtained by dividing a flow rate per unit length, so the rise of the water heater characteristics, etc. are not considered.

If a water flow at a flow rate of 8.5[L/min] as a proper flow rate of shower, compared with 10A and 13A piping, the waiting time of hot water per unit length is reduced to 0.38[s/m] from 1.0[s/m]. But a flow velocity is increased to 2.65[m/s] from 1.0[m/s]. This exceeds the standard value of water hammer prevention guidelines provided in the SHASE-S 206, that is " the flow rate should be lower than 2.0 [m/s]".

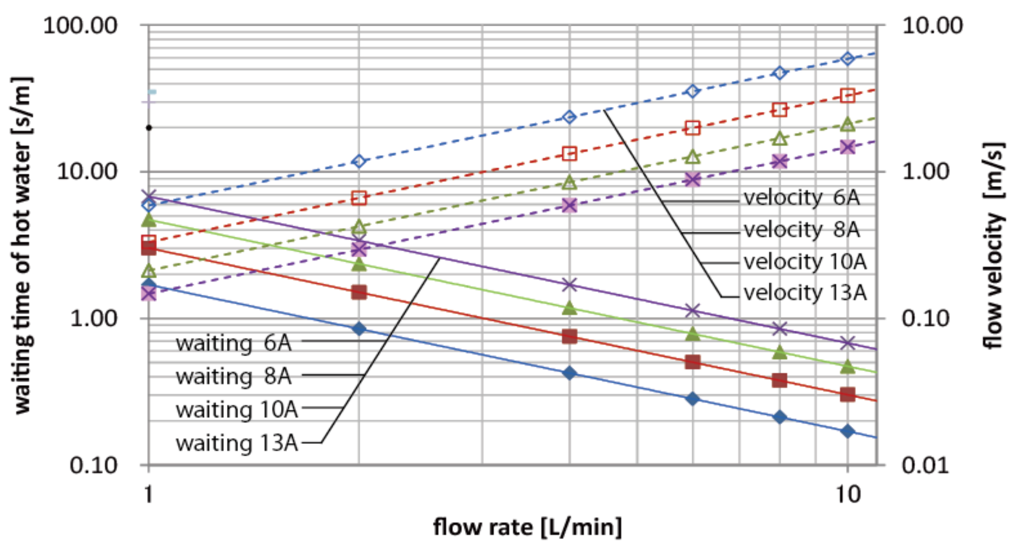

Figure-1. Flow velocity and waiting time of hot water

However, it is reported in the past studies that there is a suppressibility of occurrence of water hammer pressure from characteristics of the plastic pipe such as dilation of the pipe, etc. Based on such knowledge, in this study, we examined the possibility of using plastic pipe in the case exceeded the current standard value of the flow velocity 2.0[m/s]. As one of the considerations associated with increased flow velocity, we were investigated the occurrence for maximum water hammer pressure using the Joukowsky equation [Equation-1]. Figure-2 shows the result of the investigation.

$$\alpha = \frac{\sqrt{\frac{K \cdot g}{\gamma}}}{\sqrt{1+\frac{K}{E} \cdot \frac{D}{S}}} [m/s] \qquad h_{max} = \frac{\alpha \cdot V_0}{g} [mAq] \qquad \text{(Equation-1)}$$

α : pressure propagation velocity [m/s]
K : elastic modulus of water [kgf/m^2]
g : gravitational acceleration [m/s^2]
γ : specific weight of water [kg/m^3]
D : outer diameter of pipe [m]
S : thickness of pipe
E : elastic modulus of pipe [kgf/m^2]
V_0 : water velocity [m/s]
h_{max} : maximum water hammer pressure [mAq]

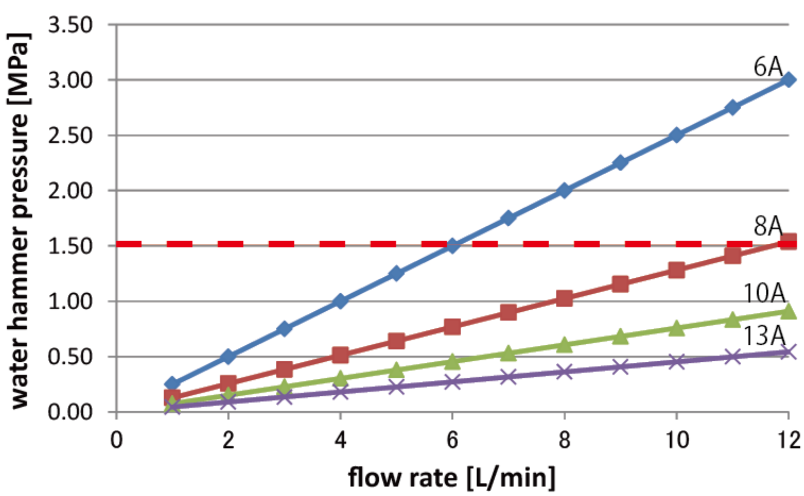

Figure-2. Maximum water hammer pressure

In order to prevent water hammer, water hammer pressure to occur should be less than 1.5[MPa] have been provided in JIS (Japanese Industrial Standards). If a flow rate at 8.5[L/min] as a proper rate of shower, 8A to 13A piping satisfies this standard value. But if the pipe diameter is reduced to 6A, there is likely to exceed the standard value.

Figure-3 shows the relationship between the pressure loss per unit length and flow rate in each pipe diameter. It was calculated by the Darcy–Weisbach equation as the water temperature of 10 [°C], coefficient of kinematic viscosity of 1.308 [m^2/s], and gravitational acceleration of 9.8 [m/s^2]. A result of the downsizing pipe diameter, pressure loss in piping is increased. Therefore, there is a possibility of the lack of flow at the most adverse pressure condition relative to the water pressure. In order to ensure the minimum required pressure of equipment used in dwelling unit, measures may be needed, such as changing the setting of pressure reducing valve.

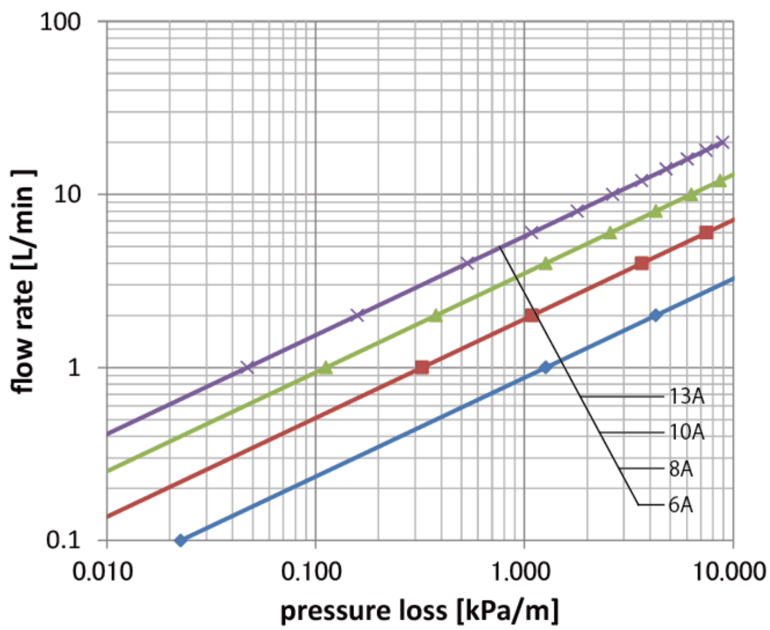

Figure-3. Relationship between pressure loss and flow rate

3-2. Study on Energy Reduction

Figure-4 (a)(b)(c)(d) shows the change in water temperature each pipe diameter (6A to 13A) when the water stopped in pipe. It is calculated from Equation-2. The temperature of a slim pipe is easier to drop. If the faucet have been closed for about 5 minutes without thermal insulation to the pipe, the water temperature drops of each pipe size is following: 21.3[K] in 6A pipe, 16.0[K] in 8A pipe, 9.0[K] in 10A pipe, and 6.2[K] in 13A pipe. In addition, even if the thickness of the thermal insulation to the pipe is varied, the effect of preventing a decrease in water temperature can not be expected.

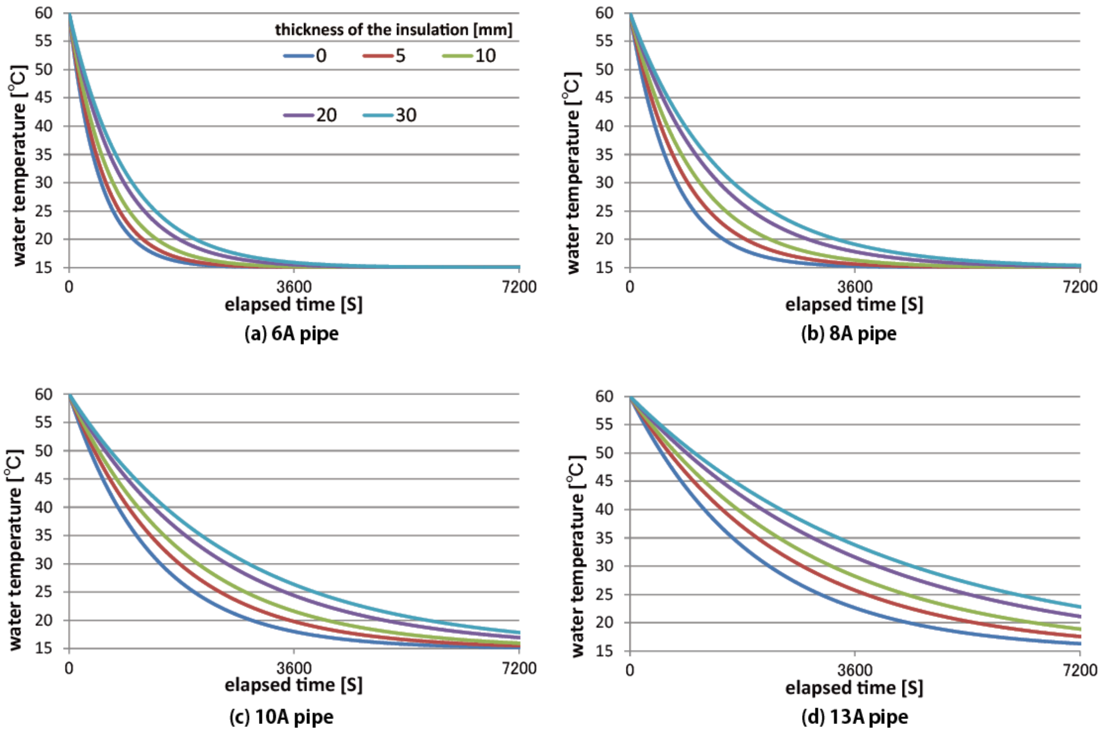

Figure-4 (a)~(d). Relationship between pressure loss and flow rate

$$q = \frac{2\pi(t_w - t_r)}{\frac{2}{d_h \cdot \alpha} + \frac{1}{\kappa} \cdot \ln\frac{d_h}{d_0}} \qquad \text{(Equation-2)}$$

q : heat loss [W/m]

t_w : water temperature [°C]

t_r : air temperature [°C]

d_0 : outer diameter of pipe [m]

d_h : outer diameter of the insulation [m]

α : surface heat transfer coefficient [W/m^2/°C]

κ : thermal conductivity of the insulation [W/m/°C]

On the other hand, focusing on the amount of heat loss of pipe shown in Figure-5, it can be seen that heat loss is smaller in the slim pipe.

Volume and surface area of the pipe is related to the result. From the relationship between volume and surface area of each pipe diameter shown in Figure-6, it is find that the percentage of surface area to volume of the pipe increases in the slim pipe. The potential heating value of the slim pipe is smaller because pipe volume is small.

Therefore, the degree of impact of heat loss from the pipe surface increases and the water temperature drops is easier in the slim pipe. Meanwhile, even if the water temperature in the tube fell significantly by lengthening the time to stop water, the amount of heat loss is small.

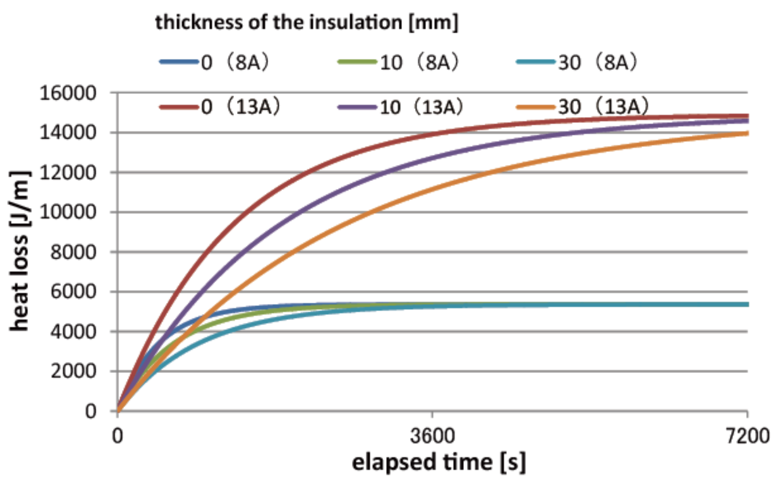

Figure-5. The amount of heat loss of pipe

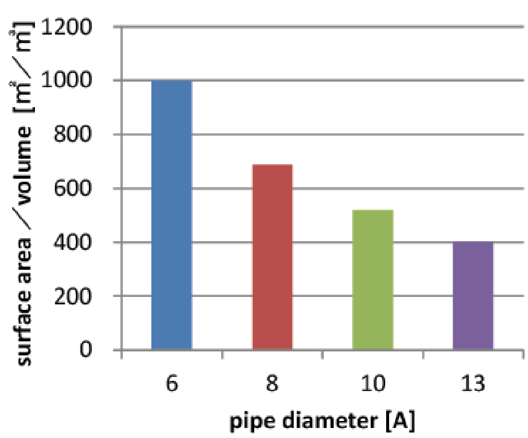

Figure-6. Relationship between surface area and pipe volume

From the shortening of the waiting time of hot water, result to reduce the wasted water and lead to the protection of water resources and the reduction of hot water supply energy. In this study, we assume the typical scale of multiple dwelling houses provided by Urban Renaissance Agency. It is calculated that the decreased volumes of the wasted water and the amount of the reduction of hot water supply energy consumed by the instantaneous gas water heater. The calculation was conducted under the condition that shown in Table-1. Figure-7 shows the result of calculating the amount of wasted water a year par building. When the pipe diameter reduce to 10A from 13A, volume of wasted water is kept to about 2800[ton/year/building], approximately 40% of reduction can be expected. Also, the amount of gas used for wasted water reduced to about 2900[m^3/year/building] from about 4900[m^3/year/building], about 2000[m^3/year/building] to be reduced. These effects will be larger by using 8A and 6A pipe. As described above, it can be said that downsizing of pipe diameter is effective in reducing environmental impact since it reduces the amount of wasted water and is also obtained energy saving of hot water supply.

Table-1. Calculation condition

number of dwelling units	300 to 500 [units]
average number of unit residents	2.2 [people]
discharge temperature (cold water : hot water)	40 [℃] (15[℃] : 60[℃])
flow rate	8.0 [L/min]
times to use	8 [-]

4. Conclusion

In this paper, numerical calculation was determined in order to examine the effects and problems of the downsized diameter piping system.

(1) Flow rate is increased, and the waiting time of hot water is reduced.
(2) There is likely to exceed the standard of “ the flow velocity should be lower than 2.0[m/s]”, which is stipulated in the guidelines to prevent water hammer in SHASE-S 206. However, even if the flow rate is exceeded, the occurrence of water hammer pressure can be suppressed to some extent by the characteristics of plastic pipe.
(3) Using slim pipe increases the pressure loss. In order to obtain the appropriate pressure, pay attention to selection of pressure reducing valve and pump settings.
(4) As the pipe diameter becomes smaller, the temperature drop is faster. However, the amount of heat loss is reduced. The relationship between surface area and volume of the pipe has great influence.
(5) By the reduction of “waiting time of hot water”, the amount of “wasted water” is greatly reduced. Therefore, the effects that conservation of water and reduction of

energy used in the water heaters can be obtained.

Based on the findings described above, we will construct the simulated piping system using a slim plastic pipe and conduct verification experiments. This will be carried out, including the development of water faucet, consideration of the terms and conditions to build a downsized diameter piping system.

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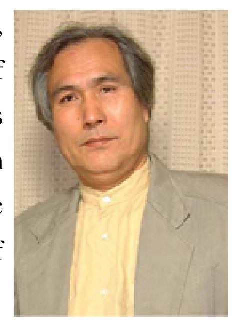

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Experimental analysis for the evaluation of the system efficiency of residential CO_2 heat pump water heaters in case of reheating operation of water in the bathtub

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Abstract

On the saving of energy consumption in housing sector, it is very important to analyze the hot water usage in each household because the ratio of energy consumption is accounted for about 30% in the total usage. We have studied on the evaluation of running efficiency for the heat pump water heaters with CO_2 refrigerant set up in the monitoring houses which were selected from the different areas of climate in Japan. These investigated results had been presented at the 33rd(2007) to the 37th (2011) international symposium of CIB-W62. In the paper presented at last year, S.Murakawa and four others clarified the factors affected to the efficiencies of heat pump unit (HPCOP) and heat pump system (SCOP) including a storage tank by the technique of multiple regression analysis.

From these results, we pointed out the performance affected by the boiling up temperature of hot water from 60 degrees to 90 degrees Celsius. As for the one of reason of going up the temperature, it could be mentioned the reheating operation of water in the bathtub controlled by automatic or manual because the hot water temperature in the bathtub has been dropping for the duration of a taking bath or non-taking bath. The style of a taking bath using the same hot water in a bathtub is very popular in a family of Japan. Usually, the boiling up temperature of hot water has been kept with higher level through one or two weeks when the operation of reheating is occurred one time. During the term for high level of the boiling up temperature, the efficiency of performance of the CO_2 HP system has gone down.

In this paper, we clarify these performances for the new models of CO_2 heat pump system by experiment on the basis of the simulation of hot water usage in a modeling household in the laboratory controlled with air temperature and humidity.

Keywords
Residential CO_2 heat pump water heater, Efficiency of CO_2 heat pump, Housing, Experiment, Reheating operation of water in a bathtub, Hot water supply loads

1 Introduction

In case of Japan, the ratio of energy consumption on the hot water usage of standard households is accounted about 30% to the total usage. Therefore, it is important to save the energy consumption in this sector. As for the saving system of energy consumption for hot water usage, the CO_2 heat pump water heater with a storage tank has now spread in the houses.

We have studied on the evaluation of running efficiency for the heat pump water heaters with CO_2 refrigerant set up in the monitoring houses which were selected at the different areas of climate in Japan. These investigated results had been presented at the 33rd (2007) to the 37th (2011) international symposium of CIB-W62. In the presented paper at last year; S.Murakawa etc. clarified the factors affected to the efficiencies of heat pump unit (HPCOP) and heat pump system (SCOP) including a storage tank by the technique of multiple regression analysis.

From those results, we pointed out that the performance is affected by the boiling up temperature of hot water from 60 degrees to 90 degrees Celsius. As for the one of reasons of going up to the high temperature, it could be mentioned the reheating operation of water in the bathtub that is controlled by automatic or manual because the hot water temperature in the bathtub has been dropping for the duration of a taking bath or non-taking bath. The style of a taking bath using the same hot water in the bathtub is very popular in a family of Japan. Usually, the boiling up temperature of hot water has been kept with higher level through one or two weeks when the operation of reheating is occurred one time. During the term for high level of the boiling up temperature, the efficiency of performance of the CO_2 heat pump system has gone down.

In this paper, we clarify these performances for the new models of CO_2 heat pump system which are set up in the laboratory controlled with air temperature and humidity based on the experimental simulation of hot water usage in a modeling household. And, we compare the efficiencies of the CO_2 heat pump water heaters in case of the operation of reheating or non-reheating water in the bathtub.

2 Outline of the experiment

2.1 Specification and performance of CO_2 heat pump water heaters

The performance of residential CO_2 heat pump water heater is going up year by year. In this experiment, we used the most new models of CO_2 heat pump water heater that are coming on the market by four manufacturers in the year 2011.

The four kinds of CO_2 heat pump water heaters; A, B, C and D types, applied for the experiment are shown in Table 1 as the specification, and are shown in Table 2 as the performance at the rated operation. Every CO_2 heat pump water heaters have a storage tank of 370 L capacity. D type is the model in the year 2011, and the others are the model in the year 2010. Every types have several functions for heat storage of hot water that are operated by users for energy saving or for avoiding of hot water shortage. Each type has different performance among the seasons of middle, summer and winter. The annual performance factors show the values within the range of 3.3 and 3.8.

Table 1 - Specification of CO_2 heat pump water heater

Model		Model 2010			Model 2011
		A10-370L	B10-370L	C10-370L	D11-370L
Capacity of storage tank		370L	370L	370L	370L
Method of reheating bathwater		Electric heater-less	Electric heater-less	Electric heater-less	Electric heater-less
Electric power consumption	Keeping warm of bathwater	71W	100W	80W / 105W	65W
	Antifreezeing heater	-	36W	-	-
	For control	6W	5W	11W (remote control off : 5W)	-
Functions for storage hot water (The first modes are set up at the time of shipment from the factory)		Leaving up mode Large mode	Leaving up mode Large mode Volume setting mode	Refraining hot water consumption mode Leaving up mode (Standard, Large) Filling the storage tank up mode Midnight mode (Large, Small)	Leaving up mode (Energy saving) Leaving up mode

Table 2 - Performance at the rated operation of CO_2 heat pump water heater

Model						Model 2010			Model 2011
						A10-370L	B10-370L	C10-370L	D11-370L
Middle season :	Heating capability / Electric power consumption					4.5 kW / 0.895 kW	4.5 kW / 1.010 kW	4.5 kW / 0.885 kW	4.5 kW / 0.895 kW
Operating condition	DB / WB *1	Relative humidity	Boiling temperature	Cold water temperature	COP	5.03	4.46	5.08	5.03
	16°C / 12°C	63%	65°C	17°C					
Summer season :	Heating capability / Electric power consumption					4.5 kW / 0.800 kW	4.5 kW / 0.870 kW	4.5 kW / 0.820 kW	
Operating condition	DB / WB *1	Relative humidity	Boiling temperature	Cold water temperature	COP	5.63	5.17	5.52	
	25°C / 21°C	70%	65°C	24°C					
Winter season :	Heating capability / Electric power consumption					4.5 kW / 1.500 kW	4.5 kW / 1.500 kW	4.5 kW / 1.500 kW	4.5 kW / 1.500 kW
Operating condition	DB / WB *1	Relative humidity	Boiling temperature	Cold water temperature	COP	3.00	3.00	3.00	3.00
	7°C / 6°C	87%	90°C	9°C					
APF *2 *3						3.8	3.3	3.8	3.8

Note: *1 DB: Dry bulb temperature, WB: Wet bulb temperature

*2 APF: Annual performance factor of hot water supply = Annual consumption of heat for hot water supply / Annual electric power consumption

*3 Condition for computation of APF (Boiling temperature): Summer 65°C, Middle 65°C, Winter(Standard) 65°C, Winter(High) 90°C, Frost formed season(High) 90°C, Winter(Standard hot water supply mode) 70°C, Frost formed season(Standard hot water supply mode) 75°C

Figure 1 shows the distribution diagram of the system and reheating system in each CO_2 heat pump heater. As for the distribution mode of hot water from the storage tank, A and B types supply hot water from the top of storage tank and mix with cold water. On the other hand, C and D types supply hot water from the top and middle layers in the storage tank. As for the reheating system, C type has heat exchanger equipped at the inside of storage tank. The other three types have heat exchanger equipped at the outside of storage tank. A and D types have the controlled devices to supply the boiling up hot water into the bottom of storage tank at just after starting of operation because of non-coming up to the setting up temperature.

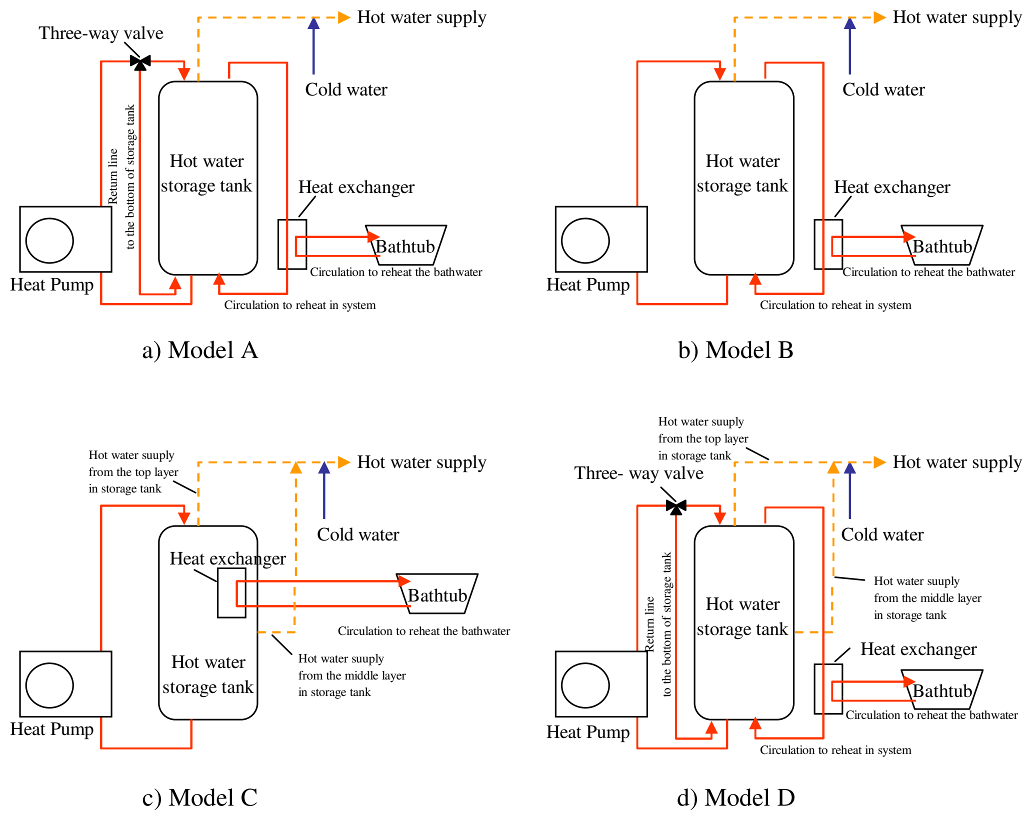
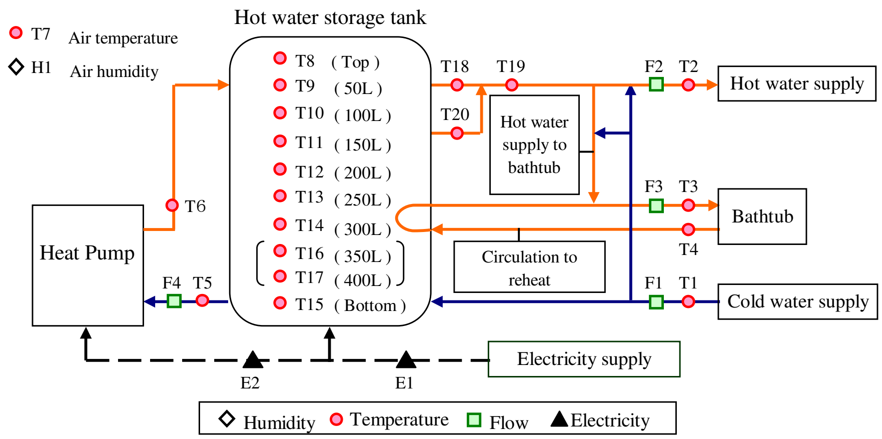


Figure 1 - Distribution diagram of the system and reheating system in each CO_2 heat pump water heater

2.2 Measurement system and items

As for the measurement items, temperature of cold and hot water in each piping line and storage tank (surface on the metal), flow rates in each piping line, electric energy in each equipment and air temperature and humidity in the testing room that the environmental conditions were controlled automatically were measured with a interval at two seconds. These measurement points are shown in Figure 2. The recorded data were analyzed by the modified values of one minute interval. Figure 3 shows an example of over-view of the CO_2 heat pump system in the testing room. In this experiment, we selected the function for heat storage of hot water having “the leaving up mode” that had been set at the shipping companies as shown in Table 1.



[Formula for computation]

1. Heat loads of hot water consumption except bathwater (C1) = c_p x ρ x (T2-T1) x F2
2. Heat loads of hot water consumption for filling bathtub (C2) = c_p x ρ x (T3-T1) x (F1-F2)
3. Heat loads of reheating bathwater (C3) = c_p x ρ x (T3-T4) x F3
4. Amount of heat from HP (C4) = c_p x ρ x (T6-T5) x F4
5. System COP = (C1+C2+C3) / E1
6. HPCOP = C4 / E2
7. Total heat loads of hot water consumption = (C1+C2+C3)
8. Remaining amount of heat storage and heat loss = C4 - (C1+C2+C3)
9. Efficiency for Storage tank = (C1+C2+C3) / C4

c_p : Specific heat at constant pressure [kJ/kg·K]
ρ : Density of water [kg/m^3]
c_p x ρ = 1

Figure 2 - Measurement points in the CO_2 heat pump system

Figure 3 - Over-view of the CO_2 heat pump system in the testing room

2.3 Standard mode of hot water demands

When we evaluate the performance of CO_2 heat pump water heaters, we have to set up the simulation model of hot water demands according to the practical usage in a household. Now, some models have been developed for testing evaluation of residential hot water supply systems in Japan. In this experiment, we adopted a model called as "the Modified M1 mode". The model is composed of six representative days as shown in Figure 4. One setting mode of water demands is composed of 30 days that are combined with the six representative days as shown in Figure 5. In this mode, average value and standard deviation of hot water demands on 30 days are set in the value of

450 L and 100 L respectively. In this mode, the utilized temperature of hot water is assumed at 40 degrees Celsius. The hot water demands through a day have a schedule of hot water usage with the time series. However, the Modified M1 mode has not loads of reheating operation. Therefore, we set up the experimental loads of reheating water in the bathtub into the Modified M1 mode as shown in next chapter.

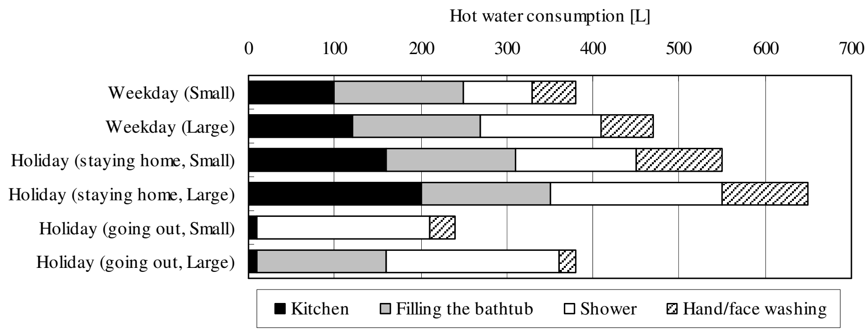


Figure 4 - Daily models of hot water demands for testing; the Modified M1 mode

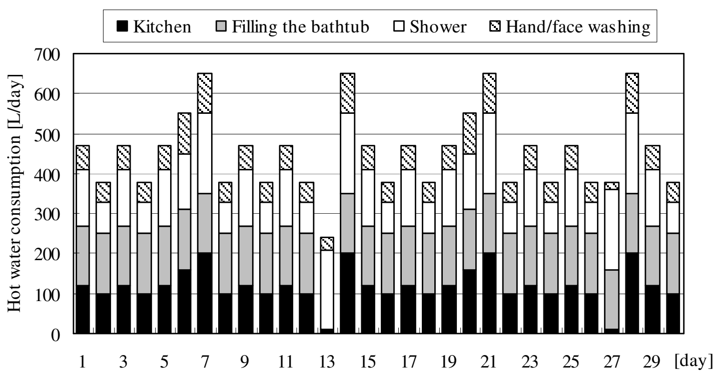


Figure 5 - Hot water demands through 30 days combined with the Modified M1 mode

3 Setup for the experimental loads of reheating water in the bathtub

Before the setup of the experimental loads of reheating water in the bathtub, we examined the performance of CO_2 heat pump affected by the three methods to put the reheating loads into the time series of the Modified M1 mode, because we expected to have operations of hot water usage with ease in the experiment. The three patterns for the occurrence of reheating loads are as follows; 1) after the finish of filling bathtub, hot water temperature in the bathtub is kept automatically through for three hours; 2) after three hours for the finish of filling bathtub, reheating load is occurred with one time of putting loads all together: 3) after the finish of filling bathtub, three times of reheating loads are occurred after one hour, two hours and three hours respectively.

In this experiment, we used the case of small demands of weekday in the Modified M1 mode, and controlled the temperature of hot water in the bathtub as the total reheating load is set with the value of 4.12 MJ in winter (JIS C 9220). C type-370 L CO_2 heat pump in year 2010 model was applied for the experiment at the conditions of 5 degrees

Celsius (air temperature), 57% (humidity) and 8 degrees Celsius (cold water supply temperature).

Figure 6 shows the outline of experimental loads patterns and the experimental results of the coefficient of performance of CO_2 heat pump unit (HPCOP). From the experimental results, we can discuss some differences for the values of HPCOP among the three methods. The operation of putting the reheating load with all together after three hours of the finishing of filling bathtub showed the smallest value. In this operation, the largest collapse of temperature stratification of hot water occurred in the storage tank.

The results between the separating reheating loads with three times and the keeping temperature automatically showed almost same values. Therefore, we applied the operation of separating reheating loads in the experimental evaluation of CO_2 heat pump water heaters.
Figure 7 shows the examples of the model of hot water demands through the time-series of a day. The three parts of reheating loads were added to the Modified M1 mode.

Figure 6 - Experimental loads patterns for reheating operation and the experimental results (HPCOP)

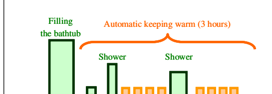
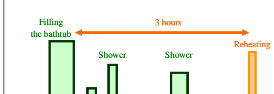
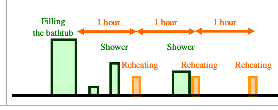
	Occurrence of reheating loads	Reheating pattern	HPCOP
Automatic keeping warm	After the finish of filling bathtub, hot water temperature in bathtub is kept automatically through for three hours.		2.67
Combined reheating	After three hours for the finish of filling bathtub, reheating load is occurred with one time of putting loads all together.		2.63
Partitioned reheating	After the finish of filling bathtub, three times of reheating loads are occurred after one hour, two hours, and three hours respectively.		2.68

Figure 7 - Examples of the model of hot water demands adding the reheating loads to the Modified M1 mode

Weekday (Small)

Time	Hot water consumption [L]	Hot water usage
6:30	3	Hand/face washing
6:35	3	Hand/face washing
[illegible]	[illegible]	Kitchen
20:45	150	Filling the bathtub
21:10	20	Shower
21:15	3	Hand/face washing
21:20		**Reheating**
21:25	10	Shower
21:30	10	Shower
21:45	3	Hand/face washing
22:00		**Reheating**
22:00	10	Shower
22:05	10	Shower
22:15	3	Hand/face washing
22:30	10	Shower
22:35	10	Shower
22:40		**Reheating**
23:15	3	Hand/face washing
23:20	3	Hand/face washing

Holiday (going out, Large)

Time	Hot water consumption [L]	Hot water usage
6:30	2	Hand/face washing
7:45	2	Hand/face washing
[illegible]	[illegible]	Hand/face washing
20:30	150	Filling the bathtub
21:00	25	Shower
21:05	25	Shower
21:10		**Reheating**
21:15	25	Shower
21:20	25	Shower
21:45	2	Hand/face washing
21:55		**Reheating**
22:15	25	Shower
22:20	25	Shower
22:25	2	Hand/face washing
22:30	25	Shower
22:35	25	Shower
22:40		**Reheating**
22:45	2	Hand/face washing

4 Comparison of the performance of CO_2 heat pump system with the operation of the reheating or non-reheating loads

In this chapter, we discuss the experimental results between the Modified M1 mode and the mode of adding the reheating loads.

Table 3 shows the experimental conditions for heat loads of hot water demands and running environmental conditions of CO_2 heat pump in the simulated three seasons. As shown in Figure 7, the reheating loads were added to the divided three parts after the finish of filling bathtub. The running time zone of the heat pump in the midnight was used the mode of electric contact with low charge that is applied for the households having the heat storage equipment. The time zone is set commonly from 11:00 p.m. to 7:00 a.m. in Japan.

Table 3 - Experimental conditions for heat loads of hot water demands and running environmental conditions of CO_2 heat pump

		Wintter	Middle	Summer	Remark
Load condition	Heat loads of hot water consumption except bathwater	The Modified M1 mode			
	Heat loads of hot water consumption for filling bathtub				
	Heat loads of reheating bathwater [MJ]	4.120	3.080	1.861	JIS C 9220 *1
Environment condition	Air temperature [°C]	5	15	25	JSTM V9103 *2
	Air humidity [%]	57	63	71	JRA4050 *3
	Cold water temperature [°C]	8	14	20	JSTM V9103

Note: *1 JIS: Japanese Industrial Standards
*2 JSTM: Standard of Japan Testing Center for Construction Materials
*3 JRA: Standard of the Japan Refrigeration and Air Conditioning Industry Association

In this paper, we will show the experimental results of using CO_2 heat pump water heaters of B and C types under the environmental conditions in winter season. The experiments were carried out through 30 days. And the data excluded 7days' recordings from the start of running were analyzed because the running data of 7days from the start should be thought as the controlled learning term of CO_2 heat pump.

Figure 8 shows the heat loads divided into the three parts of hot water demands, which are the heat loads of water demands except for bathwater, the heat loads of hot water demands for filling bathtub and the heat loads of reheating bathwater. As for the experimental results on "being reheating loads", both the total heat loads of B and C types had about 6.6% larger values than those of the experimental results on "being non-reheating loads".

Figure 9 shows the amount of electric power input for CO_2 heat pump and the amount of heating output from CO_2 heat pump. As for the experimental results on "being reheating loads", both the amount of electric power input and the amount of heating output were increased than those of the experimental results on "being non-reheating loads". The total amounts of electric power input in B and C types were increased about 31% and 44% respectively. And the total amounts of heating output in B and C types were increased about 13% and 17% respectively.

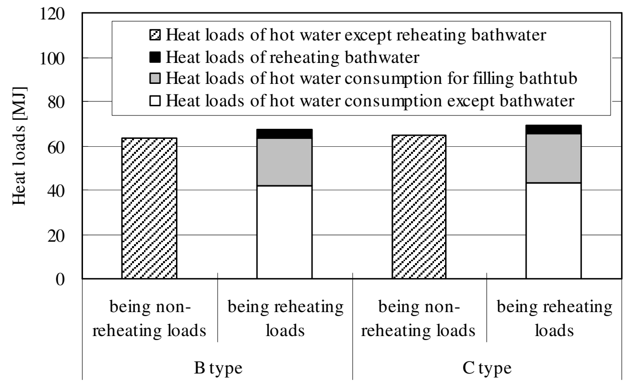


Figure 8 - Heat loads of hot water demands in winter season

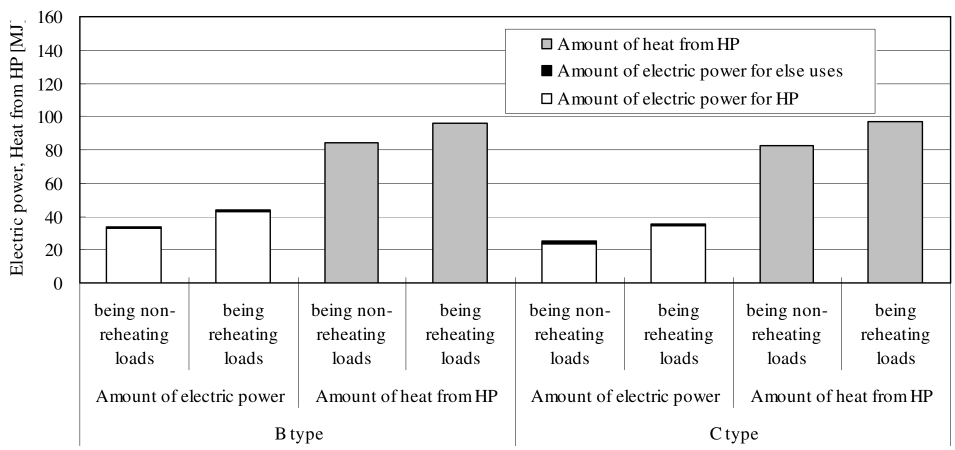


Figure 9 - Electric energy consumption and heat energy volume in the CO_2 Heat pump system

Figure 10 shows the boiling up hot water temperature and the feeding water temperature in CO_2 heat pump units. The both values of experiment on "being reheating loads" for B and C types were higher than those of the experiment on "being non-reheating loads". Especially, the difference of the boiling up temperature in C type was large. The feeding water temperature into the CO_2 heat pump unit from the storage tank in case of the experiment on "being reheating loads" was higher about 8 degrees Celsius than that of the experiment on "being non-reheating loads". These phenomena can be explained with the change of temperature stratification of hot water occurred in the storage tank in case of the experiment on "being reheating loads"

Figure 11 shows the volumes of heat storage in the tanks. As for the experiment on "being reheating loads", the average, maximum and minimum values of heat storage were larger than those of the experiment on "being non-reheating loads". In spite of about 4MJ increase for reheating loads, the average values of heat storage in B and C types showed 10MJ and 19MJ increases respectively. Also, the minimum values of heat storage in B and C types showed 12MJ and 25MJ increases than those of the experiment on "being non-reheating loads" respectively.

Figure 12 shows HPCOP and System COP. As for the both of B and C types, HPCOP and System COP of the experiment on "being reheating loads" were smaller than those of the experiment on "being non-reheating loads". In case of the experiment on "being reheating loads", HPCOP and System COP of B type had the values of 2.23 and 1.54 respectively, and HPCOP and System COP of C type had the values of 2.79 and 1.93 respectively. The performance of CO_2 heat pump water heater was decreased according to the increase of heat storage volume, boiling up hot water temperature and feeding water temperature into heat pump unit. Therefore, when the reheating operation occurs during the taking a bath, the values of HPCOP and System COP are decreased.

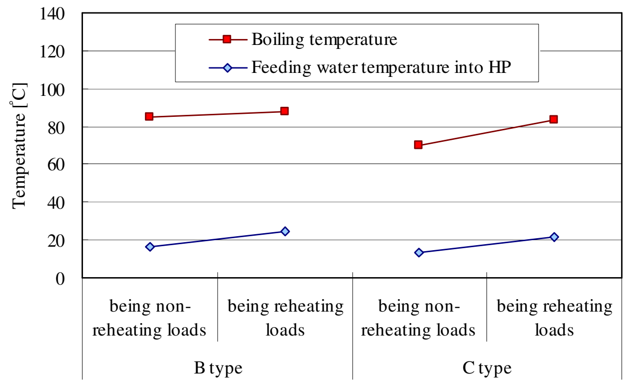


Figure 10 - Boiling up hot water temperature and feeding water temperature in the CO_2 heat pump units

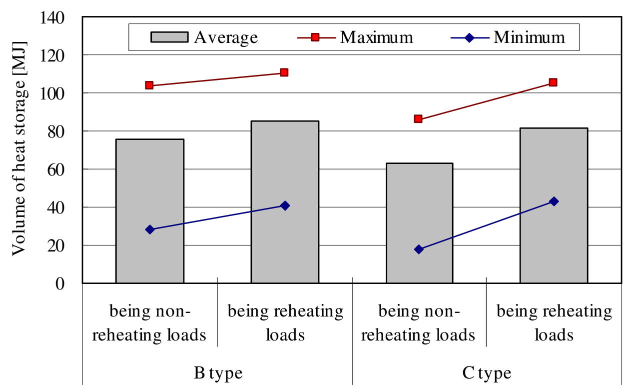


Figure 11 - Volume of heat storage in the tanks

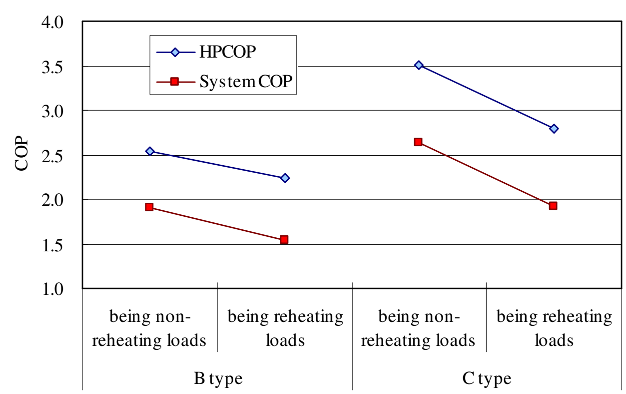
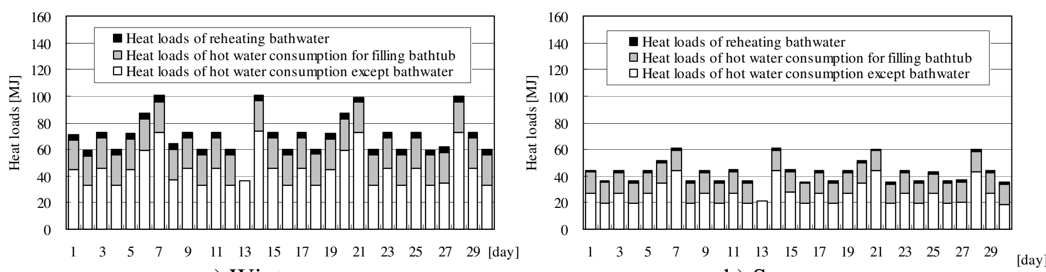


Figure 12 - Heat pump unit COP and system COP

5 Performance of four types of CO_2 heat pump water heaters in three seasons

In this chapter, we will discuss about the experimental results that were examined with the mode of hot water demands added the reheating loads for the four kinds of types; A, B, C and D types, in three seasons of environmental conditions shown at Table 3.

As an example of heat loads of hot water demands, Figure 13 shows the heat loads per day through the experimental term of 30 days for A type in winter and summer seasons. Experimental results for each type in three seasons are shown in Figure 14 – 17. On the basis of Figure 14, it could be understand that the boiling up hot water temperature showed the high levels such as 80-90 degrees Celsius for each type and each season. However, the boiling up hot water temperatures for A and D types in summer season were controlled lower until 70 degrees Celsius. The experimental results of using the Modified M1 mode in another study showed that the boiling up hot water temperatures were almost controlled by the lower temperatures under 80 degrees Celsius. Therefore, when the operations of reheating of water in the bathtub are occurred, it shows the tendency of rising up the boiling up hot water temperature. Also, the temperature of feeding water into CO_2 heat pump units shows the upward tendency.



a) Winter b) Summer

Figure 13 - Heat loads of hot water demands in case of A type

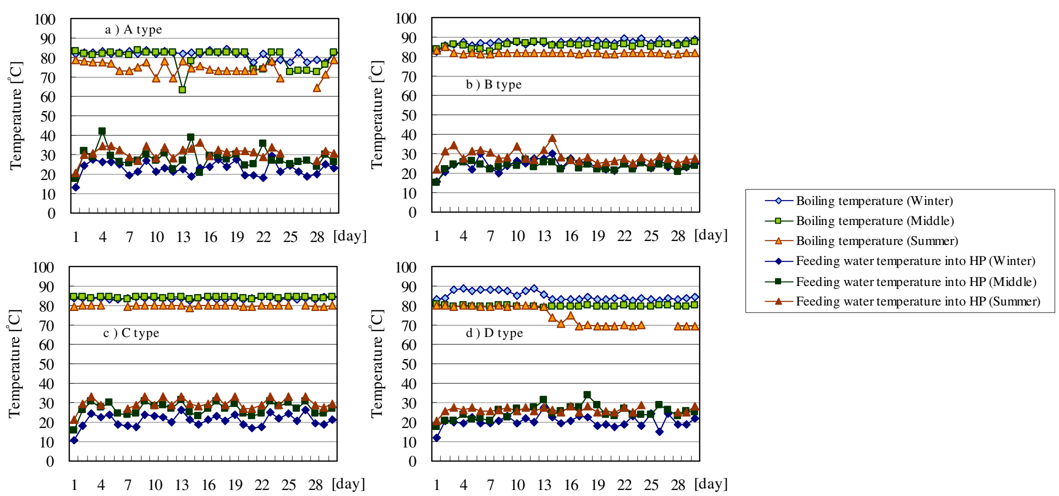


Figure 14 - Boling up hot water temperature and feeding water temperature in each CO_2 heat pump unit

Figure 15 shows the maximum and minimum volumes of heat storage in the tank. The minimum values were higher level than the experimental results by the Modified M1 mode; sometimes it fell below 20 MJ against the temperature of cold water supply.

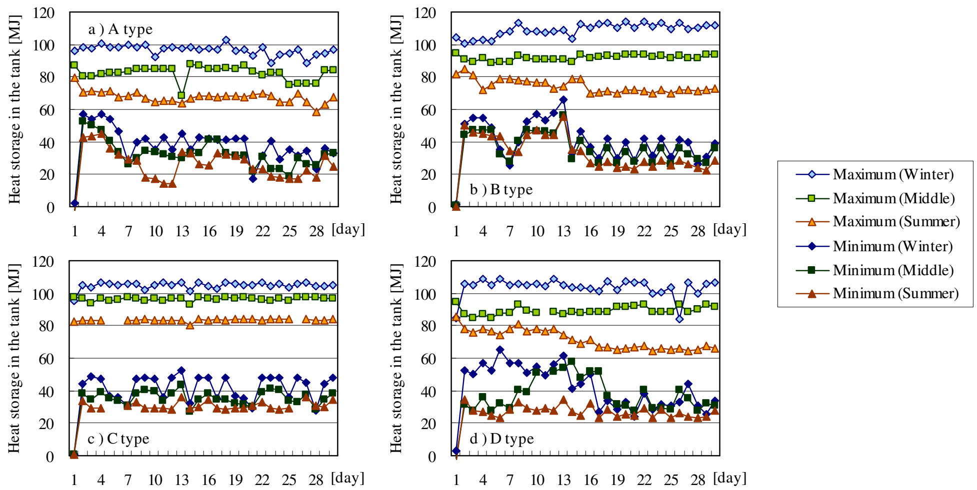


Figure 15 - Maximum and minimum volumes of heat storage in the tanks

Figure 16 and Figure 17 show HPCOP and System COP respectively. The average values of HPCOP on and after 8th days from the start of running were shown as follows according to the seasons of winter, middle and summer; A type had 2.68, 3.38 and 4.22, B type had 2.23, 2.89 and 3.40, C type had 2.79, 3.09 and 3.71, D type had 2.58, 3.41 and 4.54 respectively. The average values of System COP for the third weeks that had the highest level were shown as follows at the same style above mentioned; A type had 1.96, 2.44 and 3.35, B type had 1.62, 2.17 and 2.66, C type had 2.04, 2.22 and 2.67, D type had 1.94, 2.80 and 3.88 respectively. When the System COP was compared with the experimental results by the Modified M1 mode, the performances of A and D types in winter season did not show so big difference. However, the other types in other seasons showed lower values of 0.2-1.0.

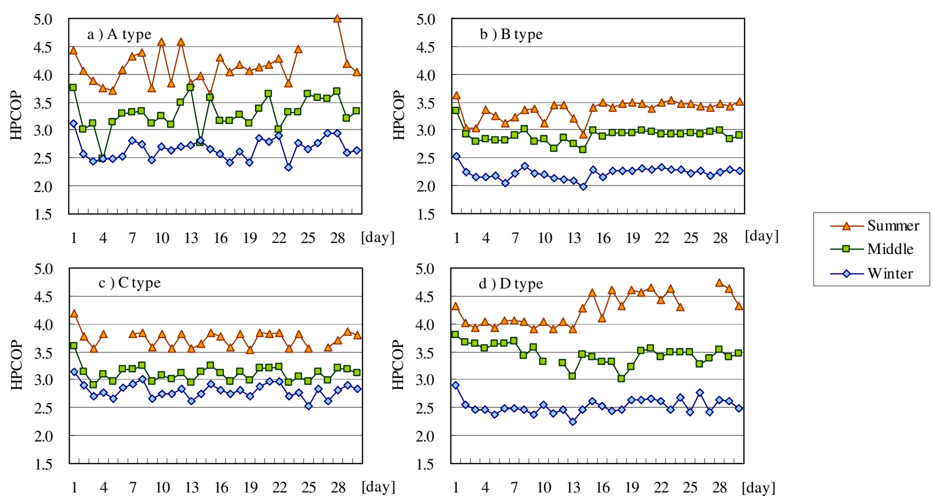


Figure 16 - COP of the heat pump units

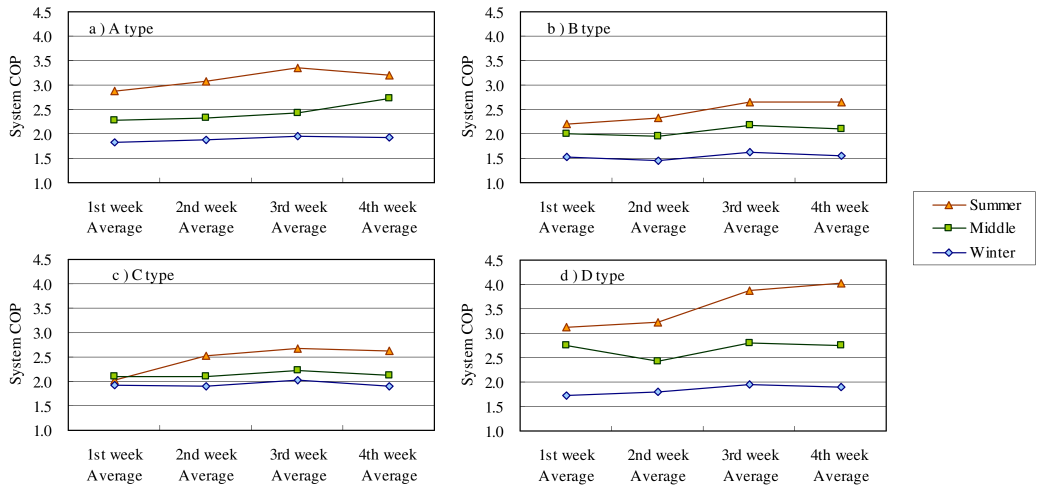


Figure 17 - COP of the heat pump systems

6 Conclusion

When we evaluate the performance of residential CO_2 hest pump water heaters, it is very important to examine by the simulation models based on the practical usage of hot water in the households. The bathing style in Japan, the filling hot water in the bathtub is used popular with a family. Therefore, the CO_2 heat pump water heaters have the functions of reheating water in the bathtub.

In this paper, we analyzed the simulation mode for hot water demands that was occurred of reheating loads for water in the bathtub. And the performances were compared experimentally with the mode of being non-reheating loads; the Modified M1 mode that has been used as the standard loads of hot water consumption in a family composed of four persons.

As the experimental results of the reheating loads, we clarified that the boiling up hot water temperature, the volume of heat storage in the tank and the feeding water into the CO_2 heat pump unit from the storage tank were going up tendency, and according to the phenomena, HPCOP and System COP that were evaluated as the performance were going down, when we compared with the results of the non-reheating mode.

We clarified the performance of CO_2 heat pump water heaters based on the practical uses in the dwelling houses located at the different areas of climate in Japan. From the series of the investigations for practical houses and the experimental studies as shown in the paper, it became definite to apply the simulation models for water demands of being reheating loads when we have the experiments for the evaluation of residential CO_2 heat pump water heaters. Therefore, our research group has developed the new simulation mode for hot water demands including the reheating loads to apply the experimental evaluation.

Acknowledgements

This study has been conducted by the Center for Better Living. Authors wish to express gratitude for the great cooperation of the participants.

7 References

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8 Presentation of Author

Saburo Murakawa is the Emeritus Professor of Hiroshima University. Now he is working at the Institute for Sustainable Science and Development in Hiroshima Univ. as the Professor of Special Appointment. His research fields are building and urban environment engineering, plumbing engineering and environmental psychology. He is now studying to develop the calculation technique for cold and hot water demands in the various uses of buildings to establish the standard method. Also, according to apply the new calculation technique, he has suggested the suitable plumbing design of saving energy.

Evaluation model of CO_2 emission for saving water strategy

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This research executed a saving water investigation and proposed a CO_2 emission estimation model for water consumption. Through investigation of the domestic water usage in people's livelihood, the structure of water consumption can be schematically understood and the water saving strategy can be concluded. The calculation model had been built to estimate the energy consumption and CO_2 emission from water demand and to evaluate the potential of water saving strategy. The quantitative potential reveals the motivation of saving water strategy and practicability of society based on saving water concept. This achievement can be referenced by Asian countries with similar environment and precipitation. On the other hand, this study can make various organizations both in public and private sectors aware of the importance of building a society based on water saving concept. As a result, various policy-making processes are anticipated to be initiated. In addition, this validation can link to the intention of green building policy. Finally, this research is anticipated to enhance the effective use of water resources, and to create a sustainable water-saving and low carbon emission society.

Keywords: water supply and drainage, water saving, CO_2 emission, green building, low carbon, sustainability

1. Introduction

Climate change and global warming had become crucial challenge to the whole world in this century. Evidences of environmental problem were comprehensively validated by academia and practical world for many years. Nowadays, CO_2 emission had been seen as the core issue which is high response to the climate change and global warming. Kyoto Protocol clearly target on the reduction of CO_2 emission to all countries of the world. Although the common consensus had not yet been reached by political sections of all countries in the world, the importance and urgency of this issue definitely cannot be ignored.

Generally, CO_2 emission was seen as the sequence of energy consumption. The request of CO_2 reduction is always emphasized on the energy section from industry, transportation and people's livelihood necessaries. On the other hand, water resource is well known to be the non-fungible element on this plant. Water resource demands have grown steadily according with the society development. Ensuring the stable supply of water is becoming the fundamental policy in many countries. However, people usually forget to see the energy consumption from the process of water supply and drainage. In fact, the water usage consumes energy from all process of water supply and drainage.

Previous researches and relevant documents reported the reciprocal relationship between water usage from people's livelihood and electricity consumption[1)]. That is water usage of one degree (m^3) approximately equal to one unit electricity consumption (kWh). There are 23 million population and daily water consumption with around 300 liter per day in Taiwan. It is a huge energy consumption item as the accumulation of population is considered[2)]. That is to say, the reduction of CO_2 emission should not ignore the contribution of water saving strategy.

The potential of water saving contribution to reduction of CO_2 emission is noticed and its quantitative evaluation is necessary to be clarified. Firstly, this research investigated the domestic water use in people's livelihood in Taiwan and clarified the schematic structure of water consumption. An estimating model was proposed to evaluate the quantitative potential of the energy consumption and CO_2 emission from water usage. Eventually, this paper aims on the promotion of saving water society and offers an evaluation method for this target.

2. Reviews and Methodology

Water-saving apparatuses have been seen some remarkable advancement in recent years. In addition to sanitary fixture such as faucet and shower valves, other home appliances-washing machines, dishwashers with advanced water saving capabilities are now appearing on the market[3)]. Water saving can also be the effective strategy to reduce CO_2 emission. In a simulation study[4)], it has been postulated that by 2020 the total CO_2 emission in Japan can be reduced to 1 % of 1990 level which is equivalent to 25% of all CO_2 emission from kitchen, bathroom and toilet, if emission from residential homes is controlled through popularization of water-saving apparatuses. This study made various organizations both in public and private sectors aware of the importance of society based on water saving concept. Policy-making processes following with this result have started recently in Japan and response to Green Building orientation[5)]. Under the policy of sustainable development by the Taiwan Government, an evaluation of Green Building system, which emphasizes energy conservation, resource protection, low waste, low environmental impact, was developed to improve the ecological living environment from 1999.

In order to improve the work of CO_2 emission reduction and clarify the potential of water resource preservation, it is necessary to share the estimation techniques and information to academic researchers, policy makers and relevant people who are involved in the field of water, environment and sustainable construction[6)]. Due to this common consensus, Asia Water saving Council was founded in 2012 Tokyo to promote the importance of water preservation and society based on water saving concept. Indeed, the water issues are different from countries of vary climate and precipitation. Regional and seasonal limitation is inherent in natural water resource. Culture customs and social behaviors also dominate the water consumption in different countries. Therefore, investigation and survey are needed to validate the relevant issues for each country.

3. Estimation model

The bench mark of evaluation between water consumption and CO_2 emission would be set as yearly calculation for each item. Thus, the result can compare to the capital CO_2 emission for whole country. Calculation from water consumption to CO_2 emission is an accumulation by individual process energy consumption. Herein, the yearly CO_2 emission from water consumption T_n can be calculated by 2 parameters, and the function is as shown as equation (1).

$$T_n = C_{pn} \times p_{on} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

T_n ：The total CO_2 emission in year(n) (kg-CO_2/ year)

C_{pn} ：The capital CO_2 emission per person in year(n) (kg-CO_2/person・year)

p_{on} ：Population (persons)

The population is constant for a country in above equation. The crucial parameter is the average CO_2 emission per person in year (n) (kg-CO_2/ person・year) C_{pn} and this parameter is from 2 directions including tap water demand and hot water usage. So, this calculation can be expressed as equation (2) as the following.

$$C_{pn} = C_{pwn} + C_{phn} \quad \text{.................................}(2)$$

C_{pn} ：The capital CO_2 emission per person in year(n) (kg-CO_2/person・year)

C_{pwn} ：The factor of CO_2 emission per person in year(n) from tap water (kg-CO_2/person・year)

C_{phn} ：The factor of CO_2 emission per person in year(n) from hot water (kg-CO_2/person・year)

The calculation of CO_2 emission from tap water usage is conducted by the coefficient of tap water CO_2 emission k_{cwn} and average yearly tap water consumption volume per person Q_{pwn}. The function is as shown as equation (3).

$$C_{pwn} = k_{cwn} \times Q_{pwn} \quad \text{....................................}(3)$$

k_{cwn} ：the factor of tap water CO_2 emission (kg- CO_2/m^3)

Q_{pwn} ：the average yearly tap water consumption volume per person (m^3/ person・year)

The factor of tap water CO_2 emission is from 3 sources including energy consumption from clean process of water supply plant, water supply in housing unit and sewage treatment. Meanwhile, the coefficient of electricity energy transfer to CO_2 emission is necessary factor to this calculation. The function can be expressed as equation (4) as the following.

$$k_{cwn} = (E_{swn} + E_{uwn} + E_{twn}) \times C_{en} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$

k_{cwn} ：the factor of tap water CO_2 emission (kg- CO_2/m^3)

E_{swn} ：the electricity energy consumption from clean process of water supply plant (kWh/m^3)

E_{uwn} ：the electricity energy consumption from housing unit water supply equipment (kWh/m^3)

E_{twn} ：the electricity energy consumption from urban sewage treatment (kWh/m^3)

C_{en} ：the factor of electricity energy consumption transfer to CO_2 emission in year(n) (kg- CO_2/kWh)

On the other hand, hot water usage in housing daily life consumes more energy and cause more CO2 emission. The energy consumption is directly caused by heating process but more complex due to its heating source. Firstly, the calculation can be expressed as equation (5). The average CO_2 emission per person in year(n) from hot water C_{phn} is dominated by the coefficient of hot water CO_2 emission (kg- CO_2/m^3) and the average yearly hot water usage volume per person.

$$C_{phn} = k_{hwn} \times Q_{phn} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (5)$$

k_{hwn} ：the factor of hot water CO_2 emission (kg- CO_2/m^3)

Q_{phn} ：the average yearly hot water usage volume per person (m^3/ person・year)

The factor of hot water CO_2 emission is more complex as above mentioned due to its heating sources. According to investigation, the heating sources have 3 types of energy including gas (LPG), electric heater and solar heating system in Taiwan. The practical usage proportion is approximate 70%, 25% and 5%. Therefore, the coefficient of hot water CO_2 emission can be expressed as equation (6) as the following.

$$k_{hwn} = C_g \times 0.7 + C_e \times 0.25 + C_s \times 0.05 \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (6)$$

k_{hwn} ：the factor of hot water CO_2 emission (kg- CO_2/m^3)

C_g ：the hot water CO_2 emission from gas energy heating source 70% [*1](kg-CO_2/m^3)

C_e ：the hot water CO_2 emission from electric energy heating source 25% [*1] (kg-CO_2/m^3)

C_s ： the hot water CO_2 emission from solar energy heating source 5% [*1] (kg-CO_2/m^3)

[*1] ：The practical usage proportion of energy including gas (LPG), electric heater and solar heating system in Taiwan.

4.Evaluation and validation

4.1 Factors of CO_2 emission

According to the composition rate of electric power production sources such as oil, coal, nuclear and hydraulic power, the CO_2 emission factors for electricity is shifting for each year. Consequently, the factors are not only changing yearly but also different from countries. Fig. 1 show the factors from 1990 to 2010. There is an increasing tendency from 1990 to 2000 in Taiwan, and be stable after 2001 with approximate 0.62 (kg-CO_2/kWh). On the other hand, it is stable with around 0.37 (kg-CO_2/kWh) except the data of 2007 in Japan.

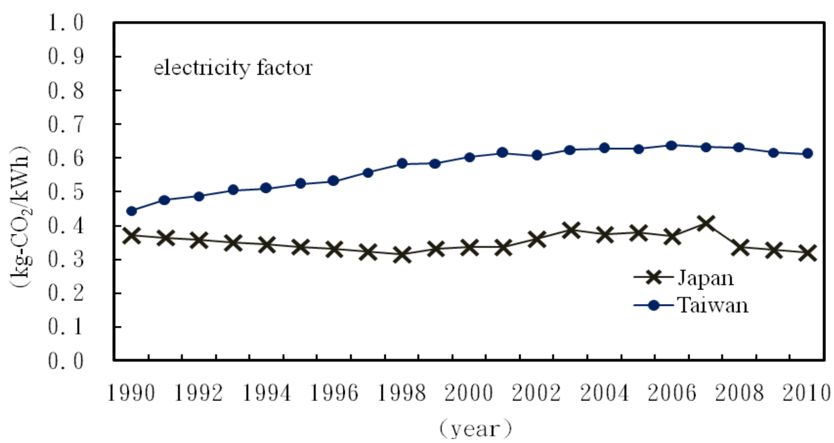

Fig.1 the electricity factors for CO_2 emission from 1990 to 2010

The water usage factors including tap water and hot water are evaluated from 1990 to 2010. A slight increasing tendency is shown in this evaluation for decades in Taiwan. It reveals that the potential of reduction for CO2 emission is existed. Table 1 show the data details during these years.

Table 1 the factors for CO_2 emission from 1990 to 2010

	Electricity ($kg\text{-}CO_2/kWh$) -Japan	Electricity ($kg\text{-}CO_2/kWh$) -Taiwan	Tap water ($kg\text{-}CO_2/m^3$) -Taiwan	Hot water ($kg\text{-}CO_2/m^3$) -Taiwan
1990	0.371	0.443	0.344	5.32
1991	0.364	0.475	0.369	5.54
1992	0.357	0.487	0.378	5.62
1993	0.350	0.504	0.391	5.73
1994	0.344	0.509	0.395	5.77
1995	0.337	0.523	0.406	5.86
1996	0.330	0.531	0.412	5.91
1997	0.323	0.556	0.431	6.08
1998	0.314	0.582	0.452	6.25
1999	0.332	0.583	0.452	6.26
2000	0.335	0.602	0.467	6.39
2001	0.336	0.614	0.476	6.47
2002	0.360	0.606	0.470	6.41
2003	0.387	0.624	0.484	6.53
2004	0.374	0.628	0.487	6.56
2005	0.379	0.626	0.486	6.55
2006	0.368	0.637	0.494	6.62
2007	0.407	0.632	0.490	6.59
2008	0.335	0.631	0.490	6.58
2009	0.328	0.616	0.478	6.48
2010	0.320	0.612	0.475	6.45

4.2 CO_2 emission of water usage

According to Kyoto Protocol, 1990 is a bench mark year for each country to target the reduction of CO_2 emission. It was seen as a very challenge to reach the goal for many countries. In the case of Taiwan, the capital CO_2 emission is almost double from 1990 to 2006 as shown as Fig.2. Although it is a difficult mission to fit the Kyoto Protocol bench mark, the government targets the 2000 to be bench mark year and the initial strategy. Due to the carbon credits and exchange mechanism movement, eventually, government policy need to improve and reach the 1990 bench mark.

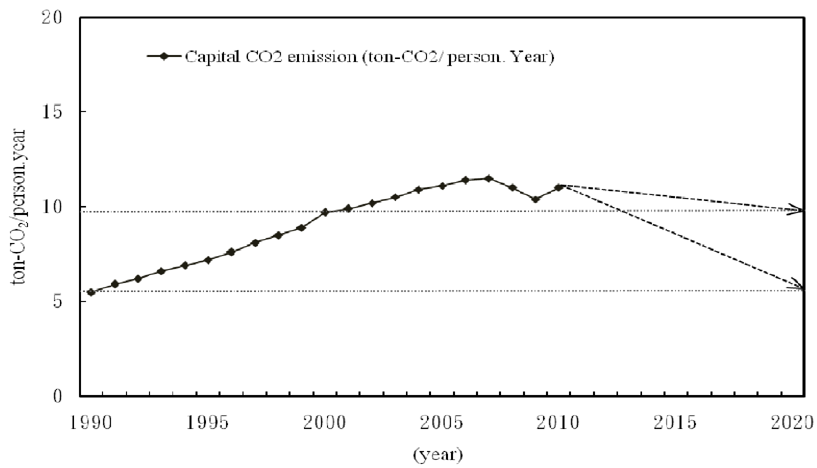

Fig.2 the capital CO2 emission of Taiwan (ton-CO2/person-year)

The CO_2 emission which is caused by water usage has a similar shifting feature with the capital value of all country in Taiwan. The total water factor of CO_2 emission is composed by tap water and hot water usage. However, the increasing rate is less than the capital value and it keeps stable situation after 2000. Fig.3 shows the factors shifting situations of tap water, hot water and total value. The hot water factor has larger value and contribution to the ratio of water factor to capital value. Herein, it also shows that the ratio of water factor to capital value is decreasing from around 3.0% to 2.0%. Table 2 shows the details of these data.

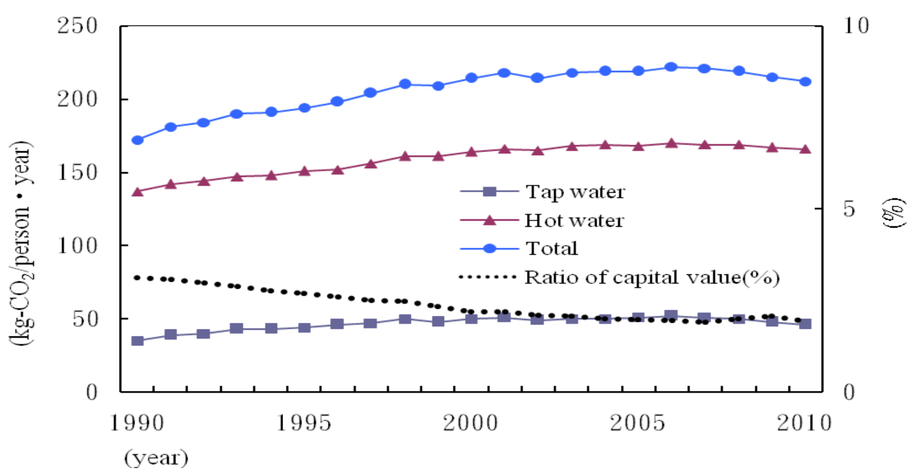

Fig. 3 the factors shifting diagram of water usage.

Table 2 the factors of CO_2 emission shifting data of water usage

	Capital factor (ton-CO_2/p.y)	Tap Water factor (kg-CO_2/p.y)	Hot water factor (kg-CO_2/p.y)	Total water factor (kg-CO_2/p.y)	**Ratio of capital value (%)**
1990	5.5	35	137	172	3.13
1991	5.9	39	142	181	3.07
1992	6.2	40	144	184	2.97
1993	6.6	43	147	190	2.88
1994	6.9	43	148	191	2.77
1995	7.2	44	151	194	2.70
1996	7.6	46	152	198	2.61
1997	8.1	47	156	204	2.51
1998	8.5	50	161	210	2.47
1999	8.9	48	161	209	2.35
2000	9.7	50	164	214	2.21
2001	9.9	51	166	218	2.20
2002	10.2	49	165	214	2.09
2003	10.5	50	168	218	2.08
2004	10.9	50	169	219	2.01
2005	11.1	51	168	219	1.97
2006	11.4	52	170	222	1.95
2007	11.5	51	169	221	1.92
2008	11.0	50	169	219	1.99
2009	10.4	48	167	215	2.07
2010	11.0	46	166	212	1.93

4.3 Potential of saving water

The water factor of CO_2 emission is high related to the water consumption. Fig. 4 shows the shifting volume of daily water consumption per person in Taipei city and other areas of Taiwan. It is obvious that the metropolitan area such as Taipei city has greater water consumption of around 30% up in the other areas of Taiwan. It also shows that water consumption is increasing during 1980s and with peak value in 1990s. The tendency is approximately stable after year of 2000 with Taipei city of around 350 liter per day and the other areas of Taiwan of around 270 liter per day.

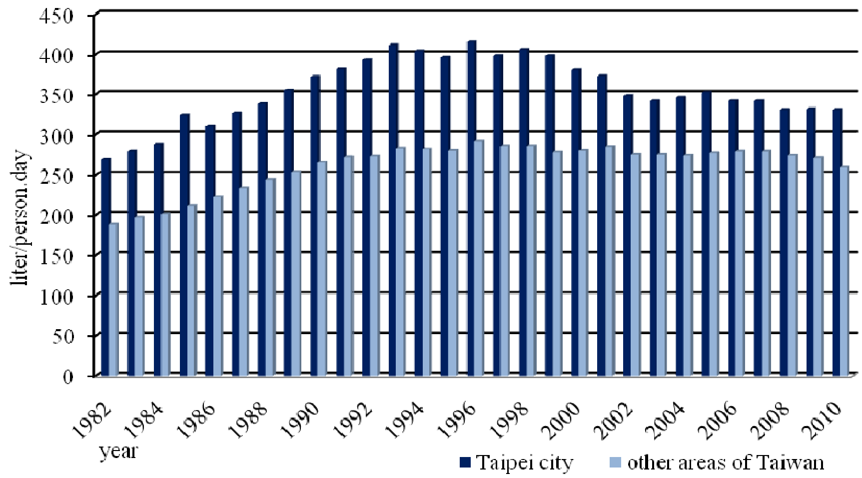

Fig. 4 the shifting volume of daily water consumption in Taiwan

According to this stable situation of water consumption, it needs more motivation to improve the water saving strategy and inovate reduction techniques to carry out the goal of saving water society. Therefore, a quantitative evaluation is necessary to validate the possibility of improvement in water saving activities. The proposed calculation model in this paper can estimate the value of CO_2 emission from water usage and evaluate the potential of saving water strategy.

In order to estimate the potential of saving water strategy, the bench mark of saving water society has to be set as target. The saving water facilities such as low flush water closet shower are the practicable step to reduce water consumption. The water use behavior is also a influence factor to reduction stetragy. Due to the facilities performance and water use behaviors is changing, the bench mark should be set as stage target. This paper concludes the stage with 5 years and bench mark target as 250, 200, 175 and 150 liter per day during 1990~2010 in Taiwan.

Eventually, the bench mark of saving water society target on 150 liter per day as the criterion of potential estimation. Fig. 5 shows the diagram of saving water protential and bench mark of saving water society. The potential can be calculated by the diffenence between practical water consumption and criterion of saving water society. That is to say, the quantitative potential of water saving is around 45% and contribution of CO_2 emission to capital ration is 0.87% in 2010. It is equivalent to around 2.3 millions ton of CO_2 emission for carbon credit. The bench mark of saving water society can be shifted to higher criterion due to improvement of facility performance and innovation of techniques such as rainwater havesting and water recycling system. Therefore, the bench mark criterion of saving water society can shift from 150 to 100 liter per day per person before 2020. The posibility needs more innovation and validation to prove its practicability in the future.

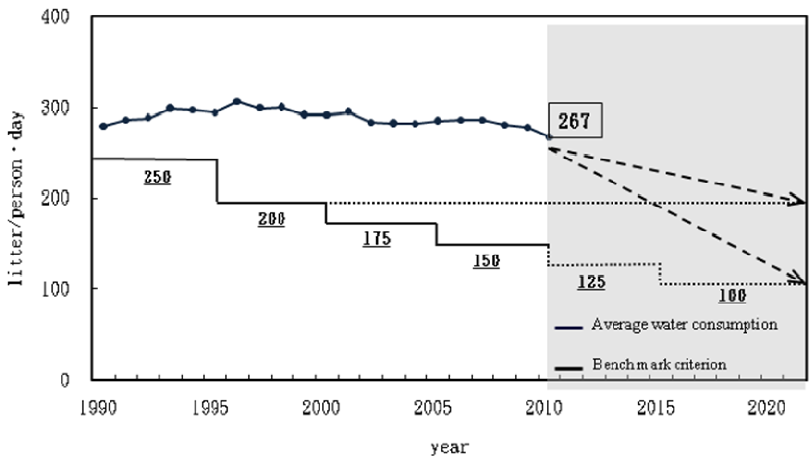

Fig. 5 the diagram of saving water protential and bench mark of saving water society.

5. Conclusion

Sustainability and reduction of CO_2 emission is the global consensus in recent years. This research aims on the practicability of society based on saving water concept and links to the reduction of CO_2 emission policy. A calculation model is proposed in this paper to estimate the CO_2 emission from water consumption. Through investigation of the domestic water use in people's livelihood, the structure of water consumption can be schematically understood and the water saving strategy can be concluded. The calculation model had been built to estimate the energy consumption and CO_2 emission from water demand and to evaluate the potential of water saving strategy.

Eventually, this research conducted estimation model of CO_2 emission from water consumption and validate the potential of water saving strategy in Taiwan. The quantitative potential reveals the motivation of saving water strategy and practicability of society based on saving water concept. This achievement can be referenced by Asian countries with similar environment and precipitation. However, more innovation and validation about low carbon society are necessary to be concerned. In order to carry out the society of saving water and low carbon, the practicability of carbon credit mechanism needs more innovations and further validation in the future.

Acknowledgements

The authors would like to thank the National Science Council of the Republic of China (NSC100- 2221-E-011-119) for financially supporting this research.

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Energy implications for water supply tanks in high-rise buildings

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Abstract

High-rise housing, a trend in densely populated cities around the world, increases energy use for water supply and corresponding greenhouse gas emissions. This paper presents an energy efficiency evaluation measure for water supply system designs and a mathematical model for optimizing pumping energy through the arrangement of water tanks in a building. To illustrate that the model is useful for establishing optimal design solutions that integrate energy consumption into urban water planning processes which cater to various building demands and usage patterns, measurement data of high-rise residential buildings in Hong Kong are employed. The results show the energy efficiency of many existing high-rise water supply systems is about 0.25 and can be improved up to over 0.3 via water storage tank relocations, corresponding to annual electricity saving up to 0.3% of the total annual electricity consumption in Hong Kong.

Keywords

Building, water supply, energy efficiency, water consumption, storage tank location

1 Introduction

Very tall buildings are a trend in recent developments in Hong Kong, where is a developed city on hilly terrain with limited usable land for buildings. It has been estimated that the current average residential building height in the city is estimated to be 25.8 storeys [1]. For high-rise buildings, gravity storage tanks on building rooftops (or on intermediate mechanical floors) are designed for distributing water through down feed pipes [2] and pressure reducing valves (PRV) with adjustable settings and screwed joints are commonly installed to minimize the problems of water leakage or damage in supply pipes and appliances caused by excessive water pressure on lower floors in low demand situations.

According to the expression below, where E_{pump} is the energy use for pumping a volumetric water demand v_{pump}, and N_B (=25.8 storeys) is the average building height [3], water supply systems in buildings account for approximately 1.6% of the total city electricity use in the city, for the total annual water consumption of 1200 Mm^3 year^{-1} [4].

$$E_{pump} = 3.6 \times \frac{1.2(N_B + 1)v_{pump}}{60} \qquad \text{… (1)}$$

An energy efficiency evaluation measure is proposed for water supply system designs in buildings, with verification measurements in some high-rise residential buildings of Hong Kong. Energy performance targets for some system designs, together with estimated energy savings potential are discussed.

2 Energy efficiency of building water supply systems

Figure 1 illustrates two water supply system designs: (a) an elevated water tank that feeds demands with little height differences (e.g. an elevated water tower over a town); (b) a roof tank that feeds distributed demands with large height differences (e.g. a roof tank on top of a building). For a high-rise building, the system design is characterised by the water lift demand height ratio h_l^* given by Equation (2), where $(h_n - h_1)$ is the height difference between the demands at the top and bottom for $i = 1,2,...n$ and h_1 is the water lift height.

$$h_l^* = \frac{h_n - h_1}{h_l} \qquad \text{… (2)}$$

The water lift height h_l is the sum of the height measured from the tank base to the tank inlet h_c - approximated by the tank volume V_c, the height difference between the demand n and the tank base h_b, and the height difference between the water surface (i.e. of the reservoir in design (a) or of the break tank in design (b)) and the top demand location h_n,

$$h_l = h_c + h_b + h_n; h_c \sim V_c^{1/3} \qquad \text{... (3)}$$

The water lift demand height ratios for system designs (a) and (b) are $h_l^* = 0$ and $h_l^* > 0$ respectively. For a high-rise building, the ratio $h_l^* \sim 1$ is dominated by the demand heights $h_l \sim h_n$ and $h_b + h_c << h_n$.

The desired minimum water pressure head H_o, say 5m (H_2O) in some design practices, is assumed at the demand point and the friction head required in the upfeed water pipe H_f is taken as a portion of the pipe length (i.e. 10% of h_l) [5],

$$H_o = 5; H_f = 0.1h_l \qquad \text{… (4)}$$

Consider the case of uniformly distributed demands along the building height (i.e. $v_1 = v_2 = ... = v_i = v_n = v$), the demand heights h_i, where $i = 1,2,...n,$ for the two designs (a) and (b) are expressed by,

$$\begin{cases} h_l^* = 0 : h_1 = h_2 = ... = h_n \\ h_l^* > 0 : h_2 - h_1 = h_3 - h_2 = ... = h_n - h_{n-1} = C_{ff} \end{cases} \quad \text{… (5)}$$

E_{out}, (MJ) the potential energy for the water demands at height h_i (i.e. 'output energy' of a design) is given below, where ρ (=1000 kgm^{-3}) is the water density and g (=9.81ms^{-2}) is the gravity,

$$\forall h_l^* : E_{out} = \rho g \sum_i v_i h_i ;\ i = 1,2,...n \quad \text{… (6)}$$

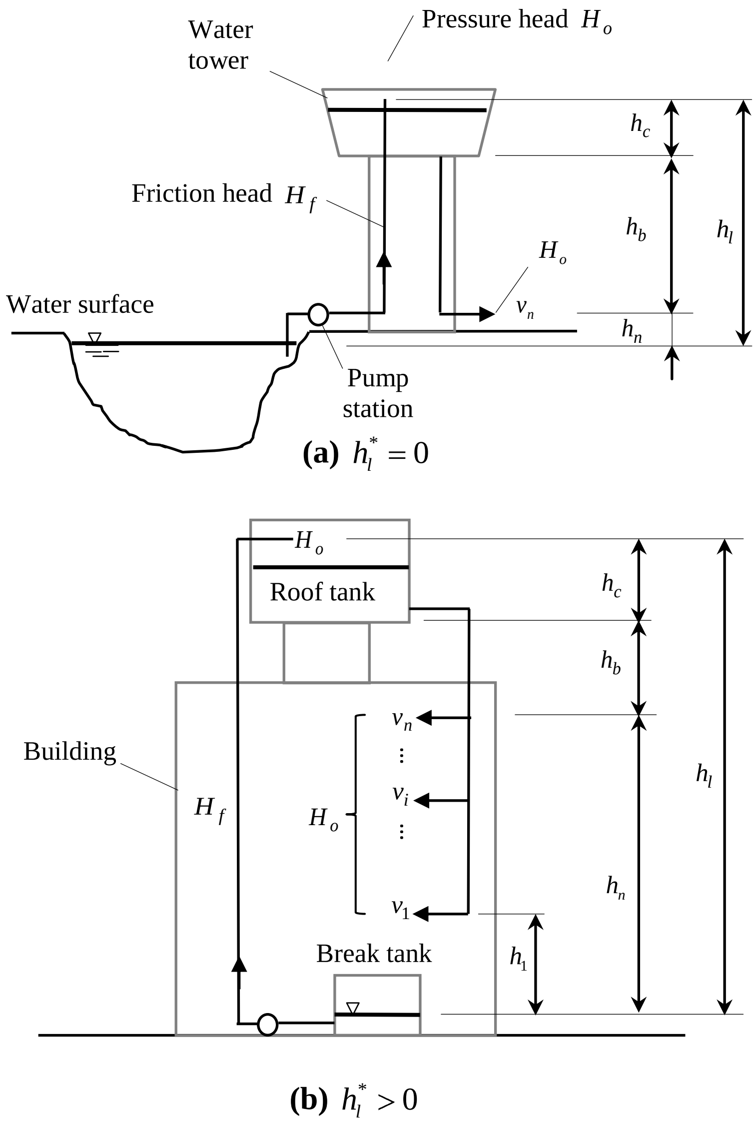

Figure 1. Gravity tank systems

It can be rewritten for both designs,

$$\begin{cases} h_l^* = 0: & E_{out} = \rho gnvh_n \\ h_l^* > 0: & E_{out} = \rho gnv\left(\dfrac{h_1 + h_n}{2}\right) \end{cases} \qquad \ldots (7)$$

The 'input energy' of both designs is the pumping energy of lifting water up to the tank E_{pump} (MJ) as defined below, where η_c is the design overall transmission efficiency,

$$\forall h_l^* : E_{pump} = \frac{\rho gnvh_l}{\eta_c} = \frac{\rho gnv(H_o + H_f + h_n + h_b + h_c)}{\eta_c} \qquad \ldots (8)$$

Energy efficiency, which is the 'output energy' divided by the 'input energy', is a measure of pumping energy performance. It can be determined for the water supply systems using the heights, pipe friction and allowable pressure head,

$$\alpha = \frac{E_{out}}{E_{pump}}; \begin{cases} h_l^* = 0: & \alpha = \dfrac{h_n \eta_c}{5 + 1.1(h_n + h_b + h_c)} \\ h_l^* > 0: & \alpha = \dfrac{\left(\dfrac{h_1 + h_n}{2}\right)\eta_c}{5 + 1.1(h_n + h_b + h_c)} \end{cases} \qquad \ldots (9)$$

Table 1. Selected number of design parameters for building water supply systems.

Pump efficiency η_p		0.65
Mechanical transmission efficiency η_m		0.90
Electric motor efficiency η_e		0.90
Total water storage tank volume V_c (m^3)		27
Height between tank base and the last demand location h_b (m)		10
Height of the bottom demand location h_1 (m)		1
Height of the top demand location h_n (m)		≥10
Height of the tank inlet measured from tank base h_c (m)		3
Friction head loss in pipes H_f (m)		$0.1h_l$
Minimum water pressure head allowed at the outlet H_o (m)		5
Occupant area ratio O_s (ps m^{-2})	(public residential)	0.085 (0.03)
	(private residential)	0.096 (0.04)
Yearly per-capita water consumption (m^3 ps^{-1} year^{-1})	(freshwater)	70 (13)
	(seawater)	22 (10)

Standard deviation shown in brackets

Table 1 exhibits some example design parameters for building water supply systems. A top demand height $h_n \geq 10$ m, i.e. a height of 3 storeys, was chosen for illustration. The design overall transmission efficiency η_c (34-62%) accounted for 50-80% of the pump efficiency η_p, about 90% of the mechanical transmission efficiency η_m and 70-90% of the electricity motor efficiency η_e [6]. For simplicity, constant efficiencies are assumed: $\eta_p = 0.65$, $\eta_m = 0.9$, $\eta_e = 0.9$, and $\eta_c = 0.5625$,

$$\eta_c = \eta_p \eta_m \eta_e \qquad \ldots (10)$$

The values of energy efficiency α for water supply system designs of h_l^* between 0 and 1 using the design numbers in Table 1 are approaching 0.5 and 0.25 for $h_l^* = 0$ and $h_l^* > 0$ respectively with an increased height h_n.

$$\begin{cases} h_l^* = 0: \quad \alpha = \dfrac{\eta_c h_n}{5 + 1.1(h_n + 13)} = \dfrac{\eta_c h_n}{19.3 + 1.1 h_n} \\ h_l^* > 0: \quad \alpha = \dfrac{\eta_c \left(\dfrac{h_n + 1}{2}\right)}{5 + 1.1(h_n + 13)} = \dfrac{\eta_c (h_n + 1)}{38.6 + 2.2 h_n} \end{cases} \qquad \ldots (11)$$

$$h_n \to \infty : \begin{cases} h_l^* = 0 : \alpha \sim \dfrac{\eta_c}{1.1} \sim 0.5 \\ h_l^* > 0 : \alpha \sim \dfrac{\eta_c}{2.2} \sim 0.25 \end{cases} \qquad \ldots (12)$$

It is noted that for a residential building height of up to 300 m in Hong Kong, the energy efficiency values are 0.44 and 0.24 for designs (a) and (b). The design parameters h_b, h_c, h_n, H_o have significant contributions to the energy efficiency.

3 Sample buildings

A survey of 5 government-funded residential buildings in Hong Kong (Table 2) was used to examine the validity and applicability of the proposed water demand model and the energy efficiency measure. It was noted that the apartments were rented to lower-income families. The buildings varied from 15 to 33 storeys, with an average height of 22 storeys. Number of apartments, apartment floor area, roof tank volumes and demand heights of all buildings are summarized in Table 2. Demand distributions in some buildings were vertically uneven as indicated through the number and size of apartments. The heights of bottom demand (h_1) were below 5 m. The data of height difference between the tank base and the top demand (i.e. h_b) were 10 m or less. Heights between any two (vertically) consecutive demands were about 2.7 m.

In each of the sampled buildings, water secured from the city mains was stored in a break tank and transferred through a pair of transfer pumps to the rooftop gravity tanks for distribution to every floor of the building. There are two separated water supply networks in Hong Kong – one for fresh water supply and the other for seawater flushing; only one old building was using freshwater for water closet flushing and had no separate flushing water tank.

3.1 Water consumptions

The average daily water consumption on a floor $v_{i,d}$ is determined by Equation (13), where $N_{s,i}$ is the number of occupants on floor i, $v_{s,d}$ is the average daily per-capita water consumption, $O_{s,i}$ is the occupant area ratio on floor i and A_i is the total apartment area on floor i [7],

$$v_{i,d} = N_{s,i} v_{s,d}\,;\; N_{s,i} = O_{s,i} A_i \qquad \text{… (13)}$$

A number of studies approximated the regional profiles of occupant area ratio O_s and average daily per-capita water consumption $v_{s,d}$ in buildings by parametric distribution functions as shown in Table 1 [8,9]. Parameters $v_{s,d}$ and $O_{s,i}$ in Equation (13) can be determined via Monte Carlo simulations at percentile $v_{s,d}, O_{s,i} = \vartheta \in [0,1]$ through the distribution functions $\tilde{v}_{s,d}$ and $\tilde{O}_s$, where ϑ is a random number taken from a pseudo random number set generated by the prime modulus multiplicative linear congruential generator [10].

$$\int_{-\infty}^{v_{s,d}} \tilde{v}_{s,d}\, dv_{s,d} = \vartheta \in [0,1]\,;\; \int_{-\infty}^{O_{s,i}} \tilde{O}_s\, dO_s = \vartheta \in [0,1]\,;\; v_{s,d} \in \tilde{v}_{s,d}\,;\; O_{s,i} \in \tilde{O}_s \qquad \text{... (14)}$$

The total (daily) water consumption is used to calculate the pumping energy input to a building water supply system,

$$nv_d = \sum_{i=1}^{n} v_{i,d}\,;\; E_{pump} = \frac{\rho g h_l \sum_{i=1}^{n} v_{i,d}}{\eta_c} \qquad \text{… (15)}$$

Table 2. Survey of 5 residential buildings in Hong Kong

No.	N_s	Apart-ments per storey	Apart-ment floor area	Height				Tank volume V_c (m^3)		Measured daily pumping energy	Energy efficiency α		
			(m^2)	h_1 (m)	h_n (m)	h_b (m)	h_l (m)	Fresh water	Flush-ing water	$E_{d,pump}$ (MJ day^{-1})	Roof tank only	(I) One tank per floor	(II) One interme-diate tank
1	36	18	32-49	4.5	99.0	6.5	109	55	27	1422	0.24	0.34	0.27
2	26	17	17-49	4.2	71.7	5.4	80	26	17	516	0.24	0.31	0.26
3	26	15-25	16-49	4.2	71.7	5.4	80	36	12	667	0.23	0.31	0.26
4	40	20	17-42	4.6	109.9	9.0	123	54	27	986	0.24	0.35	0.28
5	17	33	21	3.0	44.7	2.6	50	18	0	230	0.24	0.27	0.24

3.2 Measured pumping energy

In the surveyed buildings, electricity energy use was metered continuously for 24 hours for all water supply pumps to determine the total daily pumping energy (input energy to the system) consumption as presented in Table 2. It was noted that a single-day energy consumption monitoring period might fall between two roof tank filling cycles and the error of energy required to fill up the tank was doubled. In this study, the probable errors of measurement were taken at a half of this error and indicated as error bars in Figure 2.

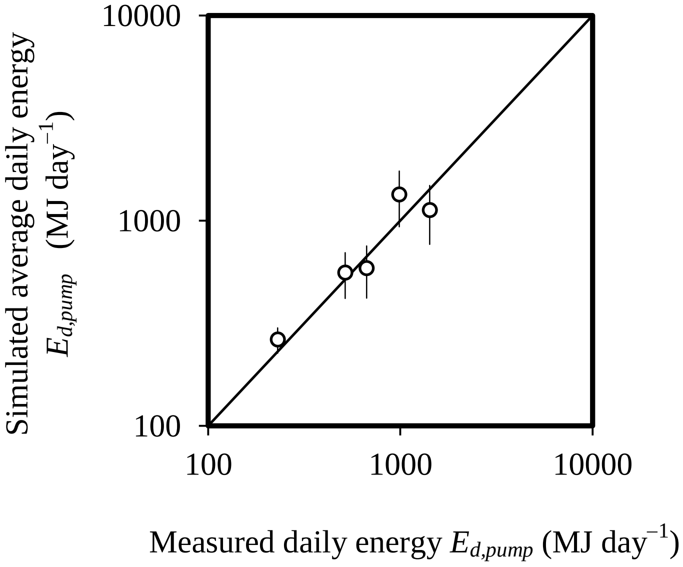

Figure 2. Daily pumping energy consumption of 5 residential buildings in Hong Kong

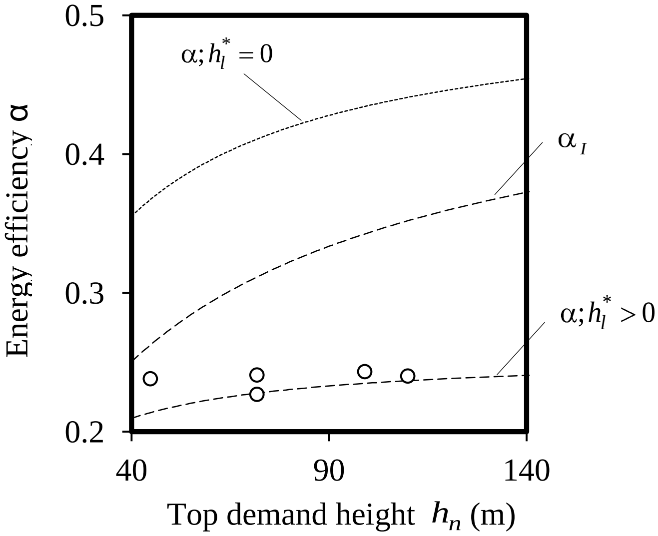

Figure 3. Energy efficiency α_I of water supply systems

Figure 2 shows the predicted daily pumping energy consumption against the measured one for the surveyed buildings. The predictions, which were based on typical pump efficiency details displayed in Table 1, reasonably agreed with the measurement results. The predicted average daily water consumption of a floor $v_{i,d}$ at height h_i was used to determine the output energy E_{out} (Equation (6)) for the buildings and thus the energy efficiency of existing roof tank design as shown in Table 2.

Figure 3 plots the energy efficiency against the top demand height, with cases $h_l^* = 0$ and $h_l^* > 0$ shown for comparison. As expected in roof tank designs, energy efficiency values obtained for the surveyed buildings were close to the lower side of $h_l^* \sim 1$. A few cases were found below $h_l^* \sim 1$ for demands were unevenly distributed and dominated by more occupants on lower floors (Building 3).

4 Energy implications of 2 example water tank arrangements

The energy efficiency of a high-rise building can be optimized by the proper arrangement of water storage tank(s). Two example designs are illustrated below:

4.1 (I) One supply tank for each demand height

An individual tank is reserved for every floor ($h_l^* = 0$) in a building. Based on the data in Table 1, the energy efficiency α_I is given by the average energy efficiency of all individual floors,

$$\alpha_I \sim \frac{1}{h_n - h_1}\int_{h_1}^{h_n} \frac{h_n}{34.3 + 1.96h_n} dh_n = \frac{1}{h_n - h_1}\left[\frac{h_n}{1.96} - 8.93\ln(34.3 + 1.96h_n)\right]_{h_1}^{h_n};\ h_1 \geq 0$$

… (16)

It can be expressed in discrete form, assuming a constant floor-to-floor height, C_{ff},

$$\alpha_I \sim \frac{1}{n}\sum_{i=1}^{n} \frac{h_i}{34.3 + 1.96h_i}\ ;\ h_1 \geq 0 \qquad \text{… (17)}$$

The calculated values of α_I for the surveyed buildings using this arrangement are shown in Table 2 and Figure 3. The arrangement offers energy efficiency improvements as shown. The energy efficiency improvement α' (in percentage $\alpha'_{\%}$) is expressed by,

$$\alpha' = \alpha_I - \alpha_{h_l^*>0};\ \alpha'_{\%} = \left(\frac{\alpha_I}{\alpha_{h_l^*>0}} - 1\right) \times 100\% \qquad \text{… (18)}$$

It is noted that using more riser pipes in this arrangement causes energy loss and energy may not be saved for top demand height h_n < 20 m. However, the improvement becomes significant for greater h_n.

4.2 (II) One roof tank and one intermediate tank

Demands v at height h in an n-storey building are subdivided on the j-th floor and zoned vertically into the upper (U) and lower (L) zones, where C_{ff} is the floor-to-floor height,

$$v = \{v_1, v_2, ... v_j\}_L, \{v_{j+1}, v_{j+2}, ... v_n\}_U;\ h = \{h_1, h_2, ... h_j\}_L, \{h_{j+1}, h_{j+2}, ... h_n\}_U \quad \text{… (19)}$$

$$h_j = h_1 + (j-1)C_{ff};\ h_{j+1} = h_j + C_{ff};\ h_n = h_1 + (n-1)C_{ff} \quad \text{… (20)}$$

Correspondingly, the energy output E_{out} is,

$$\begin{cases} E_{out,L} = \rho g \sum_{i=1}^{j} v_i h_i = \rho g j v \left(h_1 + \frac{(j-1)C_{ff}}{2} \right) \\ E_{out,U} = \rho g \sum_{i=j+1}^{n} v_i h_i = \rho g (n-j) v \left(h_1 + \frac{(n+j-1)C_{ff}}{2} \right) \end{cases} \quad \text{… (21)}$$

The water tank size is assumed proportional to the demands and the height of tank inlet h_c is given by,

$$\begin{cases} h_{c,L} = \sqrt[3]{V_c\, j/n} \\ h_{c,U} = \sqrt[3]{(1 - j/n)V_c} \end{cases} \quad \text{… (22)}$$

The energy input E_{pump} is,

$$\begin{cases} E_{pump,L} = \dfrac{\rho g j v (H_o + H_{f,L} + h_1 + (j-1)C_{ff} + h_{c,L} + h_b)}{\eta_c} \\ E_{pump,U} = \dfrac{\rho g (n-j) v (H_o + H_{f,U} + h_1 + (n-1)C_{ff} + h_{c,U} + h_b)}{\eta_c} \end{cases} \quad \text{… (23)}$$

The energy efficiency α is,

$$\begin{cases} \alpha_L = \dfrac{h_1 + \frac{(j-1)C_{ff}}{2}}{\frac{(H_o + H_{f,L} + h_1 + (j-1)C_{ff} + h_{c,L} + h_b)}{\eta_c}} = \dfrac{\eta_c (2h_1 + (j-1)C_{ff})}{2(H_o + 1.1(h_1 + (j-1)C_{ff} + \sqrt[3]{V_c\, j/n}) + h_b)} \\ \alpha_U = \dfrac{h_1 + \frac{(n+j-1)C_{ff}}{2}}{\frac{(H_o + H_{f,U} + h_1 + (n-1)C_{ff} + h_{c,U} + h_b)}{\eta_c}} = \dfrac{\eta_c (2h_1 + (n+j-1)C_{ff})}{2(H_o + 1.1(h_1 + (n-1)C_{ff} + \sqrt[3]{(1-j/n)V_c}) + h_b)} \end{cases} \quad \text{… (24)}$$

The overall energy demand efficiency is determined by,

$$\alpha_{II} = \alpha_L\, j/n + \alpha_U (1 - j/n) \quad \text{… (25)}$$

This arrangement offers some energy efficiency improvements $\alpha'_{\%}$ as exhibited in Table 2. Figure 4 graphs the energy efficiency ranges of this arrangement for a building when h_1 = 4.2 m, V_c = 40 m^3, and examples of n = 20 (0.21-0.26) and 80 (0.25-0.3).

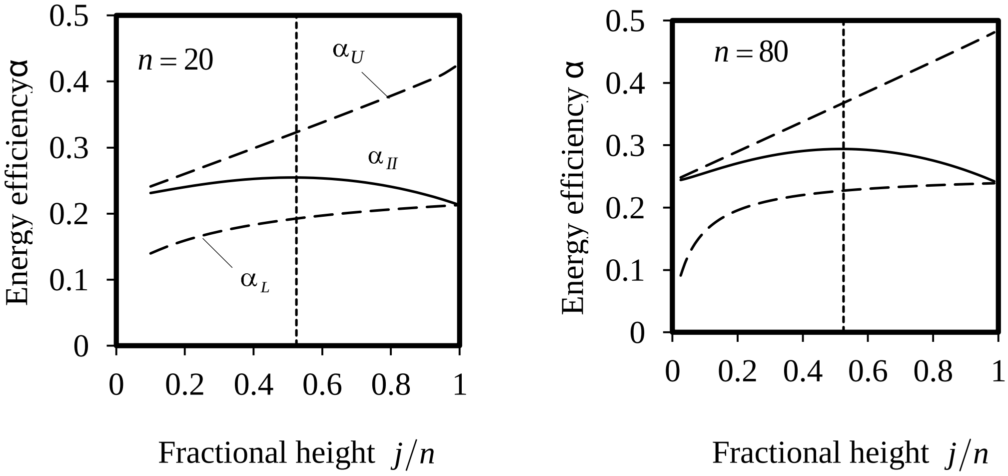

Figure 4. Energy efficiency α_{II} of a water supply system with roof and intermediate gravity tanks

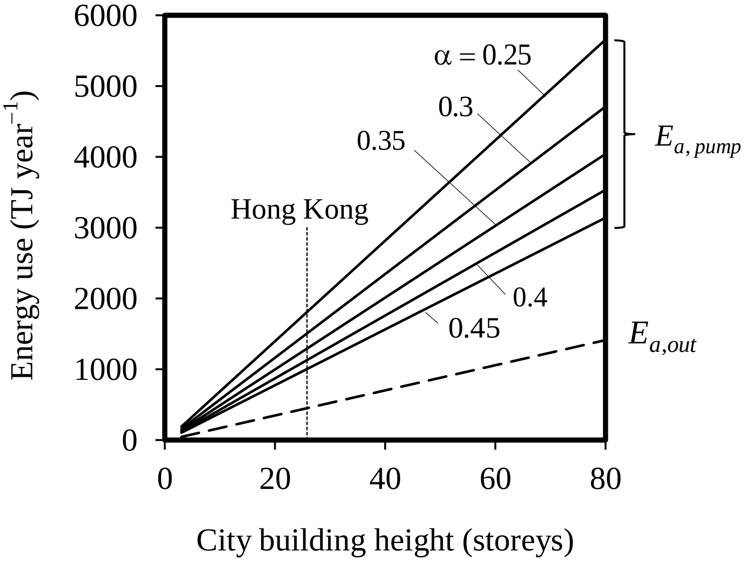

Figure 5. Annual energy consumption for building water supply systems

As there are additional pipe frictions in the separated piping networks, no significant energy savings can be achieved when the intermediate tank is close to the roof or the lowest floor. The optimal height for zoning is about the middle height of the building, i.e. $j \sim n/2$. Figure 5, in which a building height of 25.8 storeys (current average residential building height in Hong Kong) is highlighted, shows the annual energy output $(E_{a,out})$ for the water demands against building height, and the corresponding annual energy input $(E_{a,pump})$ for the roof tank systems with energy efficiency values α in between 0.25 and 0.45. It can be seen that energy consumption is proportional to building height. For the height of 25.8 storeys, $E_{a,out}$ is 456 TJ and corresponds to an energy input of 1822 TJ (1.2% of Hong Kong's total electricity consumption (149366 TJ)) at α = 0.25. The potential annual energy can be saved through efficiency improvements α' for Hong Kong is 410 TJ $(\alpha' = 0.06)$ if design arrangement (I) is adopted or 160 TJ $(\alpha' = 0.02)$ if design arrangement (II) is taken up.

5 Conclusion

Energy efficiency in buildings is a sustainable development strategy in Hong Kong. It is necessary to develop a method to systematically address energy efficiency with respect to the optimal design of high-rise water supply systems. This paper presented an energy efficiency evaluation measure for water supply system designs and developed a mathematical model for optimizing pumping energy through the arrangement of water tanks in a building. The model was demonstrated to be useful for establishing optimal design solutions that integrate energy consumption into urban water planning processes which cater to various building demands and usage patterns. The results showed that the energy efficiency of many existing high-rise water supply systems was about 0.25 and could be improved significantly via water storage tank relocations. The corresponding annual electricity could be saved was 160-410 TJ, a 0.1-0.3% of the total annual electricity consumption in the city.

6 Acknowledgement

The work described in this paper was partially supported by a grant from the Research Grants Council of the HKSAR, China (PolyU533709E).

7 List of symbols

A	Area (m^2)
C	Constant head pressure
E	Energy (MJ)
E_a, E_d	Annual energy (MJ $year^{-1}$), daily energy (MJ day^{-1})
g	Gravity (=9.81ms^{-2})
H	Pressure head of water column (m of H_2O)
h	Height (m)
i, j	Building floor counts, $i, j = 1,2,...n$
N	Number count
O	Occupant area ratio (ps m^{-2})
V	Volume (m^3)
v	Volumetric water demand over a specified period (m^3)
α	Energy efficiency
η_c	Overall transmission efficiency

η_e	Electric motor efficiency
η_m	Mechanical transmission efficiency
η_p	Pump efficiency
ϑ	Random number between 0 and 1
ρ	Water density (=1000 kgm^{-3})

Subscript

0	of reference
$1,2,...n$	of demands $1,2,...n$, from the bottom floor to the top floor
I, II	of cases I and II
a	of annually
B	of building storey
b	of water tank base
c	of water tank base to inlet
d	of daily
f	of friction in upfeed water pipe
ff	of floor to floor
L	of lower zone
l	of water lift
o	of outlet
out	of output
$pump$	of water pump
s	of occupant
U	of upper zone
%	of percentage

Superscript

$\sim$	of distribution
*	of relative
‘	of improvement

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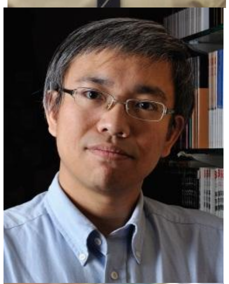

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Discussion of water saving and energy conservation in hot water transmission pipes

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Abstract

A typical central hot water system regulates the hot water temperature to a comfortable temperature, however, once the hot water leaves the storage tank and travels through pipes, the temperature of the water drops. This results in lower than desired hot water temperature for the user. Research of energy consumption in a central hot water circulation system indicates that the amount of energy required for circulation and usage is approximately the same as the amount required for generating hot water. This study discusses water saving and energy consumption in piping via an intelligent hot water circulation system. The total energy conservation of the circulation system is about 50% higher than the energy consumption of the non-circulation system. This system not only saves water, but also saves the energy within the system.

Keywords:
Energy consumption, hot water system, intelligent hot water circulation system, water saving, energy saving

1. Introduction

A typical central hot water system regulates the hot water temperature to a comfortable temperature, however, once the hot water leaves the storage tank and travels through pipes, the temperature of the water drops, as shown in "Fig.1". This results in lower than desired hot water temperature for the user, referred by Lee al. (2004, 2005). According to the conclusion of Cheng and Lee (2005) knows that energy consumption in heating part almost equals heat loss in transmission part and usage consumption without considering heating conservation efficiency. Research of energy consumption in a central hot water circulation system indicates that the amount of energy required for circulation and usage is approximately the same as the amount required for generating hot water.

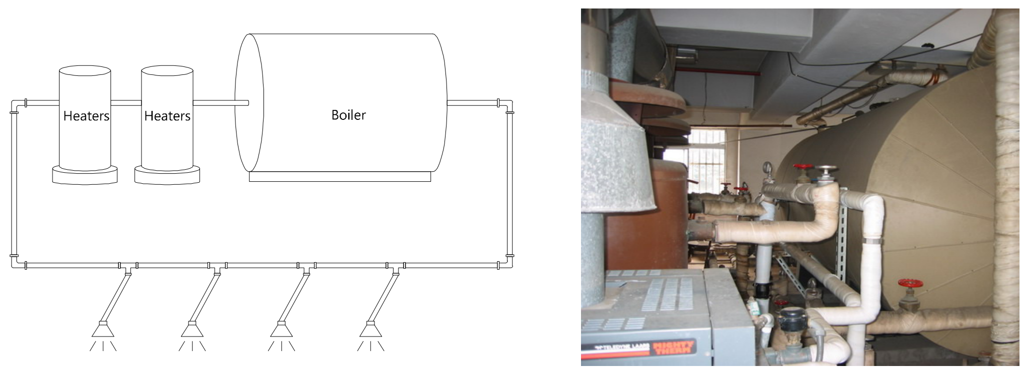


Fig. 1 Typical central circulated hot water system

Numerous studies proposed various methods such as the Building Energy Conservation Regulations in Japan, (Association of Building Environment Energy Conservation, 1996), which focused whole energy consumption of hot water supply system and included heat lose of transmission pipe. Kamada et al. (1997) and Sakaue et al. (2000) proposed a standard hot water temperature for a supply system based on energy conservation in Japan. Balaras et al. (2000) determined that the variation in pipe heat loss was by caused variations in energy consumption. Jaćimovic et al. (1998) proposed that the heat loss from heated objects is linear function of the outdoor temperature. And Morida (1980) presented heat lose calculated equation in distribution pipe.

Developing an intelligent hot water circulation system is the main solution to save temperature dropped water inner transmission pipe. This study discusses water saving and energy consumption in piping via an intelligent hot water circulation system. This system not only saves water, but also saves the energy within circulated water system.

2. Intelligent hot water circulator

For saving water and using comfortable hot water in suitable temperature, circulated and reheated water inner transmission pipe could save temperature dropped hot water waste. One circulated water pipe with a check valve (C1) setup before ball valves (faucets) to connect with transmission pipe for recycling and reheating the temperature dropped hot water in the intelligent hot water circulation system, as shown in “Fig.2”. Two inlet pipes connect with circulator, one is circulation pipe for recycling temperature dropped water, the other is cool water pipe from urban water. The controller setup with an electrical part to measure the recycled water temperature and send an electronic signal to switch the water inlet from circulated water by high efficiency pump or urban water in mechanical part. One check valve (C2) setup to avoid urban water flows into circulation pipe. The water flows out from the circulator into heater (gas, electrical, solar, etc.) or hot water tank to heat the recycled water or urban water. The intelligent hot water circulator recycles the temperature dropped water to save water inner transmission pipe and it also provides comfortable hot water using and saves much energy compared with the central circulated hot water system.

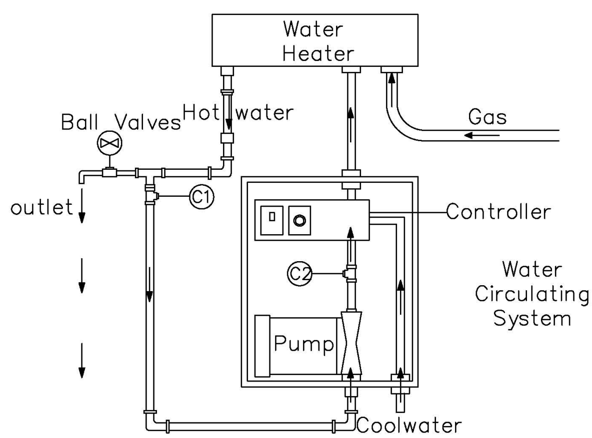


Fig. 2 Intelligent hot water circulator design concept

3. Experiment

For discussing the water saving and energy consumption in piping via an intelligent hot water circulation system, one experiment was held to measure the recycled water and energy consumption. The experiment adopts the popular heater type (80%), gas heater with 52.3kW, to heat and reheat water, and also adopted pipe material and length referred by Cheng and Lee (2006) in stainless steel pipe with insulator and up to 20 meters. In a limited experiment space and less thermal radiation interference, 1 meter test pipe (including 15cm curves) arranged in parallel to reach the design length and reduce thermal interference. The flowing velocity and temperature drop was simulated by Computational fluid dynamics (CFD) before experiment acting to design the experiment, as shown in “Fig.3”. Every circulation time before using should be under 1 minute to reheat the water till suitable temperature for comfort and energy conservation. The efficiency of pump and heater are also considered for the design.

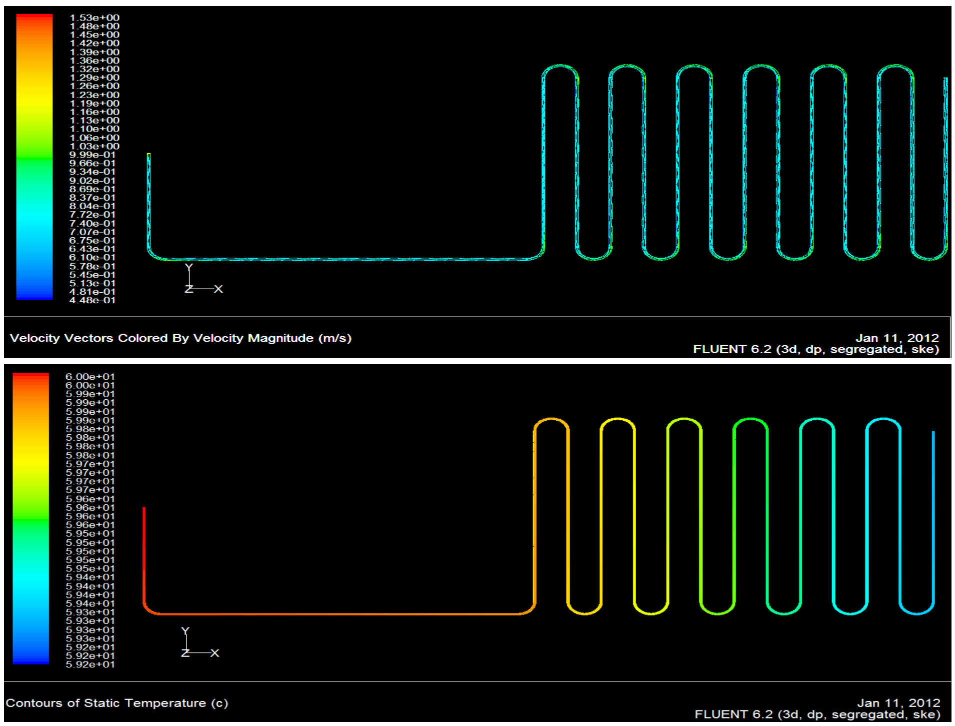


Fig. 3 Flowing velocity and temperature drop simulated by CFD

Air Temperature, water temperature (T), flow velocity (V), pressure (P), electric consumption of circulator with electronic control and pumping (E2) and heater (E1), and gas consumption (S) were measured in different pipe length (1m, 2m, 4m, 8m, 16m, and 20m) in this experiment, check valves (C) were also setup for the flow direction, as shown in “Fig. 4”. When heated water temperature reaches to the stable flowing temperature over 54℃ (heater set on 55℃), the water demand, electric consumption, and gas consumption could be compared in circulation system and in non-circulation system.

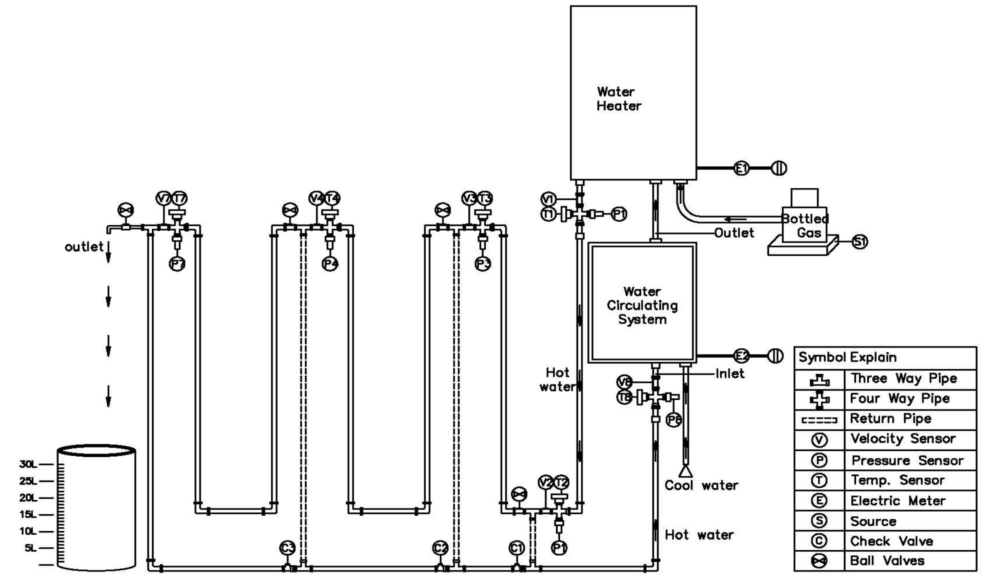


Fig. 4 Experiment concept of water saving and energy consumption

Based on the experiment design, the experiment instrument was installed on the indoor space for less influence of wind, as shown in "Fig.5". Six ball valves, six sensor sets with temperature sensors, flow meters, and pressure sensor are setup on the ball valve (faucets) inlet (T2~7, V2~7, P2~7) at 1m, 2m, 4m, 8m, 16m, and 20m from heater and also setup on the heater outlet (T1, V1, P1) in whole experiment instrument, and circulation pipes with check valves are setup between ball valves and sensor sets. Release each ball valve to flow the hot water into a water tank with level ruler to check the water waste in the non-circulation system. The experiment instrument is almost the same with the non-circulation system, except the circulation pipes, circulator, and one set sensor with temperature sensor, flow meter, and pressure sensor before circulator inlet (T8, V8, P8).

Table2 Experiment records

System	Non-Circulation					Circulation					
Factors	T	V	P	E1	S	T	V	P	E1	E2	S
Unit	*℃*	*l/s*	*Kg/cm^2*	*Wh*	*g*	*℃*	*l/s*	*Kg/cm^2*	*Wh*	*Wh*	*g*
1,2,4,8,16,20m											

All sensor sets also measure the temperature, velocity, pressure, electric consumption, and gas consumption from ball valves opening till the water temperature in stable with a set temperature, and closing. Finish test of non-circulation system and wait for 2 hours cooling the water and pipes then test the energy consumption in circulation system while acting the intelligent hot water circulator. Turn on the circulator, it recycles and reheats the temperature dropped water inner pipe immediately to save water waste but consumes a little bit energy. All data is also recorded on the table, as shown in Table 2.

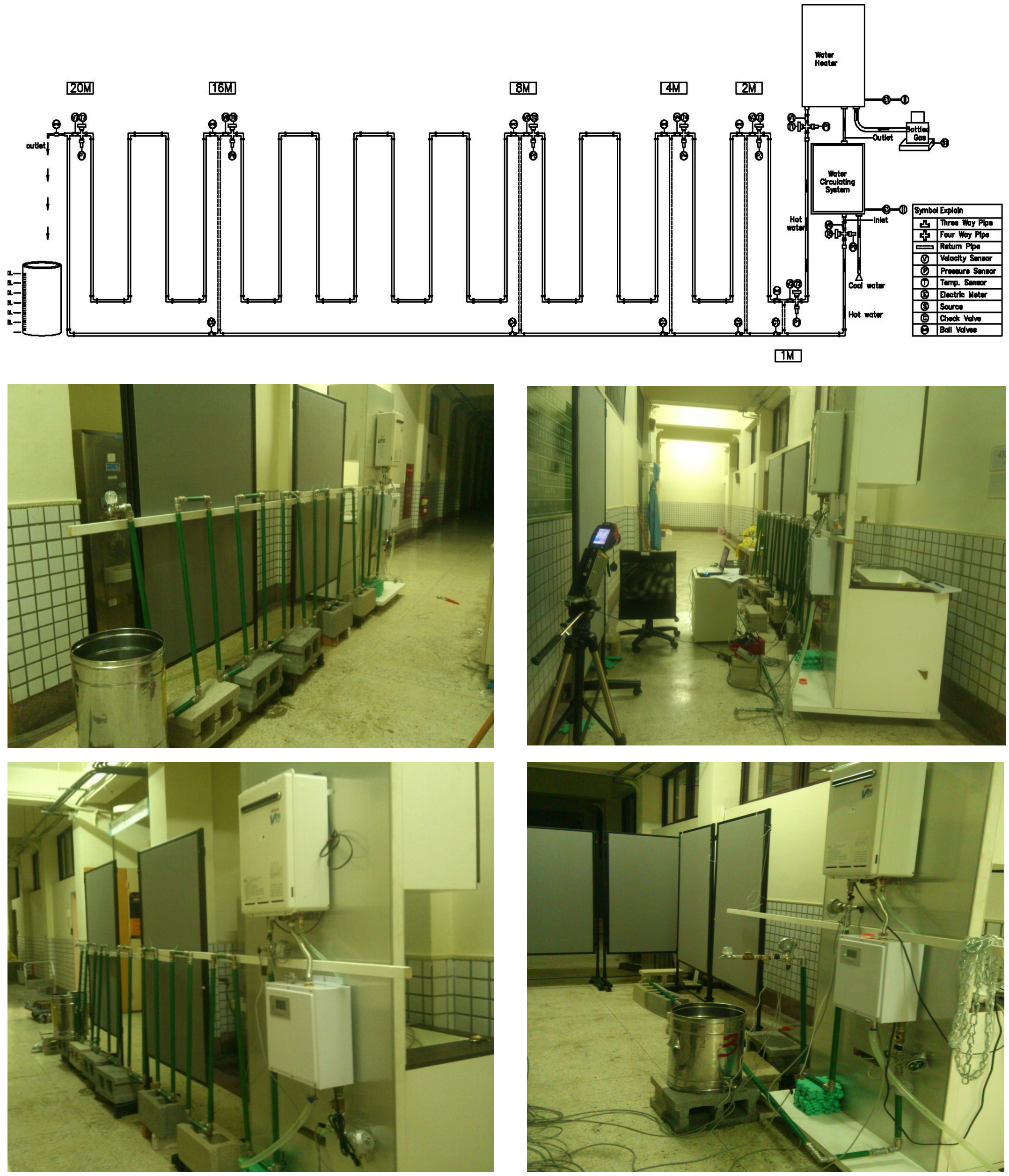


Fig. 5 Experiment instrument and Infrared thermal capture installation

The test processes were captured by Infrared thermal capture to show the hot water flowing into the pipes and heating the pipes. Turn off the water flowing, the water and pipes are cooling down by ambient temperature, as shown in “Fig. 6”. The captured photos present the temperature various from cooling pipe to hot pipe and back to cooling pipe.

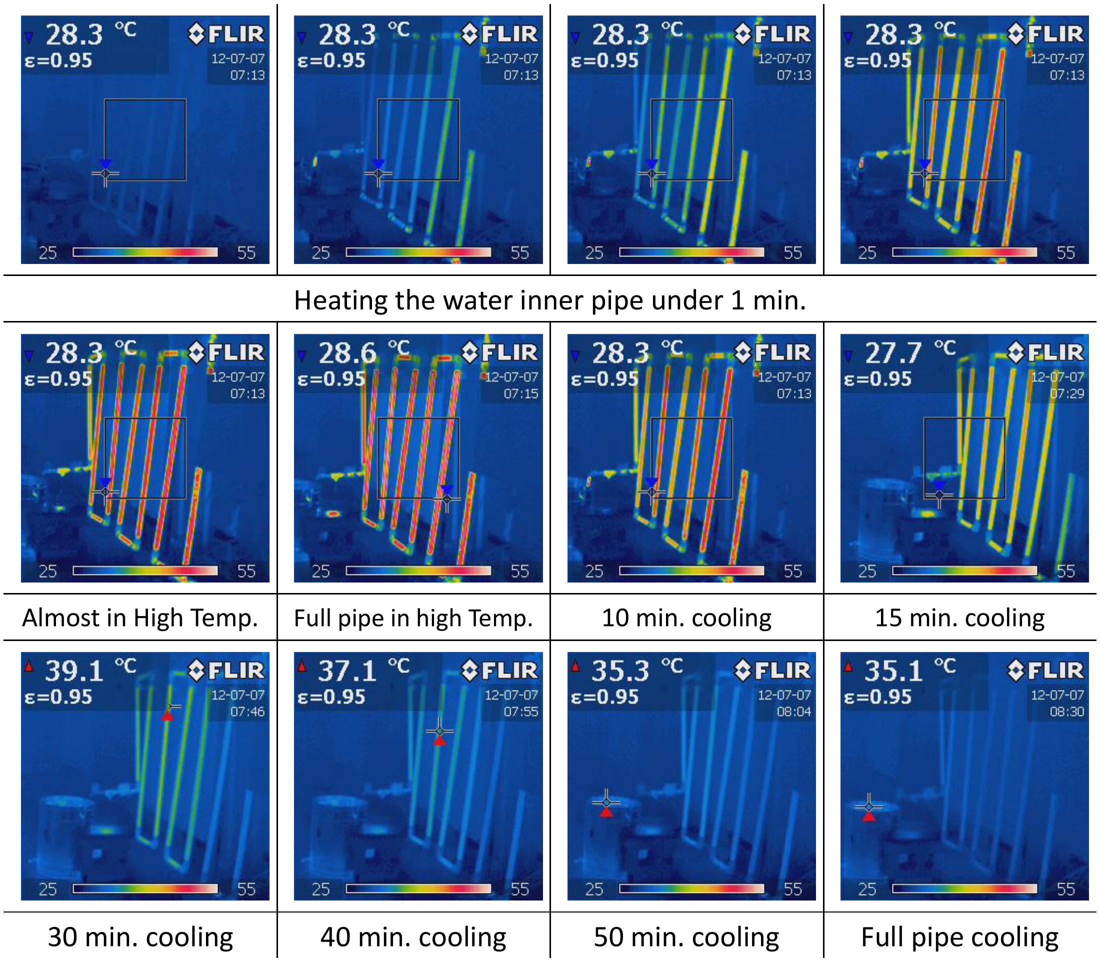
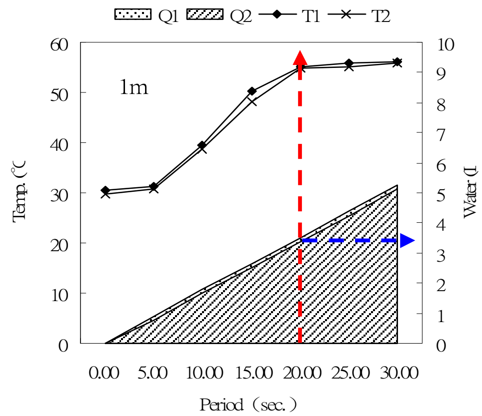


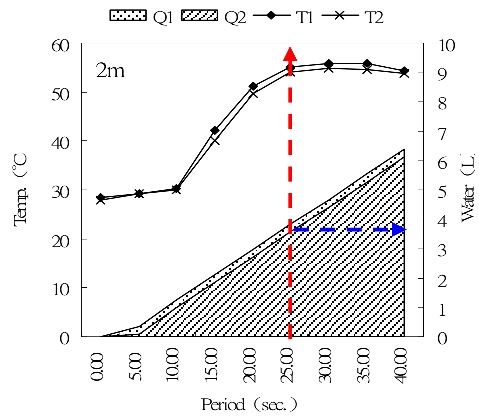
Fig. 6 Temperature various by Infrared thermal capture

4. Results

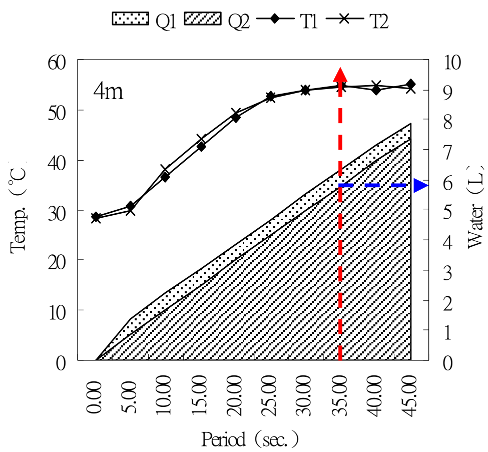
Due to discuss the energy consumption and water waste, the experiment results focus on the temperature various and water demand between heater outlet (T1, Q1) and faucet inlet (T2, Q2) in the non-circulation system, as shown in "Fig. 7". Based on the diagrams, the heating duration time is checked by the flowing out hot water temperature (T2) over 54℃ in different length transmission pipe, as marked by red lines on the diagrams. The red lines cross the two water demand volumes (calculated by flowing velocity and duration time) in heated water volume (Q1) and flowing out water volume (Q2), the volume difference between Q1 and Q2 is the remained water on the transmission pipe. Therefore, the flowing out water is the waste water in this system, as shown on the blue lines in the "Fig. 7". All related results with water waste and energy consumption in the non-circulation system are summarized on the Table 3.



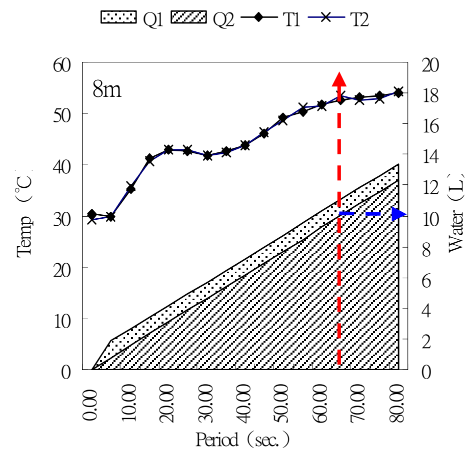
Test results of 1 meter pipe length



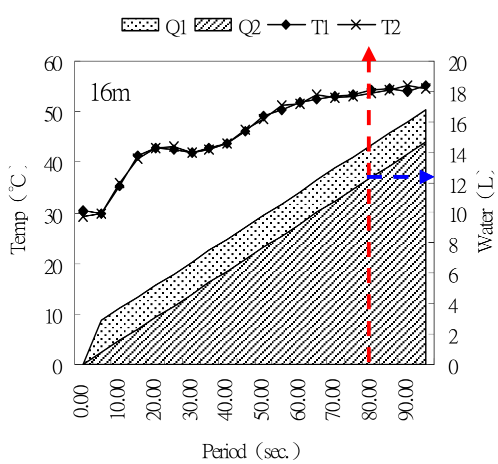
Test results of 2 meter pipe length



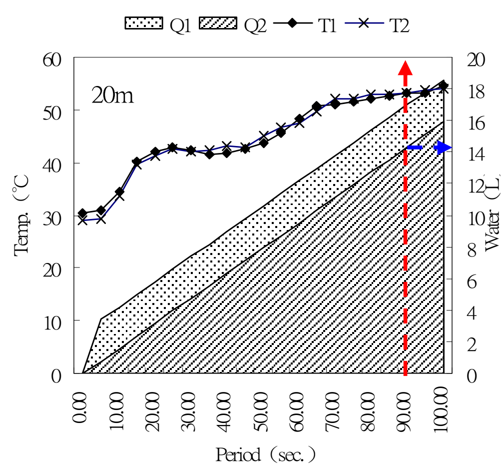
Test results of 4 meter pipe length



Test results of 8 meter pipe length



Test results of 16 meter pipe length



Test results of 20 meter pipe length

Fig. 7 Temp. various and water volume of heating water in non-circulation system

Table 3 Water demand and energy consumption in the non-circulation system

Pipe Length	Temperature	Period time	Wasted water (Q2)	Heated water (Q1)	Gas Consumption	Heater power
m	℃	*sec.*	*l*	*l*	*g*	*Wh*
1	54.78	20	3.3848	3.5175	9.1	1.8
2	54.12	25	3.5636	3.8291	11.2	2.2
4	54.37	35	5.8108	6.3417	15.3	3.1
8	54.08	65	10.0236	11.0855	27.8	5.8
16	54.03	80	12.3424	14.4661	34.0	7.1
20	54.14	90	14.3196	16.9742	38.1	8.0

Recycling and reheating the temperature dropped water by intelligent hot water circulator saves the waste water inner transmission pipe. Only electronic power consumption of circulator is added in the circulation system, the total power consumption combines the power consumption of heater and circulator, as shown in Table 4.

Table 4 Energy consumption in the circulation system

Pipe Length	Circulation Period time	Gas Consumption	Heater Power	Circulator Power	Total Power
m	*sec.*	*g*	*Wh*	*Wh*	*Wh*
1	13.0	8.8	1.2	1.3	2.5
2	15.0	10.2	1.3	1.5	2.8
4	20.0	11.9	1.8	2.0	3.8
8	30.0	16.6	2.7	3.0	5.7
16	55.0	25.8	4.9	5.5	10.4
20	60.0	31.0	5.3	6.0	11.3

5. Discussion

Compare the total efficiency of non-circulation system and circulation system. The circulation system is not only saves the water, but the gas consumption is also less than the non-circulation system because of speeding the circulation period to effect the heating performance and decrease the heater operation time, as shown in “Fig .8”. The power consumption of the circulation system in the short pipe is similar to it of the non-circulation system, but the circulator consumes much energy in long pipe by the increasing of piping friction and water mass.

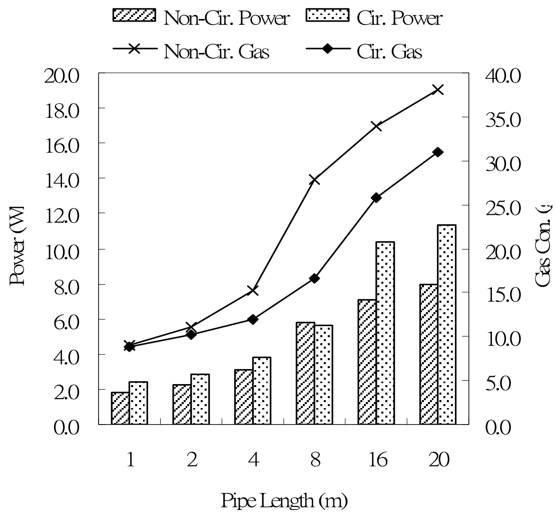


Fig. 8 Consumption of power and gas between non-circulation and circulation system

According to Cheng (2002) proposed "1m^3 water consumes about 1kWh equivalent power". The non-circulation system discharges the temperature dropped water inner pipe to waste water in different pipe length. If the water waste transfers into the equivalent power and adds it into the heater power consumption, the result shows the total energy consumption of the non-circulation system is 50% higher than the energy consumption of the circulation system in "Fig. 9". This system not only saves water, but also saves the energy within the system.

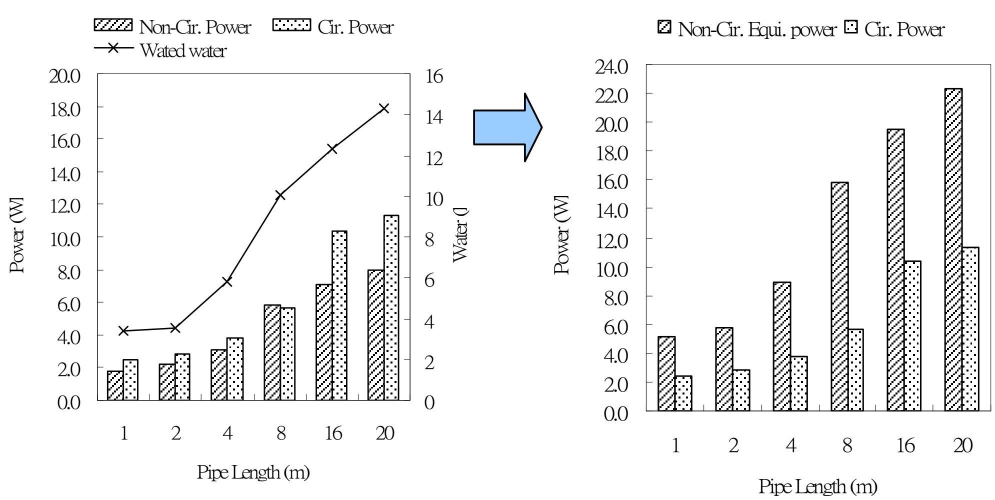


Fig. 9 Water waste transfers into equivalent power to compare the total power consumption between non-circulation and circulation system

6. Conclusion

The experiment results show that the circulation system not only saves water demand but also saves gas consumption because of speeding the circulation period to effect the heating performance and decrease the heater operation time. Although the circulator consumes a little bit higher energy than it in non-circulation system, reducing the energy consumption via the high efficiency pump is the solution.

The power consumption of the circulation system in the short pipe is similar to the power consumption of the non-circulation system, but the circulator consumes much energy in long pipe by the increased piping friction and water mass.

If the water waste transfers into the equivalent power and adds it into the heater power consumption, the result shows the total energy conservation of the circulation system is about 50% higher than the energy consumption of the non-circulation system. This system not only saves water, but also saves the energy within the system.

7. Acknowledgement

The author great thank Taung Liang Industries Co., Ltd to support the technical direction and financial to improve this intelligent hot water circulator.

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Creation of Carbon Credits by Water Saving

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Abstract
Until now, as a way of reducing greenhouse gas emissions from Japanese homes, the emphasis has been on reduction of energy consumption for air-conditioning and lighting. In recent years, there has been progress in CO_2 emission reduction through research into the water-saving performance of bathroom fixtures such as toilets and showers. Simulations have shown that CO_2 emissions associated with water consumption in Japanese homes can be reduced by 25% (1% of Japan's total CO_2 emissions) by 2020 through the adoption of the use of water-saving fixtures. In response to this finding, a program to promote the replacement of current fixtures with water-saving toilet bowls and thermally insulated bathtubs has been added to the Government of Japan's energy-saving policy. Furthermore, CO_2 emission reduction through widespread use of water-saving fixtures has been adopted by the domestic credit system promoted by the Government of Japan as a way of achieving CO_2 emission-reduction targets; application of this credit system has also begun. As part of a bilateral offset credit mechanism promoted by the Government of Japan, research to evaluate the CO_2 reduction potential of the adoption of water-saving fixtures has been done in the city of Dalian, in China.

Keywords
global warming; CO_2 reduction; water; saving-water; Japan

1. Introduction
Japan is now in the first commitment period (2008 to 2012) of the Kyoto Protocol, and has assumed responsibility for a 6% reduction in greenhouse gas (described as CO_2 below) on the basis of emission in 1990. Under the present circumstances, although a 4.1% reduction in total emissions is being achieved owing to the effort in industrial world, emissions from the housing sector are increasing by no less than 26.9%. Hence,

measures to reduce emissions from the housing sector have become important for promoting future CO_2 reduction [1]. Therefore, measures were implemented for cars and home appliances, which contribute the most to the CO_2 emission from the housing sector. In order to promote the replacement of conventional appliances with environmentally friendly cars and energy-saving home appliances and lighting, tax reduction and replacement subsidies, known as home appliance Eco-points, have been introduced. In recent years, research relating water-saving performance of bathroom fixtures such as toilets and showers with CO_2 reduction has progressed, and the fact that the widespread use of water-saving fixtures can be effective in CO_2 reduction has been recognized. Hence, housing Eco-point subsidies have been introduced to promote the replacement of traditional toilets with water-saving ones.

The method of reducing CO_2 using water-saving fixtures was adopted in the domestic credit system, which is one of the techniques used in Japan to achieve the targets for reduction of CO_2 emissions. Using the bilateral offset credit mechanism, the potential for CO_2 reduction by using water-saving fixtures was evaluated in China. Recent studies on the effect of water saving on a global warming and an example demonstrating the application of the carbon credits related to water saving are outlined.

2. Carbon Credit

A credit indicates trust, and a carbon credit is the proof of the amount of reduction in CO_2 emissions. Carbon credits are specified in the Kyoto Protocol adopted by the Framework Convention on Climate Change. In a developed country with a greenhouse gas (GHG) reduction target (i.e., allowance amount), the carbon credit system is one in which credits can be traded and can offset the CO_2 emissions that cannot be reduced only by efforts in the country of origin. The United Nations validates the credits; some credits receive certification from an accredited independent entity, and some from the government of their own country. These carbon credits have been designated as the clean development mechanism (CDM), which has obtained recognition from the United Nations. There also exist the domestic CDM credit (Ministry of Economy, Trade and Industry recognition) and the J-VER credit (Ministry of Environment recognition), which has been certified as a domestic system by the Government of Japan.

CDMs are GHG emission reduction projects carried out in developing countries that are not burdened with the targets related to allowance amount, such as use of renewable energy and energy-saving measures. The credit is defined as the reduction in emission caused by implementation of a project, relative to the amount of emission with no project (the baseline emission). The outline is shown in Fig 1.

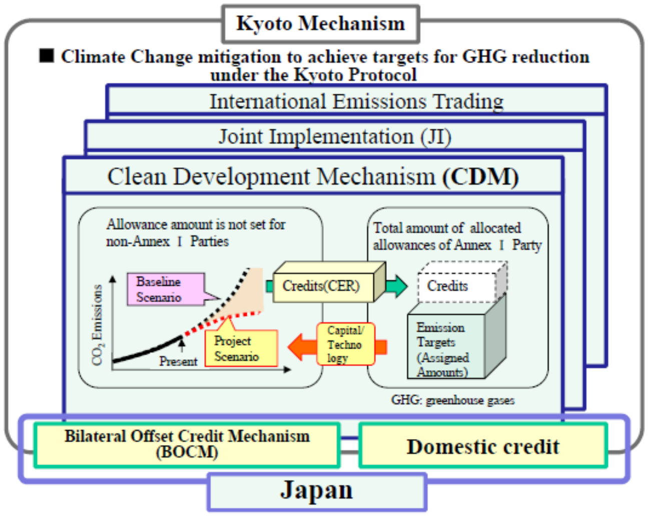


Fig 1. Outline of Carbon Credit

The number of projects registered with the U.N. CDM executive board was 3,933, as of March 2012. The sum total of the predicted reduction in emissions reached a quantity equivalent to 2% of the total amount of the global CO_2 emission, and many projects are underway in developing countries such as China, India, and Brazil [2]. The registration project classifications are shown in Fig 2. CDMs are focused on energy fields with the potential for large CO_2 reductions.

After the first commitment period (from 2008 to 2012) of the Kyoto Protocol, the 17th U.N. Framework Convention on Climate Change meetings were held in Durban, South Africa, and it was decided to continue the emission reduction measures. Simultaneously, aside from the Kyoto Protocol, a new mechanism is being tested, and it will be implemented by 2020.

CDMs require strict verification. Therefore, many verification data and measurements are required as proofs of a project. The complicated natures of procedure and cost factors have constrained the application of CDMs in developing countries.

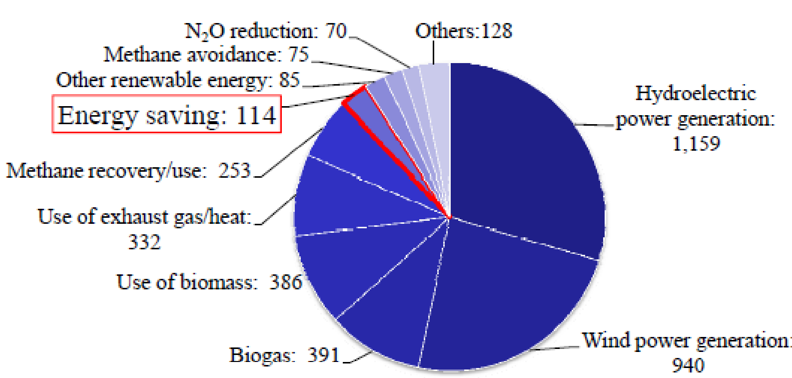


Fig 2. Projects registered in the UN CDM Executive Board

The new mechanism was proposed as a solution. For quick reduction in GHGs, rules based on the situation of each country are more effective than a globally enforced uniform rule, formulated by the U.N. (e.g., a CDM). Therefore, Japan has proposed the following. “Japan can provide developing countries with the technology, products, systems, infrastructure, etc. that contributes to GHG emission reduction, and the two countries can conduct a collaborative project. Thus, GHG emission reduction helps achieve a medium-term goal for Japan.” This new mechanism is called a bilateral offset credit mechanism (BOCM), and many feasibility investigations have already been carried out since 2010 [3].

3. Research Associating Water Consumption and CO_2 Emission

The relationship between water consumption and CO_2 emission is indicative of the energy consumption in the infrastructure for waterworks and sewer systems, as shown in Fig 3. The environmental housekeeping book in 1996 states that water consumption per 1 m^3 was equivalent to emission of 0.59 kg of CO_2 [4]. However, it was revised to include only the value of the waterworks and no further study was carried out.

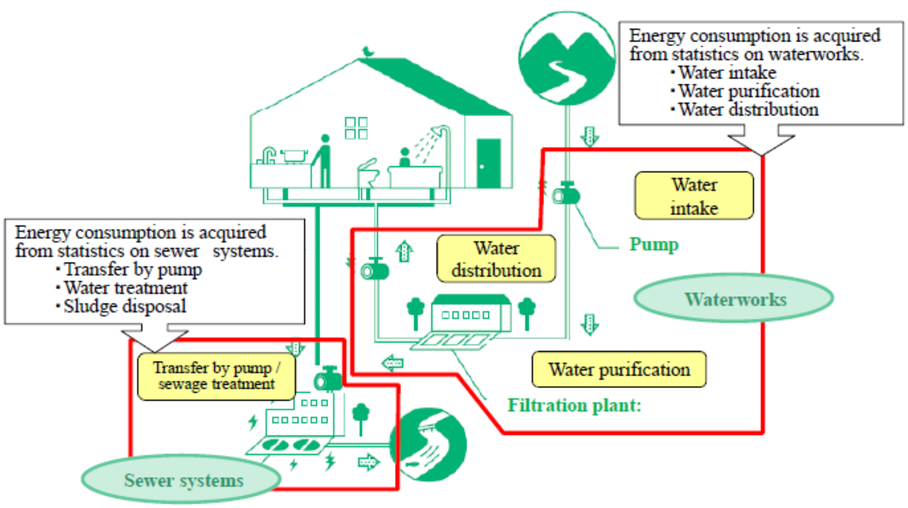
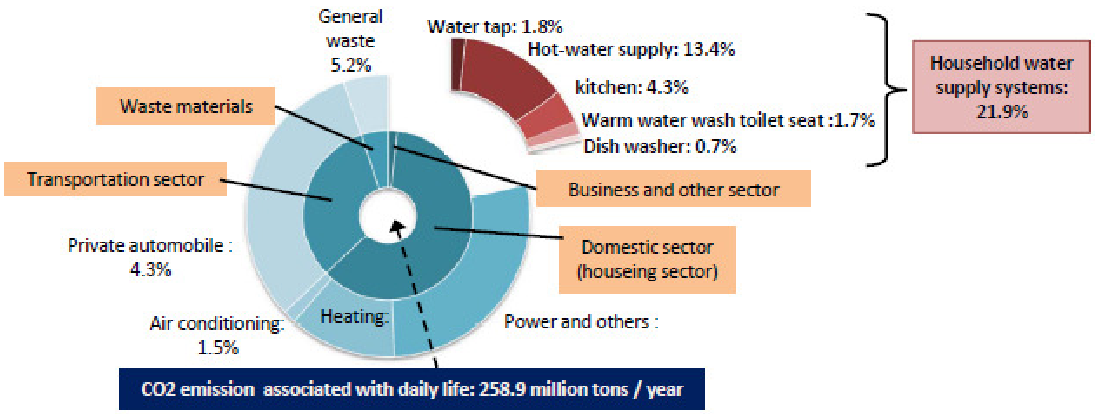


Fig 3. Calculation boundary for CO_2 emission factor of water

At the Ministry of Environment, the amount of CO_2 emission was classified and announced officially as GHG inventory data [5]. CO_2 generated in power plants by energy consumption is divided proportionally by end use as CO_2 emission from electric power consumption. For example, CO_2 discharged by electric power consumption at home is referred to as the housing sector end use. This stimulates energy saving by the end users.

However, CO_2 emission attributed to water was classified for other sectors as emission from energy consumption in the waterworks and sewer systems, and users were not urged to carry out water-saving measures. Therefore, domestic awareness of the effectiveness of water-saving measures in combating global warming was low.

Therefore, we started estimating the amount of CO_2 emission originating from residential water use in our country. It was found that CO_2 emissions originating from residential water use (including heating of water) comprise up to 5% of the total CO_2 emission of Japan [6]. The breakdown of CO_2 emissions from Japanese houses are shown in Fig 4.



[Note] CO_2 emissions from the warm water wash toilet seat and the dish washer reported in the "electricity use by equipment at home for FY2005 were added to CO_2 emissions from water supply systems and reconstructed as CO_2 emissions from Japanese houses.

Fig 4. Breakdown of CO_2 emissions from Japanese houses in Japan[1)]

It turned out that this is the third major source, following cars and home appliances. Hitherto, the energy-saving measures in the housing sector had concentrated on cars and home appliances. Owing to the result of this research, residential plumbing systems have gained attention.

Moreover, simulations were carried out to study the possible reduction of CO_2 emissions originating from residential water use [7]. The results showed that a 25% reduction of such CO_2 emission (1% of the total emission of Japan) can be achieved by 2020 through a combination of development of water-saving fixtures for industry, increased administrative support for the widespread use of these fixtures, and efforts to increase users' awareness of water-saving measures. A simulation result is shown in Fig 5.

The simulation research indicated that the widespread use of water-saving fixtures was effective in reducing CO_2 emissions from the housing sector. Owing to these research results, a replacement subsidy called housing Eco-point has been realized in Japan since 2010.

Thereafter, the development of methods for promoting the widespread use of water-saving fixtures was investigated. As a part of these measures, we aimed at realizing a domestic carbon credit system for water-saving fixtures.

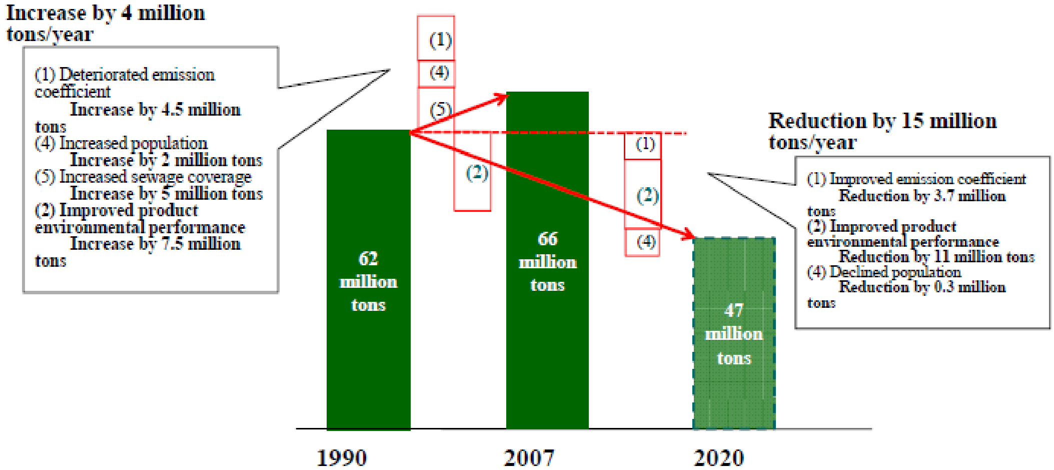


Fig 5. Estimated CO_2 emissions derived from water usage for residential fixtures

A credit is calculated by converting the reduction in use of water and hot water (as a result of the use water-saving fixtures) into the amount of CO_2 that would be saved. A credit can be exchanged for money. Thus, precise determination of the CO_2 emission factor for water is necessary for realizing the credit system.

The CO_2 emission factor of water can be determined from energy consumption and the amount of treated water in waterworks and sewer systems. Electricity contributes about 90% of the energy consumed in these systems. The CO_2 emission factor for electricity has changed annually, as shown in Fig 6. Therefore, the use of a fixed value (0.59 kg-CO_2/m^3 of water), as shown in the environmental housekeeping book, is considered unsuitable.

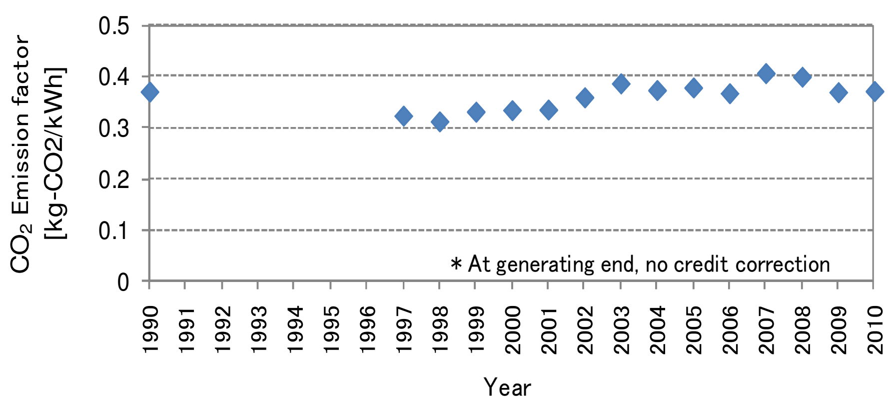


Fig 6. CO_2 emission factor of electricity[8)]

The operation management data for the waterworks and sewer systems in Japan are reported as the statistics of waterworks and the statistics of sewer systems each year. Using these data, CO_2 emission factors of water were calculated by year as average values for the whole of Japan [9]. The results are shown in Fig 7. A study of these results allowed clarification of the relationship between water and CO_2 emission and allowed recognition of the methodology of applying carbon credits to water-saving fixtures in December 2011 [10].

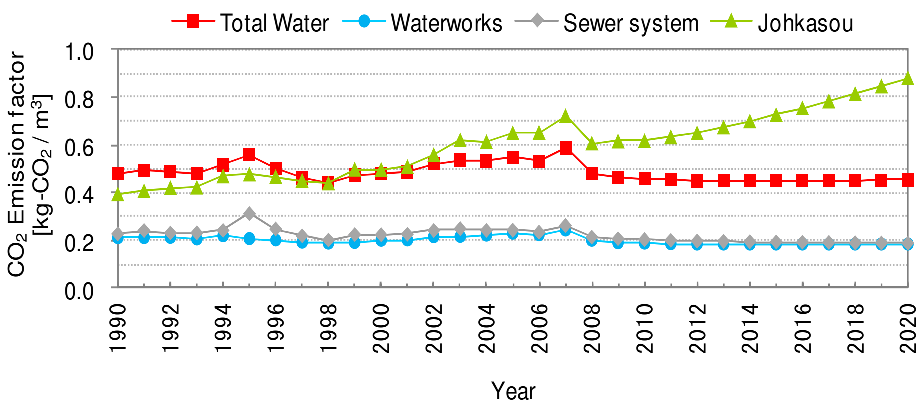


Fig 7. CO_2 emission factor of water

043: Replacement with Water-efficient Housing Equipment
043-A: New Installation of Water-efficient Housing Equipment

The scheme is shown in Fig 8. By adopting a domestic credit system, CO_2 reduction from saving water became a measure that can contribute to the management of Japan's CO_2 reduction target.

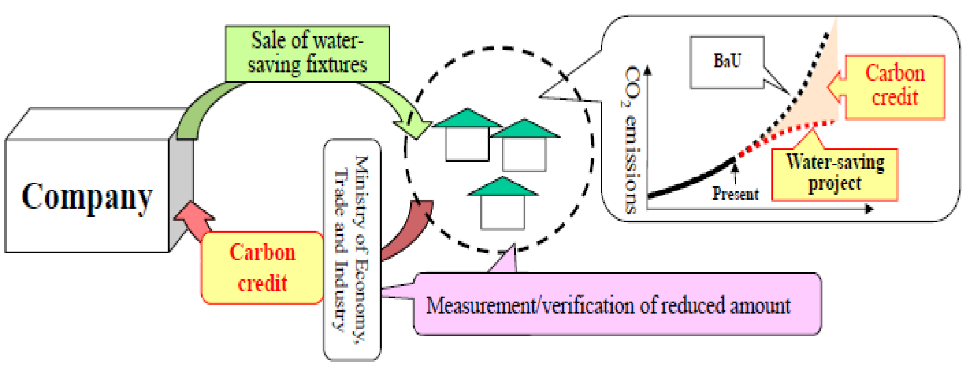


Fig 8. Domestic carbon credit scheme for water saving fixtures

4. Credit Project Using Water-saving Fixtures in Japan

The introduction of the water saving into the credit system represented a global first. In response to the approval of this methodology, a program-type reduction project (one-by-one additional participation) was proposed; this project was started by TOTO, LTD in March 2012 (Fig 9) [10]. In the case of a four-person family, a 3.8 L flush toilet bowl and 6.5 L/min air-in shower could provide annual CO_2 reductions of about 23 and 112 kg, respectively. A credit verifies the effect for each defined period after installation of the fixtures, and is published for each usable year of them. This will contribute to Japan's CO_2 reduction target during these years. Henceforth, subsidies will be expected to be linked with the credit. A user's CO_2 reduction efforts are rendered visible by the credit program.

This will lead to an upsurge in the users' environmental awareness, and it is expected that a virtuous circle of domestic CO_2 reduction will arise.

The present methodology targeted toilet bowls, showers, and bathtubs; an extension of the methodology to other fixtures is also being planned.

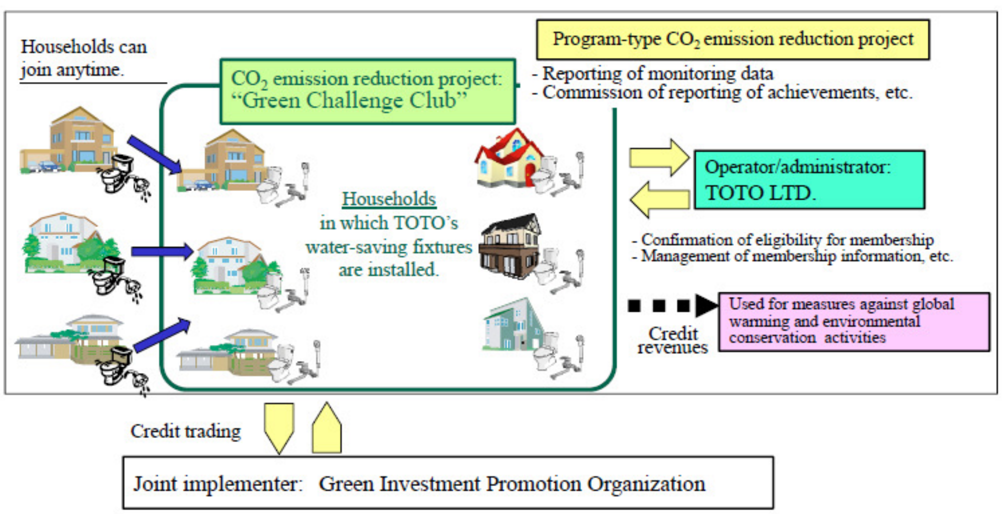


Fig 9. Outline of water-saving credit project in Japan

5. Deployment to Asia of Water-saving Credit

As part of the feasibility study program on new mechanisms carried out by the Global Environmental Centre Foundation, CO_2 reduction potential evaluation by the adoption of water-saving fixtures has been conducted in the city of Dalian in China under the title "Feasibility study of new energy-saving mechanism associated with reduction of water consumption by diffusion of water-saving hygiene devices in Dalian, China." The evaluation was conducted in 2011 fiscal year as a joint research project of Mitsubishi UFJ Morgan Stanley, Kitakyushu City, Meiji University, and TOTO.

The feasibility of applying the evaluation method developed in Japan for Dalian was examined. The evaluation formula is shown in Fig 10. The CO_2 emission factor of water was calculated from the operation management data of the waterworks and sewer systems of the evaluation region. The water-saving performance improvements due to application of the high-efficiency fixtures were given as the differences in performances between currently used or generally sold versions and the project version. These can be studied by conducting interviews in stores, visiting houses, etc. A usage model of the fixtures, such as the number of times a toilet is used, the flow rate of a shower, water temperature, and operating time, can be determined by statistical analysis of measurements and from a questionnaire for residents.

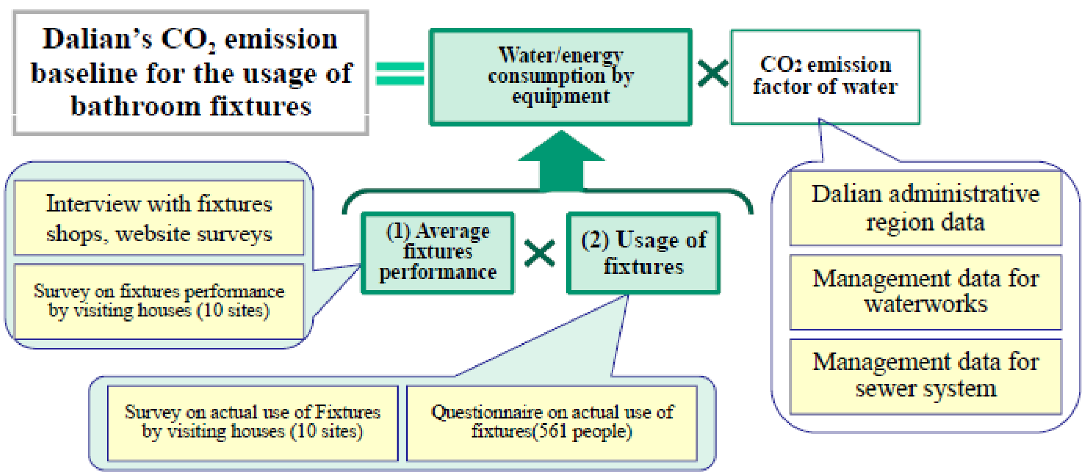


Fig 10. Potential assessment in Dalian

In the case of Japan, the baseline for evaluation was a stock-type society where construction of infrastructure, such as waterworks, sewer systems, and buildings, had almost been completed. The valuation modeling was set up as the replacement for the stock fixtures to latest one. On the other hand, modernization and city extension are being carried out in Dalian. Therefore, potential evaluation was carried out by setting up a baseline that also considered a situation where the infrastructure was being developed, corresponding to an increase in population.

The CO_2 emission factor of the water in Dalian was about 3 times that in Japan because of the high CO_2 emission factor of electricity. Further, large potential for CO_2 reduction by the widespread use of water-saving fixtures was confirmed.

Thus, the evaluation method developed in Japan was found to be applicable to a developing country. Rapid modernization and urbanization are occurring in Asian nations. Therefore, the accompanying rise in water consumption and CO_2 emission are serious issues. The widespread use of water-saving fixtures has good potential to decrease the impact of these issues. Thus, water-saving-related study will progress from the feasibility study stage to the establishment of a credit system for the Asian region and the actualization of the credit project in Asia, by means of a bilateral offset credit program.

6. Future View

Water saving was found to be effective for solving problems related to the shortage of water resources as well as issues related to global warming. Increased user awareness and administrative support are important for realizing water saving. In order to involve the users and administration, it is important to share a future image realizable by water saving. The Japanese estimation method for contribution potential for water-saving in order to develop a future plan was found to be applicable in China as well.

Therefore, an Asian Saving Water Council was established in December 2011 to promote joint research to evaluate the contribution potential of water saving for each Asian country [11]. The representatives of each country are introduced in Table 1. At the Asian Saving Water Council, construction of the standard for the fixtures, policy proposals, and social education are also discussed.

Table 1. Organization of the Asian Water Saving Council (for 2011 & 2012)

Chairman:
Kyousuke Sakaue (Japanese representative member: Professor at Meiji University)

Vice-Chairman:
Li Zhao (Chinese representative member: Vice-President of China Architecture Design & Research Group)

Managers:
Dong-hoon Lee (Korean representative member: Professor at the University of Seoul)
Cheng-Li Cheng (Taiwanese representative member : Professor at National Taiwan University)
Ling-Tim Wong (Representative member of Hong Kong : Associate professor at the Hong Kong Polytechnic University)
Akihiko Iio (Japanese vice-representative member: Professor at Japan Women's University)
Motoyasu Kamata (Japanese member: Emeritus Professor at the University of Tokyo)
Saburo Murakawa (Japanese member: Professor at Hiroshima University)
Yasutoshi Shimizu (Director General)
Kanako Toyosada (Vice Director General), etc.

As an extension of this discussion, an Asian Saving Water Council symposium was held at Meiji University in December 2011, supported by the Ministry of Land, Infrastructure, Transport and Tourism, the Ministry of Economy, Trade and Industry, and the Ministry of Environment. The necessity for water saving in Asian countries and a policy for future action in the Council were discussed at the symposium [12].

The Asian Saving Water Council promotes water-saving-related research in each country. A bilateral offset credit program is utilized for intergovernmental negotiations on policy adjustments. As a result of these projects, a water-saving society has been developing in Japan and spreading to Asia, as shown in Fig 11.

It is expected that the formation of this water-saving society will be promoted by the participation of many researchers.

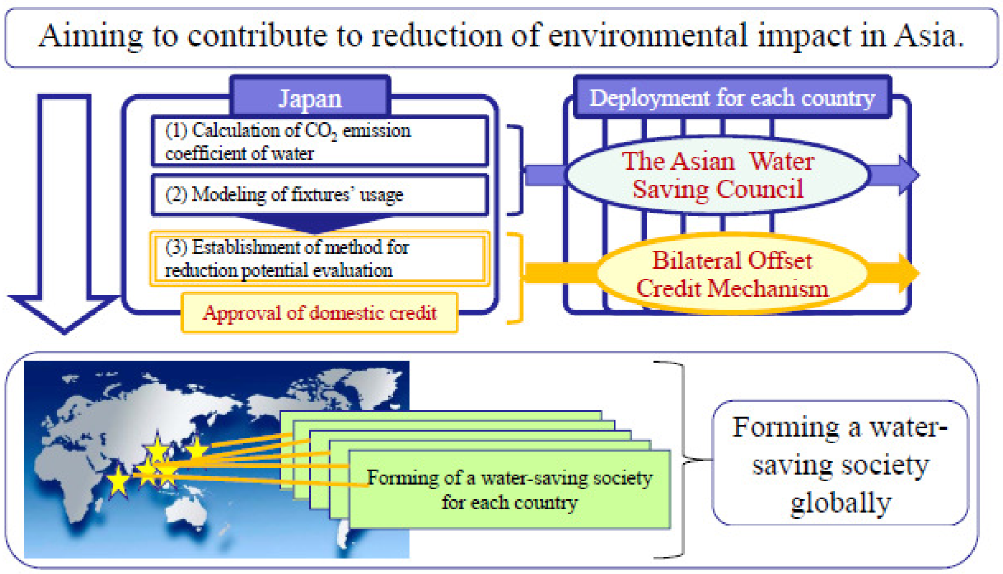


Fig 11. Concept of global deployment of water-saving studies

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Evaluation of the potential of CO_2 emission reduction achieved by using water-efficient housing equipment in Dalian, China

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Abstract
Introduction of water-efficient housing equipment leads to a reduction in electricity and fuel consumption for operating water supply and sewerage systems, and thus contributes to a reduction in GHG emissions. The authors have computed the average CO_2 emission factor associated with water use in Japan, but to the best of the authors' knowledge, such investigation has been carried out in a few countries. In this study, the city of Dalian in China was selected for a case study, and the CO_2 emission factor associated with water use here was computed from the quantity of water treated and the energy consumed at the water systems in Dalian. Next, the use model of the residential plumbing equipment was set up on the basis of a survey on water use in ordinary homes. The CO_2 emission reduction achieved by the widespread adoption of water-efficient housing equipment was calculated. On the basis of this calculation, the authors speculate that a maximum reduction of 16,000 t-CO_2/year can be achieved by the widespread adoption of water-saving toilets.

Keywords
Dalian, Saving-water, Plumbing Equipment, CO_2 reduction, CO_2 Emission Factor

1 Introduction
In a number of Asian nations, including China, the problem of water shortages is becoming more and more serious due to the continued growth in demand for water in concurrence with population increases and rapid economic growth. Water-saving measures are, in addition to the preservation of water resources, directly connected to a reduction in the amount of power required to operate water supply and sewerage

systems. They thus also contribute to the reduction of greenhouse gases or GHGs (hereafter referred to as CO_2 by using CO_2 as a representative) as a result. Such measures are attracting attention as actions with co-benefits, or multiple effects.

As a flexibility mechanism to address the CO_2 reduction objective in the Kyoto Protocol, the Kyoto Mechanism has been adopted. Under this mechanism, emission permits purchased from other countries and CO_2 reductions implemented in other countries can be considered CO_2 reductions of another country if its CO_2 emissions exceed its allocated emission level. The Japanese government has proposed to the international community the Bilateral Offset Credit Mechanism as a new system added to the Kyoto Mechanism. Under this system, CO_2 reductions achieved by providing advanced technologies, products and so forth from Japan to a developing country and implementing projects jointly can be counted as part of Japan's CO_2 reductions.

As a feasibility study for the Bilateral Offset Credit Mechanism, the Ministry of the Environment in Fiscal 2011 conducted a "New mechanism feasibility study for energy saving by reducing water consumptions through diffusion of water-efficient toilet systems to households in Dalian,China" as a joint research project by government, industry and academia.[1)] This article reports on the results of an evaluation of the CO_2 reduction potential implemented as a part of this project.

2 Calculation method

In this study, we compared a scenario in which the latest water-saving toilet bowls, utilizing the highly advanced water-saving technology of Japan, are introduced into residential households in the city of Dalian (hereafter referred to as the Project Scenario) and another scenario in which the project is not implemented (hereafter referred to as the Reference Scenario). We then conducted a calculation of the CO_2 reduction potential as the different between these two scenarios (**Fig.-1**).

First, we developed the Reference Scenario by conducting a door-to-door survey of 10 residential households and a survey on toilet dealers in the city of Dalian. The outline of

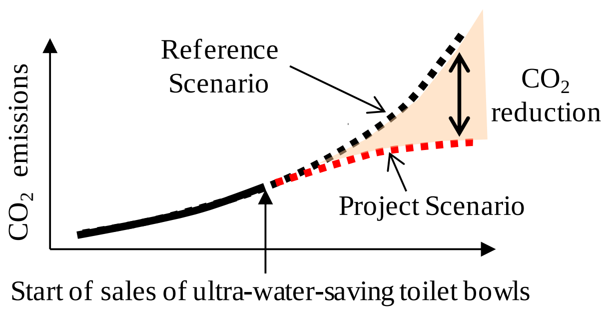

Fig. 1 Concept of CO_2 reduction potential

the door-to-door survey is presented in **Table-1**. Next, we developed the usage model for toilet bowls (the number of flushing times) by conducting a questionnaire survey regarding the use of water in residential households (**Table-2**). The CO_2 emission factor associated with water use was calculated based on the amount of water treated for water supply and sewerage systems in Dalian and the amount of electricity and fuel required for the treatment. The CO_2 reduction effect resulting from the widespread adoption of the latest water-saving toilet bowls was calculated by these results.

Table 1 Outline of door-to-door survey

No	Dates implemented	Number of family members [people]	Form of residence	Age of building [years]	Footprint [m^2]	Location
1	Oct. 10 – 12, 2011	4	Owned/apartment	15	70	Xigang, Dalian
2		4	Owned/apartment	5	159	Shahekou, Dalian
3		5	Owned/apartment	8	68	Ganjingzi, Dalian
4		4	Owned/apartment	2	70	Development Zone, Dalian
5	Oct. 29 – 30, 2011	3	Owned/apartment	5	145	Shahekou, Dalian
6		5	Owned/apartment	4	180	Shahekou, Dalian
7		2	Owned/apartment	10	70	Shahekou, Dalian
8		2	Owned/apartment	0	63	Shahekou, Dalian
9		3	Owned/apartment	18	64	Ganjingzi, Dalian
10		1	Rented/apartment	0.5	85	Ganjingzi, Dalian

Table 2 Outline of questionnaire survey

Dates implemented	Sept. 26 – Oct. 11, 2011
Subject of survey	Residential households in the city of Dalian (Jinzhou New District, Development Zone, Ganjingzi, Dalian Hi-tech Zone, Shahekou, Xigang, and Changhai)
Survey method	Questionnaire survey (forms were distributed to households and collected via mail.)
Number collected	561 respondents (237 households)
Survey details	Items regarding the use of residential plumbing equipment - Attributes of respondent - Facts regarding toilet usage (Whether full/half flushing volumes are used, number of eliminations inside and outside of the household on weekdays and holidays, number of flushing times, reason for flushing multiple time, method of cleaning up after elimination)

3 Results and discussion

3.1 Reference Scenario

A door-to-door survey of 10 residential households showed that toilet bowls with 6-L (full) and 3-L (half) flushing volumes—the volume of water used per flush—were used in 8 households, and 6-L bowls for single flush were used in 2 households. According to a survey of toilet dealers, the 6-L (full)/3-L (half) bowls were the most popular. In addition, 9-L (full)/6-L (half) bowls were available at reasonable prices. Few bowls with capacities of 5-L or less (full flushing) were sold.

The GB25502-2010 national standard for toilet bowls in China, which was announced in 2010, classifies the water efficiency of bowls into 5 categories (**Table-3**), specifying Class 5 as “standard” and Class 2 or lower as “water saving.” On the basis of these survey results, we set up the Reference Scenario as shown in **Table-4**. The Project Scenario was set up as per the latest model in Japan, and is also shown in the table.

3.2 Water-use model

(1) Attributes of the respondents

The attributes of the respondents to the questionnaire survey (**Table-2**) are shown in **Fig.-2**. We received responses from a wide range of age groups, centering on the working population in their 20s to 30s. The gender ratio was equivalent to that of the working population, and the fact that many households had two incomes was discovered. The average number of people per household was 2.4 people/household, which was slightly smaller than the average for Dalian (2.9 people/household).[2)]

Table 3 Toilet flushing standard under GB25502-2010[L/time]

Standard	Class 1	Class 2 (water-saving)	Class 3	Class 4	Class 5 (standard)
Full flushing volume	4.5	5.0	6.5	7.5	9.0
Half flushing volume	3.0	3.5	4.2	4.9	6.3

Table 4 Bowl flushing volume for each scenario

	Reference flushing volume	Project flushing volume
Full	5 L	3.8 L
Half	3.5 L	3 L

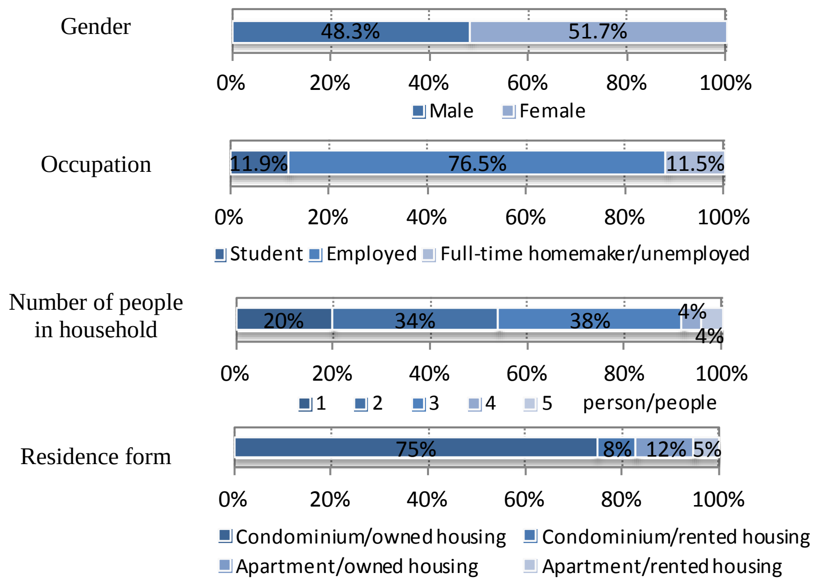

Fig. 2 Attributes of respondents

(2) Usage of toilet bowls in homes

We asked the survey participants if they used dual flush in their toilet bowls at home, and found that around 70% did. The results for those who used bowls with different flushing volumes when questioned as to which volume they used for defecation and urination are shown in **Fig.-3**. We learned that toilet bowl manufacturers designed the bowls by assuming the use of a full flushing volume for defecation and a half volume for urination, and that approximately 80% of users used the bowls in accordance with this design concept.

Measures taken to clean up after elimination are shown in **Fig.-4**. While “wiping with paper and throwing it into the bowl” and “washing with water or warm water (when a warm-water bidet function is provided)” were popular in Japan, the ratio of “wiping with paper and throwing it into a trash bin” was high in this survey. It was found that throwing used paper into trash bins, which is not a very sanitary measure, was commonplace. It was also found that the survey participants do not dispose of used paper in toilets bowls, or that sometimes flush the toilet twice, because the performance of the toilets bowls (excrement flushing and draining performance) is not satisfactory.

The total number of eliminations per person per day (total for both defecation and urination) is about 8 on average on both weekdays and holidays, which is nearly equivalent to survey results in Japan.[3)] We conducted a correlation analysis of the total number of eliminations according to the attributes of the respondents using quantification method I, and no significant differences were found.

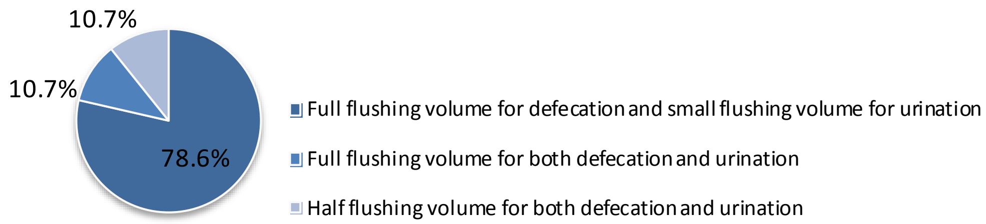

Fig. 3 Use of full/half volume flushing lever

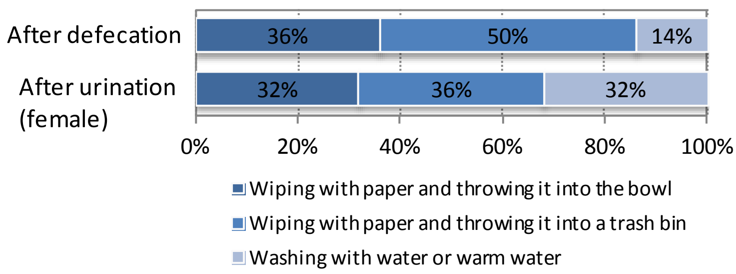

Fig. 4 Cleaning up after elimination

The results of the correlation analysis of the number of eliminations on weekdays inside and outside of the home are shown in **Table-5**. The average number of eliminations at home on weekdays was 4.6, which was slightly larger than that for outside at 3.3 eliminations. There was a high correlation according to occupation for eliminations both inside and outside the home with a significant difference the two.

In answer to the question how many times on average they flushed the toilet per use, more than 70% replied “once,” and the resulting average was 1.25 times (**Fig.-5**). When asked the reason as to why they flushed multiple times, more than 60% replied “because the bowl does not clear with one flush" (**Fig.-6**). As described earlier, this seems to be the result of the poor performance of the toilet bowls in excrement flushing and draining. To standardize the number of flushing times based on the model of the number of eliminations, we made corrections based on the difference in type of elimination and flushing volume. Although based on the assumption that a "full flushing volume" is used for defecation and a "half flushing volume" for urination, we included the value for "number of full flushings for urination" in the "full flushing volume" for each category in consideration of the percentage of people who use a full flushing volume for urination. This "number of full-volume flushings for urination" was calculated by multiplying the number of urinations inside and outside of the home by occupation as shown in **Table-6** by 0.11, which was the rate of use of the full flushing volume for urination (**Fig.-3**). However, it was decided that the reply for "using a half flushing volume for both defecation and urination" would not be taken into consideration in this calculation as it may cause pipe blockages due to an insufficient volume of water to carry away the excrement.

We calculated the number of flushing times for various occupation by multiplying the number of flushing times for both defecation and urination calculated above by the average number of flushing times per elimination (use of toilet) (**Fig.-5**): 1.25 times (**Table-6**).

Table 5 Results of correlation analysis on number of eliminations on weekdays

Attribute		Inside household		Outside household	
		Partial correlation factor	Average [times/person・day]	Partial correlation factor	Average [times/person・day]
Total			4.6		3.3
Gender		0.04		0.00	
Age		0.26		0.21	
Occupation	Student	0.46	4.7	0.45	3.5
	Employed		4.3		3.7
	Full-time homemaker/unemployed		6.9		0.9

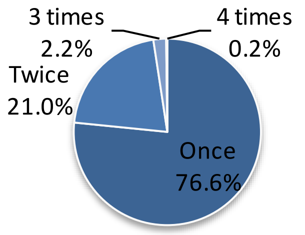

Fig. 5 Number of flushing times
(times/per toilet use)

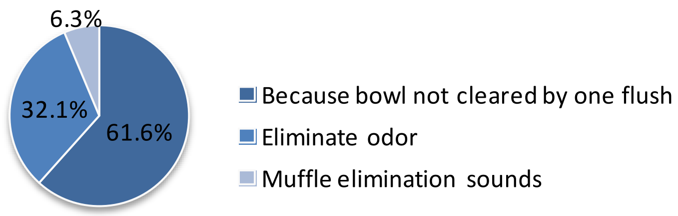

Fig. 6 Reason for flushing multiple times

We included the effect of the reduced number of double flushings as the result of the improved transport performance of drainage water arising from the implementation of the project, as it was found that double flushing is often conducted because the transport performance of drainage water is insufficient in existing toilet bowls. The reference toilet bowl model, with 1.8 uses/person・day for full flushing and 4.3 uses/person・day for half flushing (**Table-6**) was obtained by taking into consideration the number of flushing times per use of toilet: 1.25 times. Since the number of flushes per use of toilet would change after implementation of the project due to a reduced need to double flush, we examined the rate of change.

First, we assumed that people who currently flush multiple times will start flushing only once for the 61.6% (**Fig.-6**) reply rate for the reason "because bowl is not cleared by flushing only once," and calculated the rate of change as shown in **Table-7**. Based on this table, we calculated the average number of flushing times per use of toilet for the project bowl as shown below:

Average number of flushing times per toilet use for project bowl

= $\Sigma(A \times D)$

= 1 time * 91.0% + 2 times * 8.1% + 3 times * 0.8% + 4 times * 0.1%

= ***1.10 times/person・day***

The number of flushing times per person per day after project implementation calculated above is presented in **Table-8**.

Table 6 Number of eliminations/flushing times at home

Type	Number of eliminations inside household					
	Defecation	Urination	Total	Full flushing times	Half flushing times	Total
Employed (company employees)	1.0	3.7	4.7	1.7	4.1	5.8
Student	1.1	3.9	5.0	1.9	4.4	6.3
At home (full-time homemaker/unemployed)	1.1	4.8	5.9	2.0	5.4	7.4
Standard model	**1.0**	**3.8**	**4.8**	**1.8**	**4.3**	**6.1**

Table 7 Changes in number of flushing times before and after project implementation

Number of flushing times per use of toilet (A)	Baseline	After project implementation	
	Ratio of reply to (A) (B)	Ratio to change to one flush among (B) (C)=(B) x 61.6%	Ratio of reply (D)=(B)-(C)
1	76.6%	-	91.0%(*)
2	21.0%	12.9%	8.1%
3	2.2%	1.4%	0.8%
4	0.2%	0.1%	0.1%

* (B) + Σ(C)

Table 8 Fixture use model after project implementation

Conditions of use		
Full flushing	1.6	times/day・ person
Half flushing	3.8	times/day・ person

3.3 Calculation of CO_2 emission factor associated with water use and CO_2 reduction potential

In this study, we determined the CO_2 emission factor associated with water use by dividing the CO_2 emission volume associated with the use of electricity and fuel in water supply and sewerage systems as shown in **Fig.-7** per volume of treated water. The CO_2 emission factors for electricity and fuel used in the evaluation are shown in **Table-9**. It is evident that the emission factor for electricity is about 3 times as large as that of Japan.[4)]

The CO_2 emission factors associated with water use calculated based on the 9 purification plants managed by Dalian Water Supply Company Limited, the largest water purification and management business in Dalian (**Table-10**), and the data on 10 sewage treatment plants obtained from the Urban Construction Bureau of Dalian (**Table-11**) are shown in **Table-12**. Although general treatment methods similar to those in Japan are used in Dalian, including rapid filtration in water-purification plants and an activated-sludge process in sewage-treatment plants, the CO_2 emission factor associated with water use became larger than that of Japan because of the emission factor for electricity, as more than 90% of the CO_2 emission factor associated with water use is related to electricity.[4)]

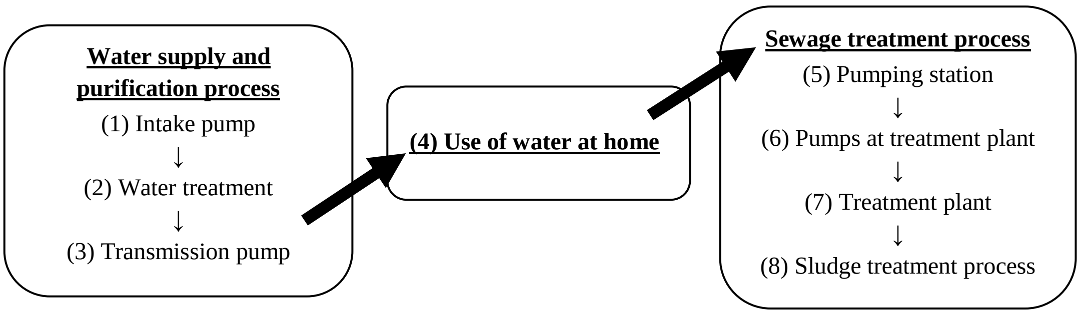

Fig. 7 Flow of water and processes covered by this evaluation

Table 9 CO_2 emission factors for electricity and fuel

Electricity*1	0.84195	t-CO_2/MWh
Diesel oil*2	3.10	t-CO_2/kg

*1: Calculated using the CDM electricity emission factor tool based on the grid power system data of the National Development and Reform Commission (2011).
CM (combined margin) value adopted.

*2: Source: China Energy Statistical Yearbook (2009)

Table 10 Historical data on water purification facilities of Dalian

Water supplied population	3.2 million
Number of treatment plants	9
Annual quantity of purified water	407,340,000 m^3/year
Annual electricity used (pumping stations)	347,337,651 kW・h/year
Annual electricity used (treatment plants)	109,625,955 kW・h/year

Table 11 Historical data and analogical values for sewage treatment in Dalian

Sewage population	2.9 million
Number of treatment plants	10
Annual sewage disposal amount	300,000,000 m^3/year
Annual electricity used (pumping stations)	1,968 kW・h/year
Annual electricity used (treatment plants)	55,053,234 kW・h/year
Annual electricity used (sludge treatment)	4,700,000 kW・h/year
Annual use of fuel for heating (pumping stations)	8,000 t/year
Annual use of fuel for heating (treatment plants)	80,000 t/year

* Diesel oil is used for fuel.

Table 12 Calculation results for CO_2 emission factor associated with water use in Dalian

	Water purification process	Sewage treatment process
Annual CO_2 generation (electricity)	384,741 t-CO_2/year	66,382 t-CO_2/year
Annual CO_2 generation (fuel)	0 t-CO_2/year	234 t-CO_2/year
CO_2 emission factor associated with water use	0.94 kg-CO_2/m^3	0.17 kg-CO_2/m^3
Energy efficiency	4,085 kJ/m^3	825 kJ/m^3

Based on the above results of this study, the CO_2 reduction potential when the project is implemented for the entire city of Dalian (population: 5,864,000, number of people per household: 2.9 people/household)[2)] was calculated to be 15,622t-CO_2/year as follows:

Volume of water saved per person

*= (5 [L/time] * 1.8 [times] + 3.5 [L/time] * 4.3[times])*
*－(3.8 [L/time] * 1.6 [times] +3 [L/time]* 3.8[times])* 365[days]*1/1000*
= 2.4 [m^3]

Volume of water saved per person × total population of Dalian × CO_2 emission factor associated with water use

*= 2.4 [m^3] * 5,864,000 [people] * 1.11 [kg-CO_2/m^3]*

= 15,622 t-CO_2/year

4 Conclusion

In this study, we found that a CO_2 reduction potential of approximately 16,000 t-CO_2/year can be expected by popularizing the use of the latest water-saving toilet bowls from Japan in the city of Dalian, China. It is assumed that there will be impacts equivalent to or larger than those in Japan through the CO_2 reduction potentials of Asian nations with CO_2 emission factors larger than Japan that can be addressed by saving water. In the future, we plan to develop a model for water use and its CO_2 emission factor associated with water use for the entire Asian region by expanding the study area.

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Evaluation of the consequences of the implementation of efficiency measures in water efficiency and CO_2 emissions. Case study in a single family dwelling

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Abstract
Due not only to population growth but, fundamentally, to economic development and lifestyle, drinking water is a scarce resource in nowadays, and has become over the last decades an economic good. Climate changes have compounded this scenario and it is expected that in some countries, like Portugal, the expected change in precipitation regime may in the short / medium term aggravate situations of water stress. In buildings, the efficiency in the water use can be promoted through various measures, based on the principle of 5R: reduce losses, reduce consumption, reuse water, recycle water and reuse alternative sources. In the supply and consumption of drinking water is also spent much energy, namely in the abstraction, treatment, transport and heating. This consumption is estimated in a value between 0.22 and 8.25 kWh/m^3. It is therefore necessary to apply measures to reduce water and energy consumption and consequent CO_2 emissions. In this paper it is developed a study to assess the consequences in the water consumption, energy efficiency and CO2 emissions of some measures of water efficiency in buildings, taking as a case study a single family dwelling.

Keywords
Water efficiency, energy consumption, CO_2 emissions.

1 Introduction

Water is undoubtly an unquestionable natural resource which needs to be preserved. The main activities that depend of the water are also the ones that contribute mostly to its degradation. Water resources are being, over decades, intensively over explored and polluted, and it is estimated that in a few years, could be reached high values of water stress in Europe. Portugal is already in the ranking of countries with medium water stress (10-20%) (Melo-Baptista, J. 2002). To avoid the deterioration of this situation it is imperative to consider different approaches of water management, such as measures based on the principle of 5R for the buildings: reduce losses, reduce consumption, reuse water, recycle water and reuse alternative sources (Silva Afonso & Pimentel-Rodrigues, 2011).

One way of reducing consumption is the use of efficient products. The labeling of products for water efficiency is generally implemented voluntarily in several countries. Already exist in the world various models of certification and labeling of products, with the aim of promoting efficiency among citizens. The United Kingdom, the Nordic countries and Ireland are examples of European countries where this certification is already applied. Outside Europe, there are several examples that can be referenced, including Australia, USA, Japan, among others.

Under the National Programme for the Efficient Use of Water (PNUEA, 2001), the ANQIP (National Association for Quality in Building Services) decided to introduce in Portugal a certification system for products, through the labeling of efficient products. Initially, this certification model was only implemented for cisterns, as these are the products of higher consumption in building in Portugal (Pimentel-Rodrigues & Silva-Afonso, 2008). Today, the model is already being implemented, in addition to the cisterns, to showers, taps and flush valves.

On the other hand, dwellings generally have a high concentration of energy demand and consequently are responsible for a high amount of greenhouse gas (GHG) emissions, including CO_2. Globally are responsible for approximately 40% of total world energy consumption. Most of this energy is for the provision of lighting, water heating, cooking and air-conditioning (Duarte *et al*, 2010). However, more than 50% of the consumption can be reduced by efficiency measures (ADENE, 2011).

To meet these high values was established in 2005 the EPBD - Energy Performance of Buildings Directive (Directive no. 2002/91/EC) which requires the construction and its heating, cooling and ventilation systems are designed and executed so that the amount of energy required in use is low, taking into account the prevailing conditions and the occupants. This is a joint initiative of the EU Member States and the European Commission. The main objective is to improve the sharing of information and experiences in implementing this important European legislation (EPBD, 2011).

Increased efficiency in water use in buildings leads to the reduction of water consumption and wastewater effluents, increasing energy efficiency and contributing to the reduction of GHG emissions (Silva Afonso & Pimentel-Rodrigues, 2011; Kyvelou, 2009).

In this paper it is developed a study to assess the consequences in the water consumption, energy efficiency and CO2 emissions of some measures of water efficiency in buildings, taking as a case study a single family dwelling.

2 Case Study

2.1 Site description

The single family dwelling studied is located in Almacave, in the municipality of Lamego, North of Portugal. It is inhabited by three people. It consists of three floors and a garden. In the basement are the garage, two storage rooms, a laundry, a drying area, a bedroom and a bathroom.

In the ground floor are the room, a bathroom, a kitchen, an entrance hall and an office. The first floor consists of two suites, two bedrooms and a bathroom. The garden surrounds the house and is approximately 170m².

2.2 Methodology

2.2.1 Estimative of water consumption in the dwelling

Consulting the water bill is possible to know the consumption of water in the housing and then estimate the water used for each device, with the help of the percentages proposed in Almeida et al, 2001 (Figure1).

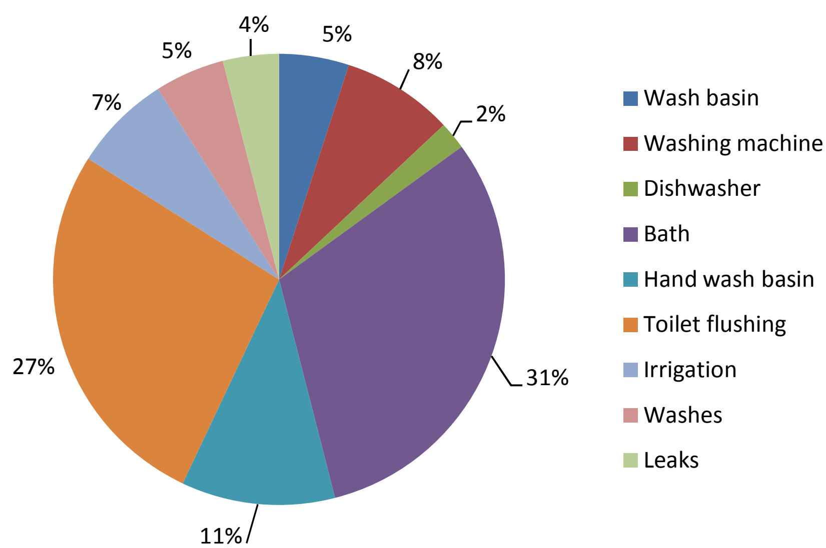

Figure 1: Water consumption distribution by device.

2.2.2 Estimative of the time used in each domestic device

After knowing the characteristics of various types of existing devices, in particular brands and models, it is possible to know the flows and make a subsequent estimate of the time of use (equation 1).

$$t = \frac{Month\ Consumption(L/month)}{Flow\ (L/min)} \qquad (min/Month) \qquad \text{equation 1}$$

2.2.3 Estimative of the water consumption with efficient devices

It was made a search for more efficient equipment in order to reduce the consumption as well as its characteristics of these products. To study the water consumption of new appliances it was applied the equation below:

$$Consumption = flow\ (L/min) \times t\ (min/month) \qquad (L/month) \qquad \text{equation 2}$$

In the building under study, irrigation and general washes are going to be stocked with rainwater using a SAAP (system of rainwater harvesting).

2.2.4 Water savings

To know the water saving by the implementation of these measures it was made the comparison between the existing consumption and the consumption with efficient equipments.

2.2.5 Energy savings and CO_2 emissions reduction with the application of the efficient devices

The heating of a m^3 of water at 37ºC spends 30 kWh of energy. To know the energy savings associated with the savings on hot water it's enough to make an interpolation using the consumptions of water. This is not however the only saving obtained with efficient devices, because the reduction of water consumption in buildings implies a reduction of the volume of water abstracted, treated and pumped, and also a reduction in the volume of treated and pumped wastewater.

In a study conducted in the city of Aveiro, in Portugal, with 73000 inhabitants (27000 homes), it was concluded that energy consumption in the public water supply system and in the wastewater drainage and treatment system was 1.97 kWh/m3 (Silva-Afonso et al., 2011). The city of Aveiro presents the typical characteristics of medium-sized cities in Portugal, so this value can be regarded as a normal value in the country.

Considering CO_2 emissions, it's known that are emitted 369.23 g of CO_2 per kWh of electricity consumed in Portugal (Silva Afonso *et al.*, 2011). Thus, a simple interpolation it's also used for the determination of CO_2 emissions related with the production of hot water.

The value of 369.23 g of CO_2 per kWh of electricity resulting from the mix of technologies used in Portugal to produce electrical energy (including hydro, coal, wind, natural gas and others, also involving the import).

2.3 Results and Discussion

2.3.1 Estimative of water consumption in the dwelling

From the water bills of the last three years it was determined the consumption of water per month, calculating the average consumption of each month:

Consumption = 27.61111 m^3/month= 27611.11 L/month

From the percentages in Figure 1 was calculated consumption of each device, considering that only three of the five bathrooms are used:

- Bath $\Rightarrow 27611.11 \times 0.31 = 8559{,}44$ L/month $\begin{cases} \text{2 Baths} \rightarrow 20.7\% \Rightarrow 5709.15 \text{ L/month} \\ \text{1 Shower} \rightarrow 10.3\% \Rightarrow 2850.29 \text{ L/month} \end{cases}$
- Hand wash basin $\Rightarrow 27611.11 \times 0.11 = 3037.22$ L/month
- Wash basin $\Rightarrow 27611.11 \times 0.05 = 1380.56$ L/month
- Dishwasher $\Rightarrow 27611.11 \times 0.02 = 552.22$ L/month
- Washing machine $\Rightarrow 27611.11 \times 0.08 = 2208.89$ L/month
- Toilet flushing $\Rightarrow 27611.11 \times 0.27 = 7455.0$ discharges/month
- Irrigation $\Rightarrow 27611.11 \times 0.07 = 1932.78$ L/month
- Washes $\Rightarrow 27611.11 \times 0.05 = 1380.56$ L/month
- Leaks $\Rightarrow 27611.11 \times 0.04 = 1104.44$ L/month

In Figure 2 there is represented the water consumption per month.

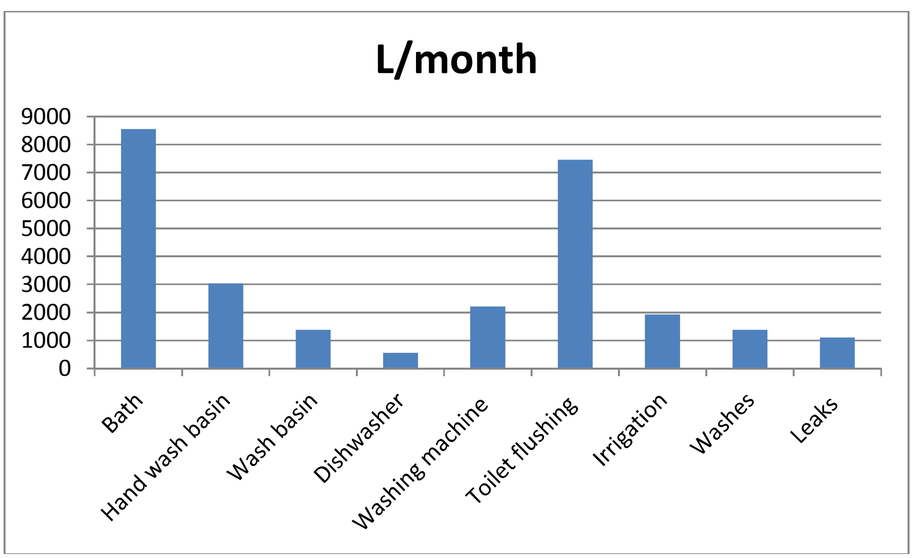

Figure 2: Water consumption distribution per month.

2.3.2 Estimative of the time used in each domestic device

The time of use of each domestic device per month is presented bellow.

- Bath and shower:

  - $\mathbf{t = \frac{5709.15}{12} = 475.76\ min/month}$
  - $t = \frac{2850.29}{7.6} = 375.04\ min/month$

- Hand wash basin ⇒ $t = \frac{3037.22}{7.5} = 404.96\ min/month$
- Wash basin ⇒ $t = \frac{1380.56}{12} = 115.05\ min/month$
- Dishwasher ⇒ $t = \frac{552.22}{0.27} = 2045.26\ min/month$
- Washing machine ⇒ $t = \frac{2208.89}{0.82} = 2693.77\ min/month$
- Toilet flushing ⇒ $t = \frac{7455.0}{6} = 1242.5\ min/month$

2.3.3 Estimative of the water consumption with efficient devices

After a brief consultation on the market, efficient devices were chosen to replace the existing ones (Table 1).

Table 1: Efficient devices characteristics.

Quantity	Designation	Mark	Reference	Water consumption (L)	Pressure (Bar)	Flow (L/min)
3	Hand wash basin	Roca	5A3027C00	-	1	5,6
1	Shower	Roca	5A0127C00	-	1	7,9
2	Bath	Roca	526245070	-	1	11,9
3	Toilet flushing tanks	Roca	34151S..0	4,5	-	-
1	Wash basin	Roca	526172370	-	1	5

Considering the flow incorporated in these devices, and knowing the time of use, it was calculated the water consumption of each device:

- Bath/Shower
  - 2 Bath's → $11.9 \times 475.76 = 5661.57\ L/month$
  - 1 Shower → $7.9 \times 375.04 = 2962.81\ L/month$

- Hand wash basin $\Rightarrow 5.6 \times 404.96 = 2267.79$ L/month
- Wash basin $\Rightarrow$ $5 \times 115.05 = 575{,}23$ L/month
- Toilet flush $\Rightarrow 4.5 \times 1242.5 = 5591{,}25$ L/month

Making the sum of each consumption is obtained total consumption:

$$C_{TOTAL} = 5661.57 + 2962.81 + 2267.79 + 575.23 + 5591.25 + 552.22 + 2208.89 + 1932.78 + 1380.56 + 1104.44 = 24237.54 \text{ L/month}$$

As said, irrigation and general washes are going to be stocked with rainwater using a SAAP (system of rainwater harvesting).

2.3.4 Water savings

Using more efficient devices the consumption achieved is of 24236.56 L/month, which corresponds to a reduction of 3374.55 L / month in the total consumption (12.22%).
With the rainwater harvesting system, considering that it will be used for irrigation and washing, for the months of June, July, August and September (summer - high consumes), the saving accomplish is 3313.2 L/month, which makes a total of 6687.75 L/month, corresponding to a water saving of 24.22%.

2.3.5 Energy savings and CO_2 emissions reduction with the application of the efficient devices

Considering that the consumption in the shower / bath, sink and lavatory is associated with the production of hot water, should be recalled that it's used in these devices a total of 12977.22 L/month and 11467.40 L/month before and after implementation efficiency of the apparatus, respectively.

So, per month:

- Before: 1000 L $\rightarrow$ 30 kWh X = 389.32 kWh of energy
  12977.22 L $\rightarrow$ X

  1 kWh $\rightarrow$ 369,23 g CO_2 Y = 143747.4 g CO_2
  389.32 kWh $\rightarrow$ Y

- After: 1000 L $\rightarrow$ 30 kWh X = 344.02 kWh of energy

11467.40 L → X

1 kWh → 369.23 g CO_2 Y = 127023.20 g CO_2

344.02 kWh → Y

The energy savings correspond to 45.29 kWh/month and the CO_2 emissions are reduced in 16724.13 g CO_2/month.

The adoption of efficient products (labeled with the letters A, A+ or A++) can lead to savings of up to 33% (Silva-Afonso et al., 2011). In this case has been achieved 11.63% savings in energy consumption and CO_2 emissions, only with respect to the devices with hot water.

In Table 2 it's presented a summary of the savings achieved with these efficient measures.

Table 2: Water and energy consumption and CO2 emissions before and after the adoption of more efficient devices (hot water).

Scenario	Water Consumption (L)	Energy consumption **(kWh)**	**CO_2** emissions **(g)**
Before	12977.22	389.32	143747.37
After	11467.40	344.02	127023.24
Savings	1509.82	45.29	16724.13

Considering also the savings in energy in the public network, resulting from the use of the SAAP and efficient devices in the building, we can add:

$$6687.75 \text{ L/month} \times 1.97 \times 10^{-3} \text{ kWh/L} = 13.17 \text{ kWh}$$

In terms of CO_2 reduction:

$$13.17 \text{ kWh} \times 369.23 \text{ g } CO_2\text{/kWh} = 4855.37 \text{ g } CO_2$$

The total savings are:

Energy: 45.29 + 13.15 = 58.44 kWh/month

CO2 emissions: 58.44 x 369.23 = 21577.80 g CO2/month

3 Conclusions

As water is a resource progressively scarce, water efficiency in homes, which passes through the uptake of efficient products, it's extremely important to reduce water consumption. In Portugal, studies show that these measures may lead to savings of up to 30% of water, with effects in reducing energy consumption and CO_2 emissions.

This study revealed potential savings in terms of water consumption of 3373.57 L / month, or 12.22% with the use of more efficient equipment, and it is possible to achieve a saving of approximately 24% using the SAAP irrigation and washing in the months of higher consumption. The implementation of more efficient products enabled a reduction of power consumption and CO_2 emissions of 13,3%.

These results show the importance of efficient water use in buildings, not only as a means of reducing water consumption, but also by his tribute to improve the energy efficiency of buildings and reducing emissions of greenhouse gases.

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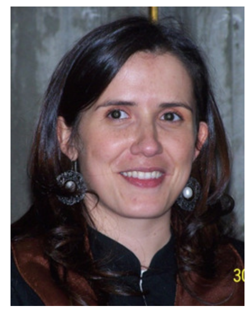

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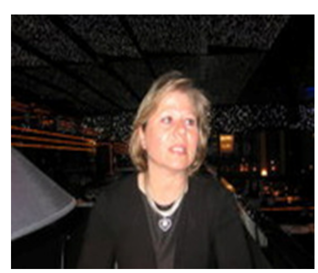

An evaluation of the performance of a fuel cell co-generation system installed in a detached house in a cold district in Japan

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Abstract

We measured the amount of electricity generated and the rejection heat recovery by the polymer electrolyte fuel cell co-generation system (PEFC-CGS), the consumption of hot water and the amount of heat radiating from the heating system connected to the PEFC-CGS. We calculated the energy efficiency of the system under real conditions. The energy efficiency of the system was calculated as follows; the hot water demand, plus the amount of heat radiating from the heating system connected to the PEFC-CGS, plus the amount of electricity generated, divided by the natural gas consumed, plus the electricity consumed. The average energy efficiency was 0.86.

Keywords

Polymer electrolyte fuel cell co-generation system; System efficiency; Natural gas; Cold district in Japan

1 Introduction

Residential energy consumption has been increasing year by year in Japan. Hot water supply systems account for 30% of all residential energy consumption. We have to reduce the amount of energy used by hot water supply systems. A polymer electrolyte fuel cell co-generation system (PEFC-CGS) extracts hydrogen from natural gas which then reacts with oxygen in the air to generate electricity. While generating electricity, the fuel cell also creates heat energy. We can use both heat and electricity to reduce residential energy consumption. The manufacturer of the PEFC-CGS says a performance evaluation monitoring electrical energy efficiency and effective rejection heat recovery efficiency was performed under controlled conditions in a test chamber. A performance evaluation in a real home will differ from the evaluation under specific conditions because residential consumption of hot water and electricity and outdoor air temperatures change daily, unlike those in a test chamber. It is important to carry out a performance evaluation under real conditions. There has been only a few cases in Nagano prefecture. So, we measured the amount of electricity generated and the rejection heat recovery by the PEFC-CGS, the consumption of hot water and the amount of heat radiating from the heating system connected to the PEFC-CGS. We calculated the energy efficiency of the system under real conditions. The energy efficiency of the system was calculated as follows; the hot water demand, plus the amount of heat radiating from the heating system connected to the PEFC-CGS, plus the amount of electricity generated, divided by the natural gas consumed, plus the electricity consumed.

2 Outline of measurement

2.1 Outline of target house

Figure 1 shows the floor plan of the first floor and figure 2 shows the floor plan of the second floor. The target house is located in Nagano city, Nagano prefecture, Japan. The total floor area is 130m^2. The inhabitants are a husband, wife, daughter and son. The PEFC-CGS was installed in the target house. The PEFC-CGS supplies hot water and heating. An air-conditioner that heats by hot water was installed in the living-dining room. One fan convector was installed in the Japanese-style room (1F) and the other was installed in the Western style room (1F). Two bathroom dry heaters were installed in the changing room and bathroom. The underfloor heating was put in the living-dining room and kitchen. These heating systems connected to the PEFC-CGS. Two fan convectors were installed in each Western style room (2F).One air-conditioner which was run by electricity, was installed in the Western style room (1F).

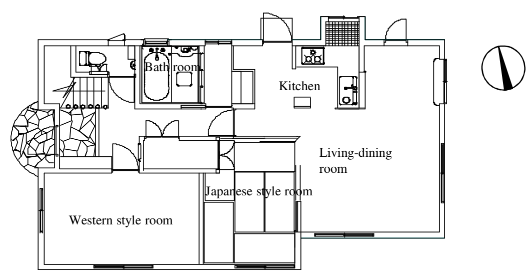

Figure 1-Floor plan of first floor

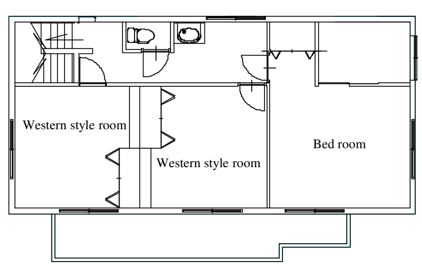

Figure 2-Floor plan of second floor

2.2 Outline of the PEFC-CGS

Table 1 shows the performance of the PEFC-CGS. Figure 3 shows the system diagram. We measured the temperature and quantity of the supply water, hot water, re-heated water from the bathtub, heating and rejection heat recovery. We measured the amount of gas consumption, electricity consumption and electricity generation of the PEFC-CGS. We measured the electricity consumption of the target house supplied from the electricity power company. The PEFC-CGS uses natural gas in the fuel cell unit and the hot water unit. We measured the amount of gas consumption in both units.

Table 1-Performance of the PEFC-CGS

Fuel cell unit			Hot water unit		
Electricity generation output		250W-700W	Water tank capacity		200litres
Rated generation efficiency(HHV)	700W	31.5%	Heating capacity	Hot water	42kW
	250W	27.0%		Re-heated water from the bath	12kW
Rated heat recovery efficiency (HHV)	700W	49.5%		Heating	17.4kW
	250W	27.0%	Rated electricity consumption		340W
Temperature of hot water from heat recovery		>60℃	Electricity consumption for prevention of freezing		130W
Fuel		Natural gas(13A)			

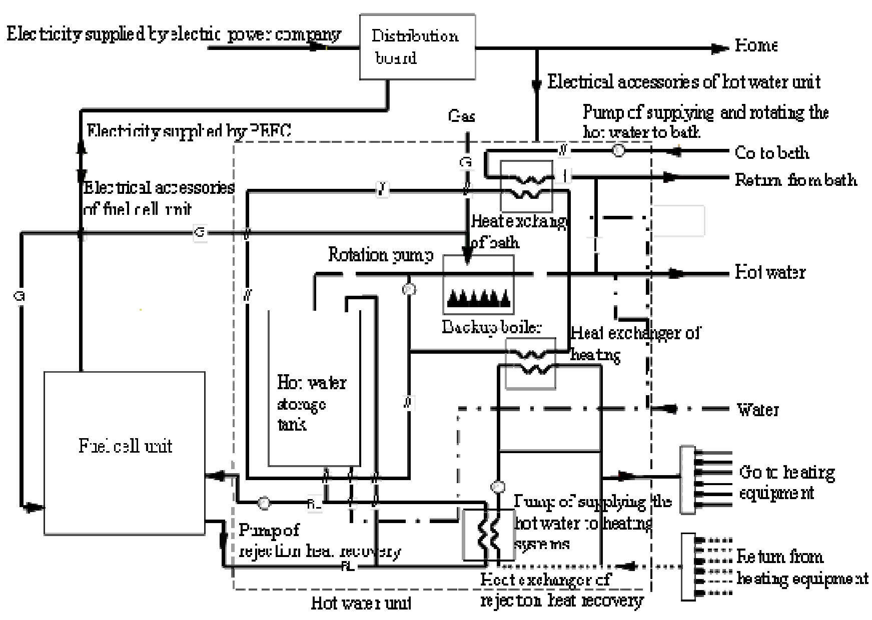

Figure 3-System diagram

2.3 Term of measuring

The term of measuring was from 1st May 2011 to 30th April 2012. Table 2 shows the number of effectual days, the number of days of filling the bathtub with hot water and the number of heating days. We set four terms. The four terms were as follows; The spring term was from March to May, the summer term was from June to August, the autumn term was from September to November and the winter term was from December to February.

Table 2-Number of effectual days

	Winter term (day)	Spring term (day)	Summer term(day)	Autumn term(day)	All terms (day)
Number of effectual days	91	92	53	74	310
Number of days of filling the bathtub with hot water	80	79	44	65	268
Number of heating days	91	67	1	24	183

3 The amount of hot water consumption and heating demand

Hot water was used for four purposes and we measured the amount used for each. The four purposes were as follows; filling the bathtub, re-filling the bathtub, re-heating water from the bath and all other hot water usage, such as washing dishes or hands, etc. The PEFC-CGS supplied the heat to the following heating systems; two areas of the floor heating systems, an air-conditioner that heats by hot water, two fan convectors and two bathroom dry heaters.

3.1 Equivalent amount of 40℃ hot water consumption corresponding to hot water consumption of the target house

We converted the amount of hot water consumption of the target house to the amount of 40℃ hot water consumption. Figure 4 shows the seasonal variation of the equivalent amount of 40℃ hot water consumption corresponding to hot water consumption of the target house. The equivalent amount of 40℃ hot water consumption includes the amount of hot water for filling the bathtub, re-filling the bathtub and all other usage of hot water consumption except for the bathtub.

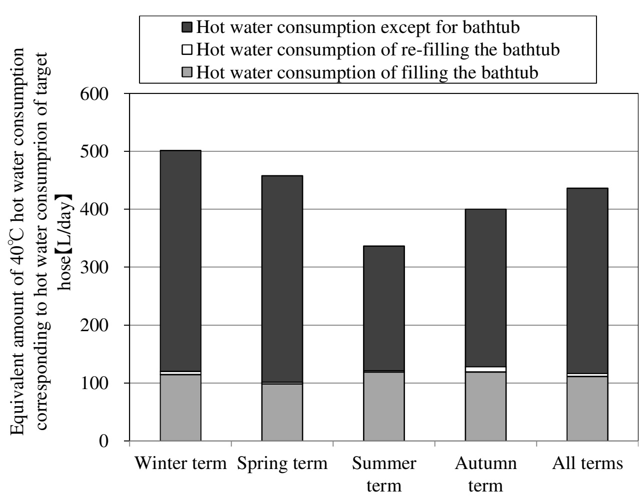

Figure 4-Seasonal variation of the equivalent amount of 40℃ hot water consumption corresponding to hot water consumption of the target house of each term

3.2 Thermal demand

We calculated the hot water demand and the radiation amount of the heating systems connected to the PEFC-CGS. The hot water demand includes filling the bathtub, re-filling the bathtub, re-heating the water from the bathtub and all other hot water consumption except for the bathtub. Figure 5 shows the seasonal variation of the hot water demand for each purpose, the radiation amount of the heating systems, the daily average outdoor temperature and the daily average supply water temperature. The inhabitants filled the bathtub with hot water every day during the autumn term to the spring term. On some days the inhabitants did not fill the bathtub with hot water during the summer term. The inhabitants used the shower instead. The heating system was used from the beginning of November to the middle of May.

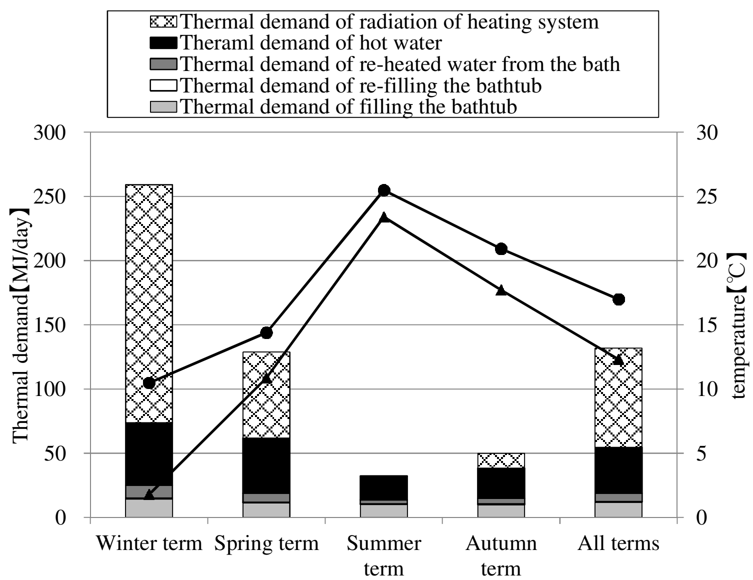

Figure 5- Seasonal variation of the thermal demand, daily average outdoor temperature, daily average supply water temperature

4 The demand of electricity of the target house and the ratio of electricity supply of the PEFC-CGS

We defined the amount of electricity to the house that was supplied by the PEFC-CGS as W_1. We defined the amount of electricity that was supplied by the electric power company as W_2. We defined W_1 divided by W_1 plus W_2 as the electricity contributing ratio. Figure 6 shows the seasonal variation of the change of the amount of electricity that was supplied by the PEFC-CGS, the amount of electricity that was supplied by the electric power company and the electricity contributing ratio. The electricity contributing ratio of the spring term was the highest. The ratio was 71.4%. The average ratio was 68.7%.

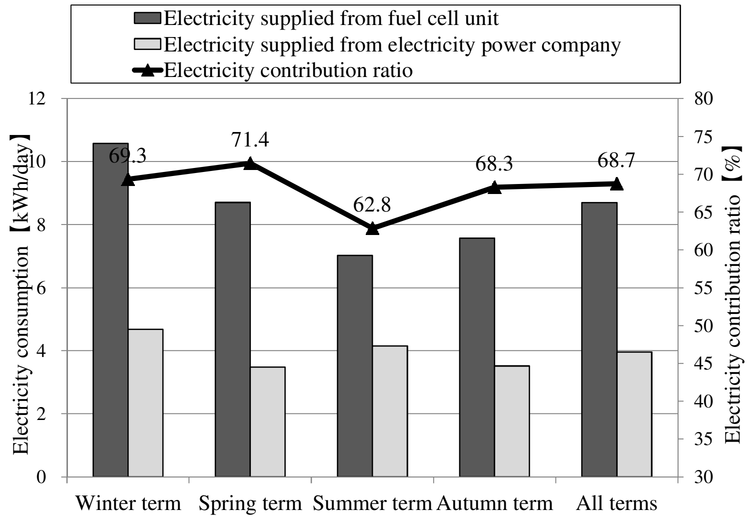

Figure 6- Seasonal variation of the electricity contributing ratio

5 Operational status of the PEFC-CGS

5.1 Gas consumption of the PEFC-CGS

The reforming parts of the fuel cell unit and the backup boiler used natural gas. Figure 7 shows the seasonal variation of the three kinds of gas consumption for each term. The three kinds of gas consumption were as follows; the gas consumption of the generation unit when it was run, the gas consumption of the hot water unit (backup boiler) when the fuel cell unit was run, the gas consumption of the hot water unit when the fuel cell unit was stopped. The value was an average amount per day. The winter term value of the gas consumption of the PEFC-CGS was the highest. The value was 9.2Nm^3/day. The total term value was 5.5Nm^3/day. The gas consumption for generation during the winter term was 2.9 Nm^3/day and the summer term was 2.1Nm^3/day. The different amount between the winter term and the summer term was small. The gas consumption of the backup boiler during the winter term was 6.3Nm^3/day and the summer term was 0.3 Nm^3/day. The different amount between the winter term and the summer term was the highest. The reason why the winter term's gas consumption increased was the hot water demand increased and the heating demand also increased. The rejection heat recovery could not supply all of their demand, so the backup boiler ran frequently.

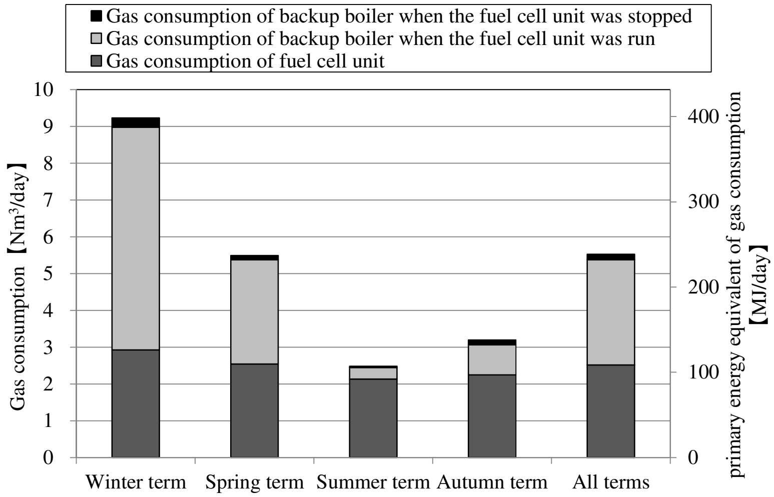

Figure 7- Seasonal variation of the gas consumption of the PEFC-CGS

5.2 Electricity consumption of the PEFC-CGS

The amount of electricity consumption of the electrical accessories included the electricity consumption of the pump for rejection heat recovery, the pump for supplying and rotating the hot water to the bath, the pump for supplying the hot water to the heating system, the rotating pump, the heater for the prevention of freezing and controlling parts. Figure 8 shows the seasonal variation of the electricity consumption of the PEFC-CGS for each term. The electricity consumption of the PEFC-CGS was the highest during the winter term. The electricity consumption of the PEFC-CGS was the lowest during the summer term. The reason why the winter term's electricity consumption increased was the pump for supplying the hot water to the heating system worked frequently and the heater for prevention of freezing worked frequently. The inhabitants used the underfloor heating that connected the PEFC-CGS from morning to evening almost every day.

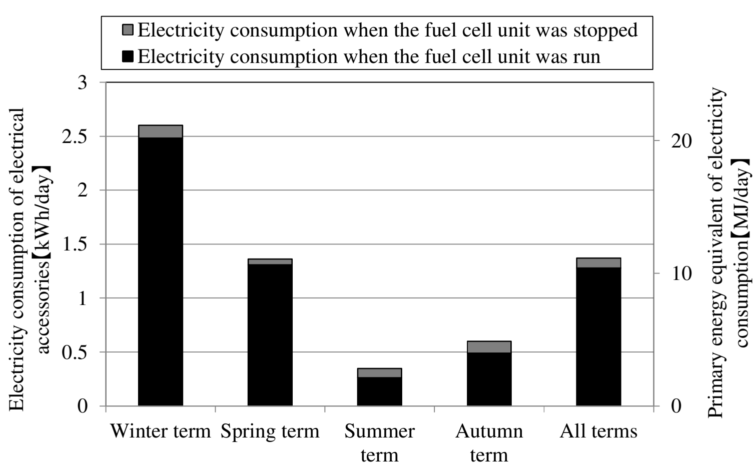

Figure 8- Seasonal variation of the electricity consumption of the PEFC-CGS of each term

5.3 The relationship between the amount of electricity supplied by the PEFC-CGS and thermal demand

Figure 9 shows the seasonal variation of the relationship between the amount of electricity supplied by the PEFC-CGS and thermal demand. In this paper, the thermal demand means the thermal demand for hot water, plus filling the bathtub, re-heating the water from the bathtub, re-filling the bathtub, and radiating the heating systems. So, the thermal demand was the heat that was supplied by the PEFC-CGS as hot water and heating. Figure 9 shows that on some day's the amount of electricity supplied by the PEFC-CGS was very little. The reason why was the PEFC-CGS was stopped once per month to self-check the amount of escaped gas.

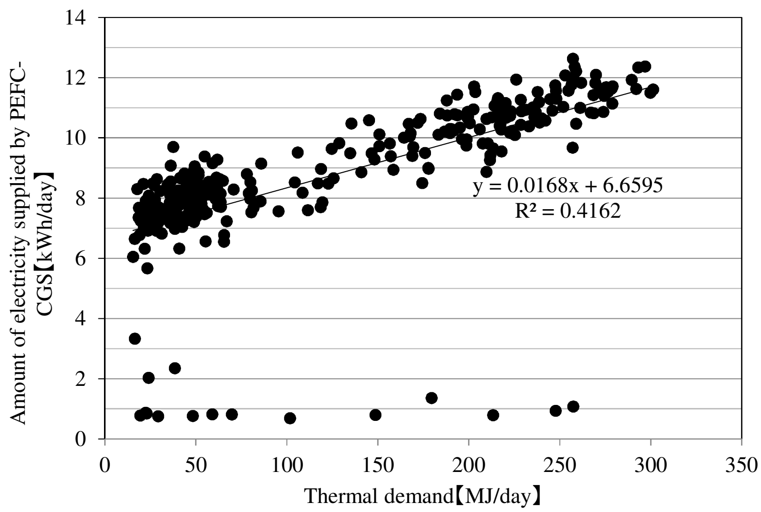

Figure 9- Seasonal variation of the relationship between the amount of electricity supplied by the PEFC-CGS and thermal demand

6 An evaluation of the performance of the PEFC-CGS

6.1 The consumption of primary energy

We calculated the consumption of primary energy. The primary energy equivalent of natural gas was 43.14MJ/Nm^3.The primary energy equivalent of electricity was 9.76MJ/kWh. The consumption of primary energy of the PEFC-CGS includes the equivalent amount of primary energy corresponding to the fuel cell unit and the backup boiler gas consumption, and the equivalent amount of primary energy corresponding to the electricity consumption of the electrical accessories of the hot water unit. Figure 10 shows the seasonal variation of the consumption of primary energy of the PEFC-CGS and the equivalent amount of primary energy corresponding to electricity supply from the PEFC-CGS. The average consumption of primary energy of the PEFC-CGS was 228.3MJ/day. The average equivalent amount of primary energy corresponding to the electricity supply from the PEFC-CGS was 81.2 MJ/day. We calculated the following ratios; the equivalent amount of primary energy corresponding to electricity supply from the PEFC-CGS divided by the consumption of primary energy of the PEFC-CGS. The ratio of the summer term was 62.1%. This value was the highest out of all the terms.

The ratio of the winter term was 24.4%. This value was the lowest out of all the terms. The reason why the value of the winter term was the lowest was the gas consumption of the backup boiler increased because the hot water demand and the amount of heat radiation increased. The average ratio was 35.6%.

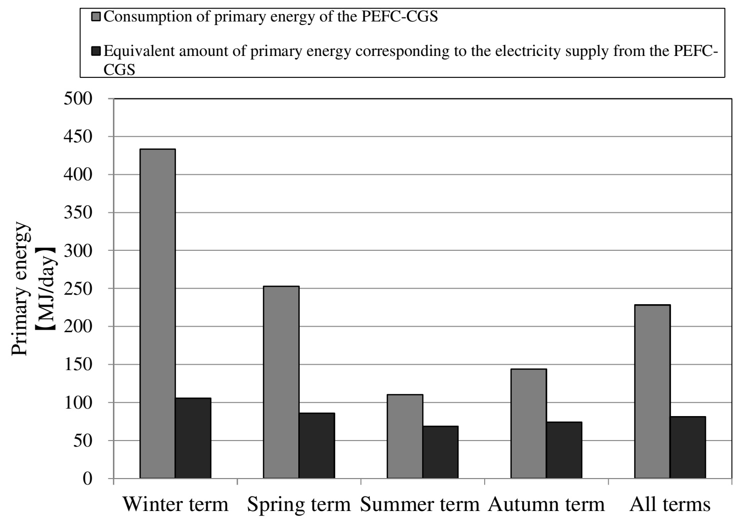

Figure 10- seasonal variation of the consumption of primary energy of the PEFC-CGS and the equivalent amount of primary energy corresponding to electricity supply from the PEFC-CGS

6.2 The energy efficiency and the amount of electricity supplied by the PEFC-CGS

We calculated the energy efficiency(η_1). When we calculated it we used 9.76MJ/kWh as the primary energy equivalent of electricity. We calculated the energy efficiency as the following equation.

$$\eta_1 = \frac{Q_1+Q_2+W_1\times b}{(G_1+G_2)\times a+W_2\times b} \cdots(1)$$

η_1 :Energy efficiency
Q_1: Hot water demand [MJ]
Q_2: Heat radiating from the heating system connected to the PEFC-CGS [MJ]
W_1: Amount of electricity supplied by the PEFC-CGS [kWh/day]
W_2: Amount of electrical accessories [kWh/day]
G_1: Gas consumption of the fuel cell unit [Nm^3]
G_2: Gas consumption of the hot water unit (backup boiler) [Nm^3]
a: Primary energy equivalent of natural gas (HHV) [43.14MJ/ Nm^3]
b: Primary energy equivalent of electricity [9.76MJ/kWh]

Figure 11 shows the seasonal variation of the energy efficiency(η_1) of the PEFC-CGS. The energy efficiency of the summer term was 0.91. This was the highest out of all the terms. The energy efficiency of the winter term was 0.84. This was the lowest out of all the terms. The average energy efficiency was 0.86.

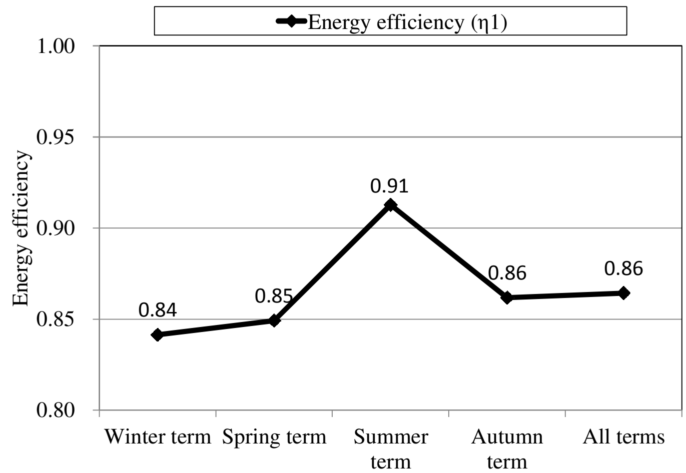

Figure 11- Seasonal variation of the energy efficiency(η_1) of the PEFC-CGS

6.3 The energy efficiency and the amount of electricity supplied by the PEFC-CGS

Figure 12 shows the seasonal variation of the energy efficiency and the amount of electricity supplied by the PEFC-CGS. The values of the energy efficiency were scattering when the amount of electricity supplied by the PEFC-CGS was less. The values of the energy efficiency closed up when the amount of electricity supplied by the PEFC-CGS was increased.

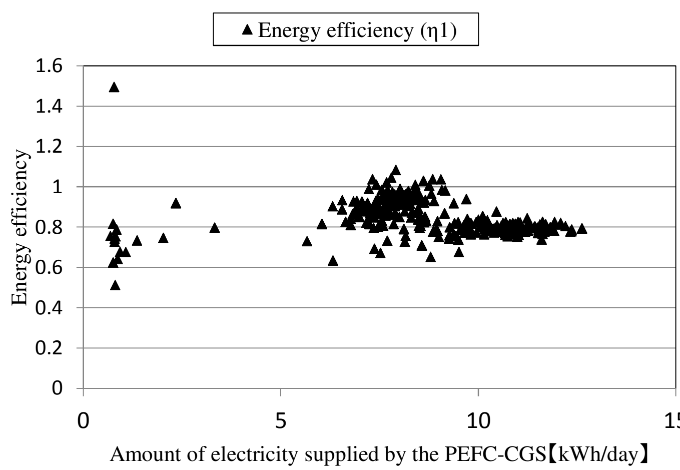

Figure 12- Seasonal variation of the energy efficiency and the amount of electricity supplied by the PEFC-CGS

6.4 The energy efficiency and the daily average outdoor temperature

Figure 13 shows the seasonal variation of the energy efficiency and the daily average outdoor temperature. The highest daily average outdoor temperature was 28.9℃. The lowest daily average outdoor temperature was -3.2℃. The values of the energy efficiency closed up when the daily outdoor temperature was lower. The values of the energy efficiency were scattering when the daily outdoor temperature was higher.

However, on some days, the values of the energy efficiency rose when the daily outdoor temperature was higher.

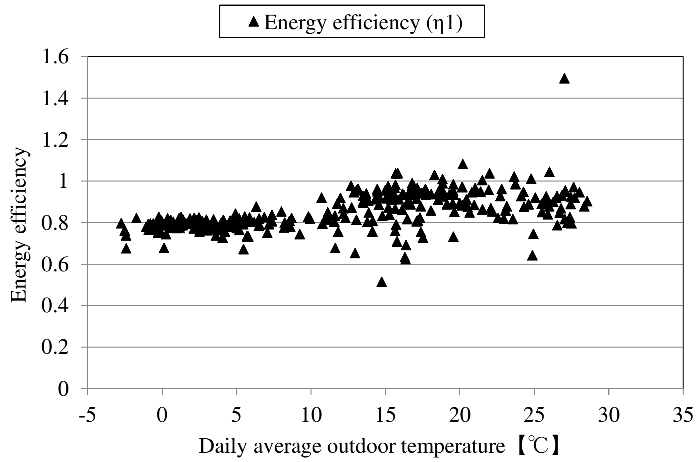

Figure 13- Seasonal variation of the energy efficiency and the daily average outdoor temperature

7 Conclusion

We measured the amount of electricity generated and the rejection heat recovery by the PEFC-CGS, the consumption of hot water and the amount of heat radiating from the heating system connected to the PEFC-CGS. We calculated the energy efficiency of this system under real conditions. The following results were obtained.

1) We calculated the following ratios; the amount of electricity to the house that was supplied by the PEFC-CGS divided by the amount of electricity to the house that was supplied by the PEFC-CGS, plus the amount of electricity that was supplied by the electric power company. The ratio of the spring term was the highest. The ratio was 71.4%. The average ratio was 68.7%.
2) The average consumption of primary energy of the PEFC-CGS was 228.3MJ/day. We calculated the following ratios; the primary energy corresponding value of the amount of electricity supplied from the PEFC-CGS divided by the consumption of primary energy of the PEFC-CGS. The ratio of the summer term was the highest. The ratio was 62.1%. The average ratio was 35.6%.
3) We calculated energy efficiency of the PEFC-CGS. The energy efficiency of the PEFC-CGS was calculated as follows; the hot water demand, plus the amount of heat radiating from the heating system connected to the PEFC-CGS, plus the amount of electricity generated, divided by the natural gas consumed, plus the electricity consumed. The energy efficiency of the summer term was 0.91. This was the highest out of all the terms. The average energy efficiency was 0.86.

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