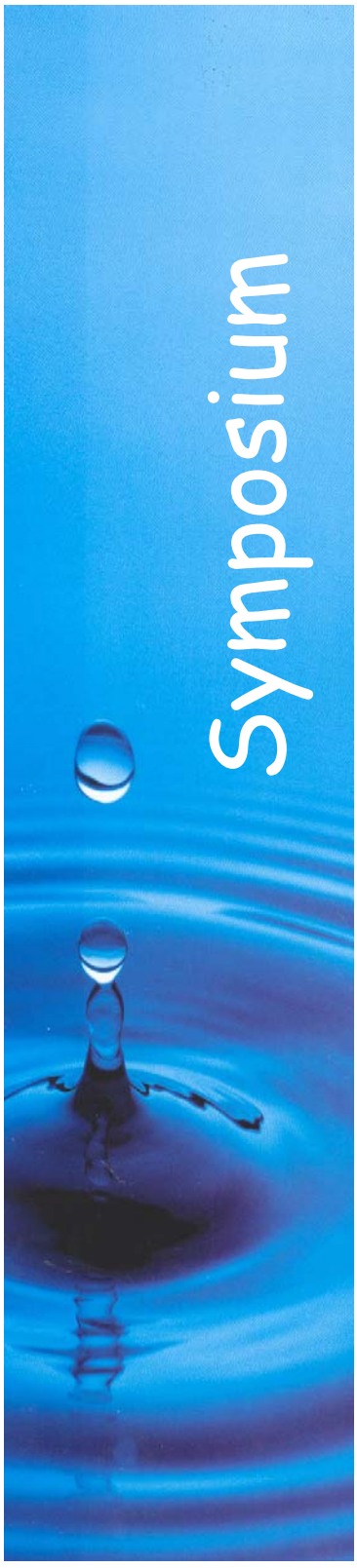
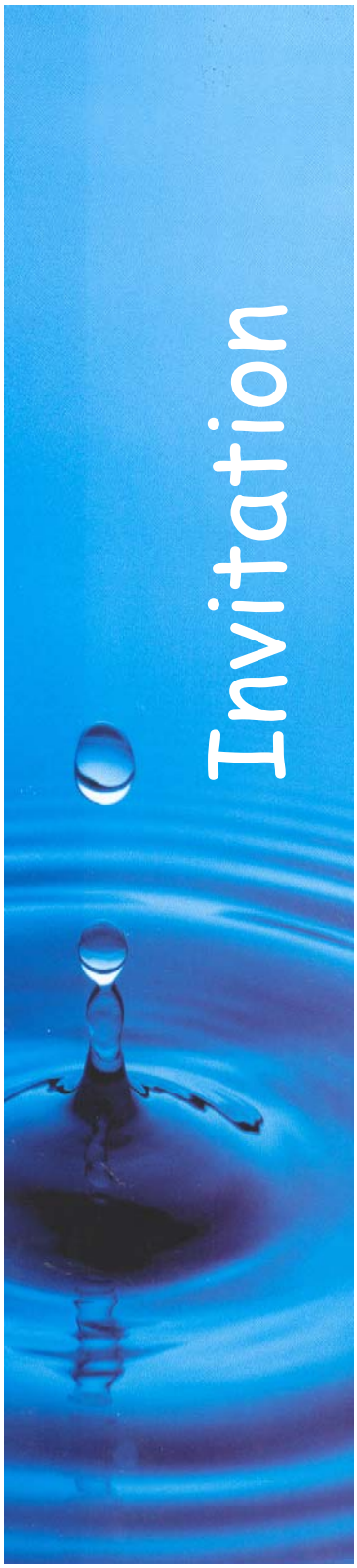
CIB W062



Water Supply and Drainage for Buildings

September 14-16, 2005
Brussels, Belgium

Organised by:
Belgian Building Research Institute (BBRI)



Invitation

The 31st International Symposium of CIB W062 will take place from September 14-16, 2005 in Brussels, Belgium.

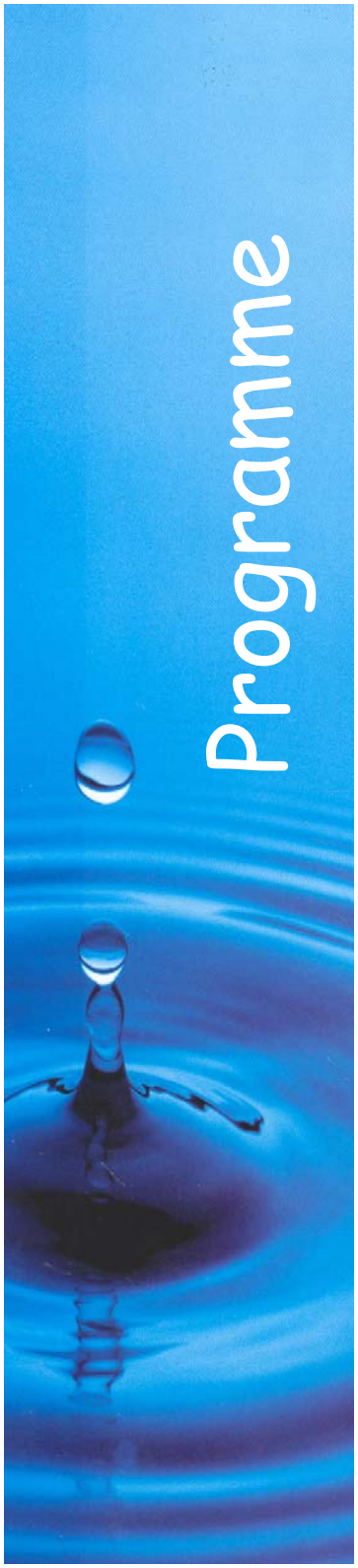
This symposium is open to all experts, practitioners and all those who are interested in the field of water supply and drainage for buildings and matters related to this field.

During the 6 technical sessions held on Wednesday 14th and Thursday 15th September an overview of the latest technological developments will be presented through 35 papers.

The symposium language is English. Oral presentations and discussions and guided tours will be in English only.

Scientific Committee

K. De Cuyper	Coordinator of CIB W062, BBRI, Belgium
F. Derrien	CSTB, France
L.S. Galowin	National Institute of Standards and Technology, USA
O.M. Gonçalves	Escola Politecnica University of Sao Paolo, Brasil
F. Kiya	Kanagawa University, Japan
E. Petresin	University of Maribor, Slovenia
J.A. Swaffield	Heriot Watt University, Scotland, United Kingdom



Wednesday 14 September 2005

08.15 **Registration**

08.50 **Welcome**

09.00 **Session A: Sustainable Construction - *Chairman: Prof. Kiya***

A1 Forecast of amount of water saving in housing complex and amount of carbon dioxide reduction according to it
Y. Asano, Japan

A2 Water efficient appliances for water efficient homes
M. Shouler, United Kingdom

A3 The application of remote reading of water meters at university campi regarding water conservation programs - Case study : University of São Paulo
H. Tamaki, G. Silva, F. Tonetti and O. Gonçalves, Brasil

A4 The multiple functions of irrgation ponds in Japan
K. Fukagawa, S. Murakawa and D. Nishina, Japan

10.20 Questions & Answers

10.40 **Coffee Break**

11.00 **Session A: Sustainable Construction (cont'd)- *Chairman: Prof. Cheng***

A5 Examination of rain water use system in house in consideration of infiltration and reservation
H. Kose, Japan

A6 Sustainable approach of existed building rainwater system from drainage to harvesting in Taiwan
M. Liao, C. Cheng, Y. Liu and J. Ding, Taiwan

A7 Proposal of a hybrid drainage system that enables free-plan housing technology
M. Otsuka and Y. Minami, Japan

12.00 Questions

12.15 **Lunch**

13.45 **Session B: Drainage Systems : Risk for Infection Spread**
Chairman : Prof. Swaffield

B1 Research of infection spread risk evaluation in building drainage system
C.J. Yen, C.L. Cheng, J.R. Ho, Taiwan

B2 Identification of possible cross contamination scenarios facilitated by building drainage and ventilation systems, and the contributory role of modelling positive transient pressure propagation
L.B. Jack, S. Filsell, United Kingdom

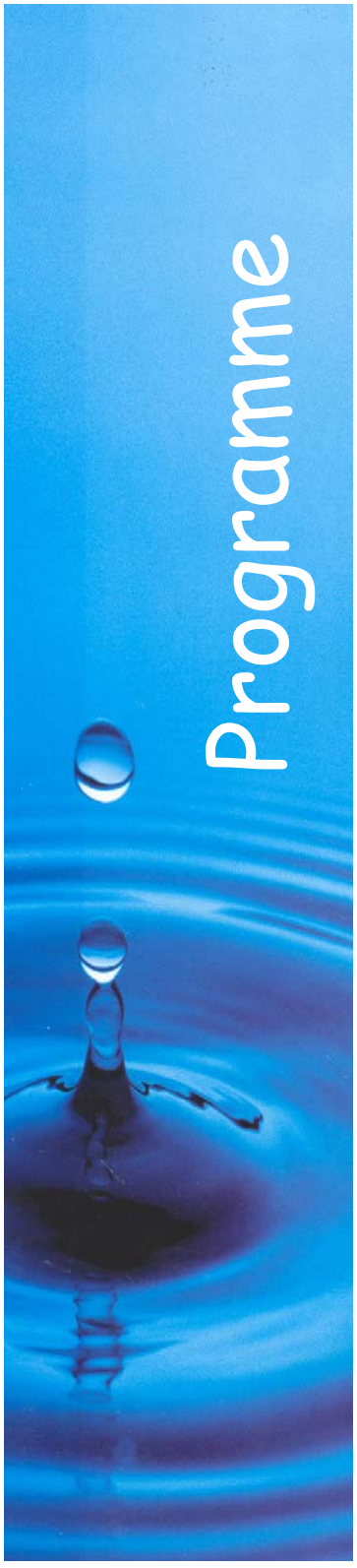
B3 Decision-making and assessment tool for current design of high-rise building drainage system in Taiwan
C.L. Cheng, K.C. Ho, C.J. Yen, Taiwan

B4 Research on the performance evaluation of building floor drains
W.H. Lu, C.L. Cheng, C.P. Hsiao, Taiwan

B5 Transient identification of defective trap seals
D.P. Campbell, United Kingdom

15.25 Questions & Answers

15.50 **Coffee Break**



16.10 **Session C: Drainage Systems : Modelling**
Chairman : Dr Galowin

C1 The influence of the branch pipe geometry on the performance of the discharge stack
T. Mateescu, V. Cotorobai, M. Profire, M. Slavu, Romania

C2 Investigation of the effect of swept entry configuration on the air entrainment and self-siphoning behaviour in gravity drainage systems
A. Öngören, R. Materna, M. Tanner, Switzerland

C3 Considerations on the influence of the exterior climatic parameters on the pressures in discharge stacks
T. Mateescu, V. Cotorobai, C.-D. Galatanu, M. Slavu, Romania

C4 Study on how to improve the capacity of a drainage system with air admittance valves
K. Kawasaki, M. Otsuka, K. Shigeta, N. Hongo, Japan

C5 Modelling the impact of a sealed building drainage and vent system on the propagation of air pressure transients
J.A. Swaffield, United Kingdom

C6 Airflow distribution in complex building drainage networks : an electrical analogy to aid understanding
M. Gormley, D.P. Campbell, United Kingdom

18.10 Questions & Answers

18.30 **Closure of 1st Symposium day**

Thursday 15 September 2005

09.00 **Session D: Drainage Systems: Miscellaneous**
Chairman : Dr Derrien

D1 Performance evaluation of drainage piping systems with food disposers in actual high-rise apartment houses
K. Shimmura, Japan

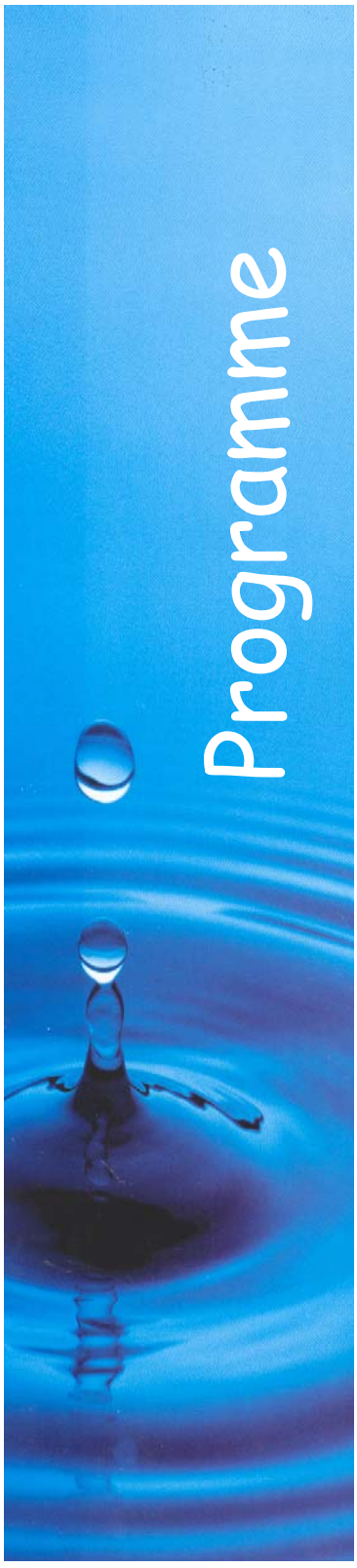
D2 A new approach of sizing a drainage stack for residential buildings in Hong Kong
L.T. Wong, K.W. Mui, Hong Kong

D3 Life time test of dry urinals
M. Demiriz, Germany

D4 Evaluation of water-efficient toilet technologies to carry waste in drainlines
W. Gauley, J. Koeller, Canada

10.20 Questions & Answers

10.40 **Coffee Break**



11.00 **Session E : Water supply**
Chairman : Prof. Petresin

E1 Architectural significance of original water supply systems : Sanliurfa as a case
A. Temizsoy, Turkey

E2 Potable water slow sand filtering application a two centuries basis
L. Galowin, United States

E3 After the Tsunami : water supply and sanitation, from emergency response to rehabilitation
M. Gormley, United Kingdom

12.00 Questions & Answers

12.15 **Lunch**

13.45 **Session E : Water supply (cont'd)**
Chairman : Prof. Gonçalves

E4 A Flushing water consumption model for residential buildings in Hong Kong
L.T. Wong, K.W. Mui, Hong Kong

E5 Design and maintenance of safety shower installations
O. Nuijten, The Netherlands

E6 First ten years of practical experiences with the use of water hydraulic diodes for elimination of water hammer
E. Petresin, N. Matjaz Perc, Slovenia

E7 An original tool to investigate drinking water distribution system
O. Correc, F. Derrien, Y. Diab, France

15.05 Questions & Answers

15.25 **Coffee Break**

16.10 **Session F : Sanitary Hot Water**
Chairman : Mr De Cuyper

F1 Estimating water consumption in nursery and elementary public schools
M.S.O. Ilha, O.M. Gonçalves, S.V. de Amorim, L.P. Pedroso, *Brazil*

F2 An analysis on the loads of hot water consumption of the guest rooms in a hotel
H. Takata, S. Murakawa, D. Nishina, A. Tanaka, Japan

F3 An analysis on the loads of the hot water consumption in the restaurants
S. Murakawa, D. Nishina, H. Takata, A. Tanaka, Japan

F4 Empirical approach to transmit energy for hot water plumbing systems
M.C. Lee, C.L. Cheng, Y.H. Lin, Taiwan

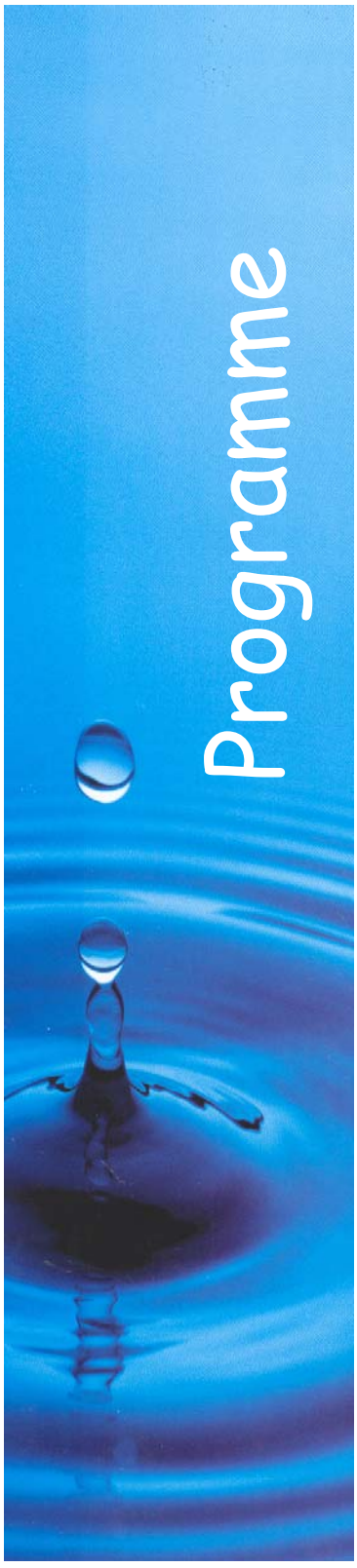
F5 Recent movement for countermeasure to legionella in public bath in Japan
F. Kiya, N. Ichikawa, S. Koshimizu, H. Akai, M. Ogawa, Japan

F6 Regulation on legionella prevention in collective water systems
W.G. van der schee, The Netherlands

17.50 Questions & Answers

18.10 **Closure of the technical sessions**

18.30 – 19.30 **Plenary Meeting of CIB W062-Members: upon invitation only.**



Friday 16 September 2005: visits

7h30 : Departure by bus at the Bedford Hotel for the city of Ghent
9h00 : Visit of a wastewater treatment plant (*outside visit, appropriate clothing required – weather can be rainy*)
10h30 : Transfer by bus to BECETEL (Belgian Testing Centre for Pipes)
11h00 : Visit of BECETEL
12h30 : Lunch
13h45 : Transfer by bus to the city of Bruges
14h45 : City tour by Horse tram
15h45 : Free time
17h00 : Transfer by bus to Damme
18h00 : Conference Dinner in the Damme Country and Golf Club
21h30 : Return to Brussels.

Accompanying Persons Programme :

Wednesday 14 September 2005

8h15 : Registration at the Bedford Hotel
8h50 : Welcome session
9h00-12h00 : Guided tour by bus and on foot through Brussels : Royal commune of Laeken, Cinquantenaire Park, Quartier Louise, Grand'Place, Manneken Pis (*outside visit, appropriate clothing required : weather can be rainy*).
12h15-13h45 : Lunch at the Bedford hotel.
13h45-14h45 : Free time
15h15-16h15 : Guided visit of the Town Hall of Brussels
After 16h15 : Free shopping in the Center of town

Thursday 15 September 2005

8h50 : Departure at the Bedford hotel for a visit of the town of Leuven.
10h00-11h00 : Guided walk in the streets of Leuven (*outside visit, appropriate clothing required : weather can be rainy*).
11h00-12h30 : Free time
12h30-14h30 : Lunch
14h30 : Return to Brussels by bus
15h30-17h00 : Visit of The Museum of Ancient Art

Friday 16 September 2005

See above

Symposium Venue

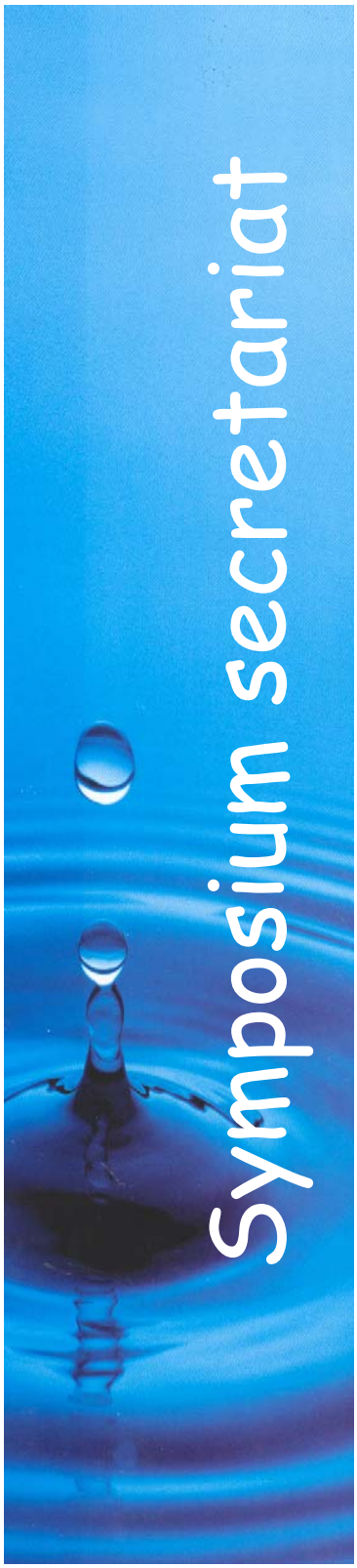
The CIB W062 Symposium will be held in Brussels, capital of the European Community, at the Bedford Hotel, rue du Midi, 135,
B 1000 Brussels Tel: +32 2 507 00 00 - Fax: +32 2 507 00 10
E-mail: info@hotelbedford.be.
The Bedford hotels is located in the city centre, nearby to :

- Brussels Grand Place : 3 min walk
- Gare du Midi at 0.5 km
- Place Louise at 2 km
- European Parliament at 5 km

Accomodation

A number of rooms have been pre-booked at the Bedford Hotel(****). Those who wish to stay at the Hotel Bedford are requested to make reservation directly by phone or fax (see above) by making reference to « CIB W062.

For other hotels, see your travel agency or
http://www.hotels-belgium.com/brussel-center/hotels.htm



Symposium Secretariat:

If you would have any further questions, please contact the Symposium Secretariat
Belgian Building Research Institute (BBRI-WTCB-CSTC)
Mrs. C. Godard or Mr W. Steeno
Lozenberg 7
B 1932 Sint-Stevens-Woluwe
Belgium
Tel: +32 2 655 77 11
Fax: +32 2 653 07 29
E-mail: carine.godard@bbri.be
www.bbri.be
www.cibworld.nl

Forecast of amount of water saving in housing complex and amount of carbon dioxide reduction according to it

Y. Asano (1)
(1)yasanok@gipwc.shinshu-u.ac.jp
Professor, Dr., Shinshu University, Faculty of Engineering, Department of Architecture and Building Engineering.

Abstract

It is important to save water as one of demand management in the housing unit. It is necessary to examine the management of the water demand to secure the stable water supply as much as possible when running short of water. On the other hand, a lot of electric powers are consumed and a large amount of carbon dioxides has been generated in the supply process and the sewage disposal. When it has been reduced, it will be lead to prevent from global warming. Therefore, saving water in the house unit comes to lead to the reduction in the greenhouse gas exhaust while executing effective use for water.
In this research, the amount of the decrease of the volume of water use in the housing complex when the latest equipments and the apparatus to save water are newly set up and used was presumed. In addition, the amount of the decrease of the generated carbon dioxide was presumed.

Keywords

Water saving; reduction of carbon dioxide

1 Introduction

The diffusion rate of waterworks in a Japanese whole area was 96.8% in fiscal year 2002, and the diffusion rate of drainage was 65.2%. The problems of shortage of water have been frequently occurring in a lot of cities now. It is necessary to execute the decentralization of the heads of rivers and an increase of the number of reservoirs and to maintain the underground water sources, because of a quantitatively steady water supply when running short of water. However, because long time and large cost are necessary to construct these facilities, it is not suitable for urgent correspondence. Then, it is important for the user side to decrease the amount of the water use.
Recently, global warming is advanced because of the green house gas. A lot of electric

powers are consumed in the water service business, and carbon dioxide has been generated in the water supply process and the sewage disposal process. Saving water leads to the reduction of electric power consumption and the amount of the exhaust of the green house gas. In this research, the water use volume of the housing complexes was calculated how able to be decreased, by applying the data of the water use volume in the detached house which were measured in objective basis. The water saving apparatus were not usual in the housing complexes at the time of the investigation. It was calculated how the amount of the discharge of carbon dioxide was able to be reduced depending on decreasing the volume of water use when by setting up the water saving apparatus.

2 Investigation of the detached houses

The data of the amount of the water use, which were investigated in 17 detached houses in Tokyo metropolitan district by the Tokyo waterworks bureau, had surveyed according to each purposed usage from July 25/1994 to October 6/1994. The analytical object was squeezed to four houses A, E, K and Q, those are shown in Table 1. The flow meter was set up to the water pipe connected with all the water use apparatuses of each house. Table 2 shows the list of the installation location of the flow meter.
The installation location was divided in five kinds of area those were the kitchen, the bath room, the hand wash space, the laundry room, the toilet. There set the hot/cold water supply at the whole area other than the toilet. Table 3 shows the amount of the water supply use according to the purpose. Table 4 shows the use frequency according to the purpose. The water use volume on each holiday and the weekday is shown in Table 5. There were a lot of volume of water use in the holiday than the weekday in the case of A, E and Q house, but a lot of volume of water use on the weekday than the holiday in K house. Table 6 shows the amount of water use a day a person. Table 7 shows the amount of water use according to the number of residents in a home of fiscal year 2000 that the Tokyo waterworks department announced.

3 Amount of water use and life schedule in the detached house

3.1 Water saving apparatus

The water saving type WCs, the combined washer-dryers and dishwashers were examined as the water saving apparatus.
The use volume of the water saving type WCs, which were used in Japan, had been attached the switched lever type applied 6 litres / flush for urination and 8 litres / flush for feces.
Diffusion of dishwashers in Japan became about 12% in 2003, and it is forecast to rise the demand in the future.
The characteristics of dishwashers are shown in Table 8. A dishwasher was picked up, since the use volume of water was the fewest in washing the maximum number of tableware.
Table 9 shows the volume of water use of the combined washer-dryers. No.2 needs

80 litres / wash based on a wash load capacity of 8.0kg, and No.4 needs 70 litres / wash based on a wash load capacity of 7.0kg, those are the fewest volume of water use.

3.2 Examination of use frequency

An appropriate use frequency of each house was calculated, when assuming that the water saving equipments had been used.
The use frequency of the toilet in each house is shown in Table 9. The distinction between feces and urination could not be done in the life schedule. All residents had been required the drain lever to be switched surely after having used WCs. The discharge of the drain after excretion of feces was made once a day on a person. Other cases were assumed to be used after urination.
The water use in the kitchen was twice a day for washing the tableware in the life schedule in each house. It was assumed that 1/3 among all use volume of waters in the kitchen was used for cooking, and 2/3 was used for washing tableware. Table 10 shows the results of requesting the volume of water used for washing tableware. The volume of water use at hand washing 55 places of tableware was 138 litres according to The Japan Electric Machine Industry Association Standard. Therefore, it was assumed that dishwasher was used once a day in the case of E, K and Q house, but twice a day in the case of A house. The amount of the water used for washing preliminary was assumed to be 5 litres.
The laundry in the case of A, E, K house was twice a day in the life schedule. A standard amount of the clothes that one adult putted out in a day was 1.5kg. The suitable capacity of washing machine was 8.0 kg in the case of A, E house, but it was 7.0kg in the case of K house, and it was assumed that washing machines were used once a day.

3.3 Amount of water saving

The amount of water saving of each house was calculated respectively separately on holiday or the weekday when the water saving type equipments had been used. Table 11 and Table 12 show each amount of water saving when the water saving type **WC** had been used.
Each amount of water saving when the **dishwashers** had been used once a day in the case of E, K and Q house, and twice a day in the case of A house is shown in Table 13 and Table 14.
Each amount of water saving when the **washing machine** which capacity was 7.0 kg had been used once a day in the case of E house, and which capacity was 8.0 kg had been used once a day in the case of A, E house is shown in Table 15 and Table 16 separately on holiday or the weekday.
The **total amount** of water saving of each house is shown in Table 17 and Table 18.
The amount of water saving is large on holiday of A house and on the weekday of K house. Table 19 shows the measurement value of the use volume of water and the expected value reduced by water saving. The forecast water saving rate to the measurement value became 28 % - 44%.

4 Making of schedule in saving water

The life schedule was made up, and times in which water had been used were indicated in this schedule, when the water saving type equipments were used. The basic unit of the volume of water that had been used in one act, was clarified to make the water use schedule. Table 20 shows the use volume of water according to the act. The volumes of water use for WC, laundry and dishwashing have been explained in Chapter 3, and them in the bathroom, for cooking and facial cleansing were according to the measurement values.
For making of water use schedule in a day, one unit was 15 minutes as interval of the life act. The toilet was used all day excluded midnight in all houses. The resident used early in the morning as a feces excretion, and other use was assumed to be a urinal excretion.
The facial cleansing act frequency in a day a person was once.
Only shower use was distinguished from taking a bath. It was assumed once a day in each house to supply the hot water in a bath.
The dishwashers were used twice a day, in the morning and evening, in the case of A house, but once a day, in the evening, in the case of E, K and Q house. The volume of water used for cooking was distributed in the morning and evening. The water use schedules of A house as a sample is shown on Figure 1.

5 Water saving in housing complex

The amount of water saving was provisionally calculated in three housing complexes. The actual data of water use volume of these housing complexes in summer was used. Table 21 shows the outline of the housing complexes. Table 22 shows the results of water saving.
The amount of water saving on the weekday was 31.6kL-76.2kL and the water saving rate was 12-18%, the amount was 32.9kL-82.7kL and the water saving rate was 13-19% on holiday.

6 Decrease in amount of carbon dioxide generation

The use amount of electric power was investigated from water service statistics in the water service business. It increased 6 % for 20 years of while the generated amount of the carbon dioxide varied from 0.000178kg/L in 1983 to 0.000189kg/L in 2002.
Reduction of the carbon dioxide generated was calculated in basis on the value 0.000189kg/L in 2002 according to save water in housing complexes. Table 23 shows the results. The carbon dioxide can be reduced 0.0217-0.0241kg a day a family. It is understood that 8.11kg a year has been reduced. This is understood to be able to reduce about 0.2 - 0.3% of the amount carbon dioxide exhausted off.

7 Refferences

(1)DEFRA, http://www.defra.gov.uk
(2)AWWA, http://www.awwa.org
(3)Tokyo metropolitan waterworks department, http://www.waterworks.metro.tokyo.jp

8 Presentation of Author

Yoshiharu Asano is a professor of Shinshu University. He teaches and conducts research in the department of Architecture and Building Engineering, Faculty of Engineering. He specializes in building equipment, water supply and drainage in buildings and specially controlled installations.

Table 1 - The residents of detached houses

House	Ranks	The number of residents	Habitation years	Family composition (sex, age)
A	2	5	16	Male (61), Female (51, 23, 22 and 20)
E	2	4	17	Male (53), Female (49, 23 and 21)
K	1	3	6	Male (72), Female (66 and 7)
Q	2	2	23	Male (73), Female (72)

Table 2 - Locations of the sensors

House	Kitchen		Bath room				Hand wash space		Laundry room		Toilet	
			Tap		Bath tub						1F	2F
	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold	Cold
A	○	—	○	○	○	○	○	○	○	—	○	—
E	○	○	○	○	○	—	○	○	○	—	○	○
K	○	○	○	○	○	○	○	○	○	○	○	—
Q	○	○	○	○	—	○	○	○	○	—	○	○

Table 3 - The volumes of water use in each purposes (litres)

	House A	House E	House K	House Q
Toilet	8.1	19.1	12.1	11.7
Laundry	174.0	114.3	119.1	
Bath	152.2	78.9	212.4	211.5
Kitchen	30.7	19.5	28.9	38.3
Facial cleansing	16.1	11.2	10.5	15.9

Table 4 - The averaged use frequencies for using equipments

		House A	House E	House K	House Q
Toilet	Weekdays	18.0	10.7	22.1	14.1
	Holiday	17.0	9.6	18.0	17.9
Laundry room	Weekdays	2.2	1.4	2.0	
	Holiday	1.7	2.0	1.0	
Shower bath	Weekdays	3.4	2.0		
	Holiday	3.6	2.3		

Table 5 - The volume of water use in a day in each house (litres)

		House A	House E	House K	House Q
Weekday	Kitchen	299	138	186	149
	Bath	516	166	170	88
	Hand wash space	83	45	34	31
	Laundry room	269	128	241	74
	Toilet	146	189	264	149
	Total	1313	666	895	491
Holiday	Kitchen	328	199	142	164
	Bath	556	143	134	181
	Hand wash space	75	44	24	33
	Laundry room	246	184	116	68
	Toilet	137	217	218	196
	Total	1342	787	654	642

Table 6 - The volume of water use in a day and a person (litres)

	Weekdays	Holiday
House A (5persons)	273	276
House B (4persons)	168	202
House C (3persons)	318	229
House D (2persons)	246	321

Table 7 - The volume of water use in a mouth and a family / in a day and a person, presented by Tokyo district water bureau in 2000.

Household members	The quantities of water use [m3/dwelling · month]	The quantities of water use in a day and a person [L/day · person]
1 person	8	270
2 persons	17	280
3 persons	23	260
4 persons	28	230
5 persons	32	210
6 or more persons	40	

Table 8 - Detail of dishwashers

	No.1	No.2	No.3	No.4	No.5	No.6
The maximum number of tableware [piece]	52	50	55	40	45	35
Water consumption [L]	12	12	11	14	12	13
Electric energy consumption [Wh]	0.88	0.85	0.8	0.43	0.92	0.775

Table 9 - Details of washer-driers

	No.1	No.2	No.3	No.4	No.5
Wash load capacity [kg]	8.0	8.0	8.0	7.0	7.0
Standard water consumption [L]	98	80	90	70	87
Electric energy consumption in washing [W]	190	250	200	140	180
Electric energy consumption [Wh]	98	95	140	87	75

Table 9 - Use frequencies of toilet of each house

		House A	House E	House K	House Q
weekday	feces	5	4	3	2
	urination	13	6	18	13
holiday	feces	5	4	3	2
	urination	12	8	15	16

Table 10 - The volume of water use in kitchen (litres)

		Cooking	Washing dishes	Total
A house	Weekday	100	199	299
	Holiday	109	218	327
E house	Weekday	46	92	138
	Holiday	66	133	199
K house	Weekday	62	124	186
	Holiday	47	95	142
Q house	weekday	50	99	149
	holiday	55	109	164

Table 11 - The saved volume of water use in using the water saving type WC in the case of weekdays (litres)

		House A	House E	House K	House Q
Number of persons		5	4	3	2
Volume per an action		8.1	19.1	12.1	11.7
Frequency of use in a day[times]	feces	5	4	3	2
	urination	13	6	18	13
Volume per a day (before)		146	189	264	149
Volume per a day (after)		118	68	132	94
Saved volume		28	121	132	55

Table 12 - The saved volume of water use in using the water saving type WC in the case of holiday (litres)

		House A	House E	House K	House Q
Number of persons		5	4	3	2
Volume per an action		8.1	19.1	12.1	11.7
Frequency of use in a day[times]	feces	5	4	3	2
	urination	12	8	15	16
Volume per a day (before)		137	217	218	196
Volume per a day (after)		112	80	114	112
Saved volume		25	137	104	84

Table 13 - The saved volume of water use in using the dishwasher in the case of weekdays (litres)

	House A	House E	House K	House Q
Number of persons	5	4	3	2
Volume in the kitchen (before)	299	138	186	149
Volume in washing dishes	199	92	124	99
Frequency in a day [times]	2	1	1	1
Volume for the dishwasher	32	16	16	16
Saved volume	167	76	108	83

Table 14 - The saved volume of water use in using the dishwasher in the case of holiday (litres)

	House A	House E	House K	House Q
Number of persons	5	4	3	2
Volume in the kitchen (before)	328	199	142	164
Volume in washing dishes	218	133	95	109
Frequency in a day[times]	2	1	1	1
Volume for the dishwasher	32	16	16	16
Saved volume	186	117	79	93

Table 15 - The saved volume of water use in using the washer-drier in the case of weekdays (litres)

	House A	House E	House K
Number of persons	5	4	3
Volume per an action (before)	174	114	119
Frequency in a day [times]	1	1	1
Volume in a day	269	128	241
Volume in a day (after)	80	80	70
Saved volume	189	48	171

Table 16 - The saved volume of water use in using the washer-drier in the case of holiday (litres)

	House A	House E	House K
Number of persons	5	4	3
Volume per an action (before)	174	114.3	119.1
Frequency in a day [times]	1	1	1
Volume in a day	246	184	116
Volume in a day (after)	80	80	70
Saved volume	166	104	46

Table 17 - Total amount of saved water in weekdays (litres)

	House A	House E	House K	House Q
Toilet	28	121	132	82
Kitchen	167	76	108	84
Laundry	189	48	171	
Total	384	245	411	164

Table 18 - Total amount of saved water in holiday (litres)

	House A	House E	House K	House Q
Toilet	25	137	104	84
Kitchen	186	117	79	93
Laundry	196	122	84	
Total	407	376	267	177

Table 19 - The volume of water use in a day (litres)

	House A		House E		House K		House Q	
	W	H	W	H	W	H	W	H
The measured volume of water use [L]	1367	1379	673	807	953	687	491	642
The expected value reduced by water saving [L]	984	1003	427	449	542	458	353	465
Water saving rate [%]	28.1	27.3	36.5	44.3	43.2	33.3	28.1	27.6

W: weekday H; holiday

Table 20 - The volume of water use in each purpose (litres)

		House A	House E	House K	House Q
toilet	feces	8	8	8	8
	urination	6	6	6	6
laundry		80	80	70	
bathroom		152	79	212	212
kitchen	cooking	51	26	29	26
	dishwashing	32	16	16	16
facial cleansing		16	11	11	16

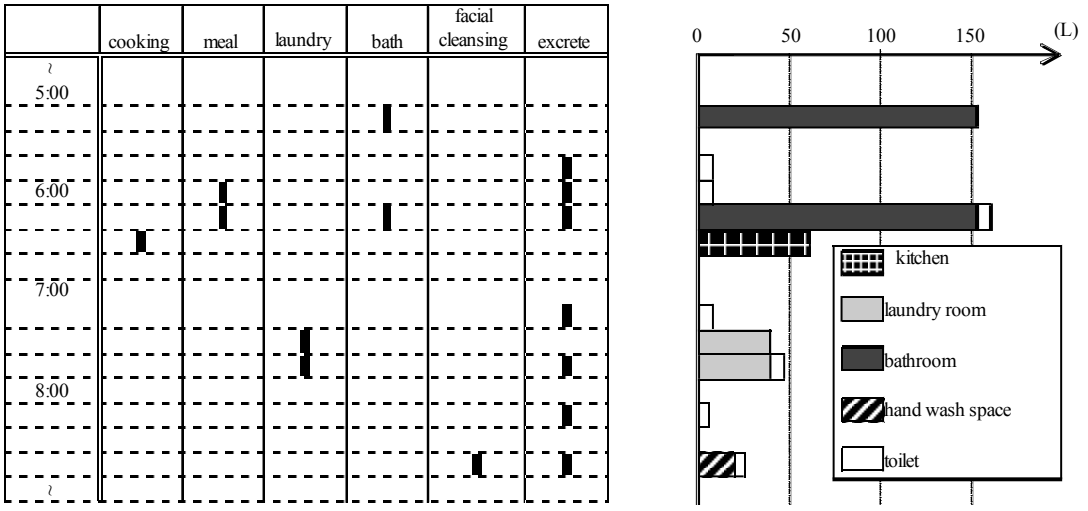


Figure 1 - The life schedule of A house as a sample

Table 21 - The hosing complexes

Day	Name	Ranks	Dwelling units	Volume of water use per day (kL)	Volume of water use by saving per (kL)
weekday	1	8	49	31.6	25.9
	2	14	74	69.5	61
	3	11	122	76.2	62.3
holiday	1	8	49	32.9	26.6
	2	14	74	69.5	60.1
	3	11	122	85.7	70.3

Table 22 - The saved quantities of water use in the housing complexes

Day	Name	Measured volume of water use per day (L)	Saved volume of water per day (L)	Saving ratio (%)
weekday	1	644	115	17.8
	2	940	115	12.2
	3	625	115	18.3
holiday	1	671	128	19
	2	939	127	13.5
	3	703	127	18

Table 23 - The reduced quantities of CO2 in a day

Day	Name	Amount of CO2 reduced per day, a family (kg)	Amount of CO2 reduced per year, a family (kg)
weekday	1	0.0217	5.21
	2	0.0218	5.23
	3	0.0216	5.2
holiday	1	0.0241	2.9
	2	0.0239	2.87
	3	0.0239	2.87

The application of remote reading of water meters at university *campi* regarding water conservation programs - Case study: University of São Paulo

H. Tamaki (1) , G. Silva (2), F. Tonetti (3), O. Gonçalves (4)
(1) humberto.tamaki@poli.usp.br
(2) gisele.silva@poli.usp.br
(3) fernando.tonetti@poli.usp.br
(4) orestes.goncalves@poli.usp.br
Depart. of Civil Eng., Building Systems Laboratory, University of São Paulo, Brazil

Abstract

The ever growing need for actions regarding water conservation at building systems level has been responsible for the development of water conservation programs. Besides their execution stages, these programs must also have the demand management, and for so, they can use tools like submetering and remote reading of water meters. In this paper, two available technologies for remote reading are showed, with emphasis for the digital field-bus system - its characteristics, its applicability conditions for university *campi* and its execution activities. The remote reading system provides a real time and more reliable source for the collection of a greater amount of data, besides the possibility of faster detection of anomalies, such as leaks (found by high flow rates during the nighttime). The system also presents an improvement regarding control parameters in comparison to *in loco* reading, due to its capability to provide flow rates profiles along the day, in which maximum and minimum values can been seen. As a case study it is presented the application of the remote reading at the University of São Paulo *campus* - *Cidade Universitária Armando de Salles Oliveira* (CUASO), within the Water Conservation Program of the University of São Paulo (PURA-USP). The system, which started working at 1998, consists of a digital field-bus (that uses the M-BUS communication protocol), electronic water meters, a communication network (pipes/cables, communication interfaces, signal amplifier/regenerator and grounding system) and a management center. By the end of 2004, 70 water meters could be read by the remote reading management center.

Keywords

Remote reading, demand management, water conservation, building systems

1 Introduction

The importance that water has for the populations' own survival and for the development of their activities, in accordance with sustainable development principles, has been increasing, acquiring new meanings and changing deep-rooted concepts.

When contextualizing the Water Conservation Programs to face the growing scarcity of this resource with quality in great urban centers, it can be concluded that they can meet the demand of action at building systems level, playing a role in the paradigm change from supply management to include demand management as well.

SILVA; TAMAKI; GONÇALVES (2004) have presented the following activities as suitable for Water Conservation Programs: planning - motivation raising, setting of goals, deepening diagnosis of the situation and defining the structure of the Program; pre-implantation; implantation - general diagnosis, reduction of physical losses, reduction of consumption at points of use, identification of habits and rationalization of water-consuming activities and program spreading, awareness campaigns and training; and post-implantation - maintenance of these two last stages and water demand management permeating the whole process.

2 Water demand management in Water Conservation Programs

Water demand management goes beyond the mere follow-up of the volume of water used and includes, besides data organization and survey of graphs, the evaluation of data and the system feedback, by means of eliminating a leak or even revising processes that use water aiming at making their use more efficient and economic.

2.1 Data survey

Besides the water consumption data (such as readings and flow rate profiles), which presupposes the control of information such as the register of water connections and the characteristics and conditions of each meter box and water meter, there is the survey of supplementary data (built area, population, existing appliances and activities carried out) that are used for the creation of consumption indicators.

2.2 Control parameters

Consumption data can be considered as directly obtained control parameters, which originate from the follow-up and direct control of consumptions. The indirectly obtained control parameters are those that make use of directly obtained data and supplementary data surveyed. These are the consumption indicators. The more utilized are monthly per capita consumption and the monthly consumption per area (TAMAKI, 2003). Among the benefits for adopting consumption indicators are:

- It allows the comparison between situations that show variations of more than one data. For example, the *per capita* consumption takes into account the fluctuation of population and consumption;
- It determines which are efficient systems and which are the ones requiring attention;
- It makes it possible to extrapolate from the indicator values for similar situations.

2.3 Intervention Procedures

In order to conclude the cycle of water demand management, it should be considered the establishment of procedures and responsibilities in the occurrence of anomalies. For instance, in case of leaks, procedures for informing their occurrence to the ones that can eliminate them and for giving feedback about the implementing of such need to be created. Likewise, the notification of the necessity of which water networks need to be repaired and of the revision of equipment must be carried out. Registrations of occurrences allow the identification of regions more susceptible to problems and more affected systems, thus showing the systems that need more attention.

Besides the interventions due to anomalies, some actions should be permanent, such as regular contact with the users, maintenance staff of the hydraulic systems and with the public utility company; or still, a continuous improvement of the knowledge of building systems, by having a precise control over the whole water network, including the water meters, their location, type, dimensions and capacities, dates of change and initial and final readings, and so on.

2.4 Instruments of water demand management

The consumption data collection can be carried out through very simple instruments, such as: water bills and *in loco* readings, or through submetering and remote reading which systematize such collection, being important instruments of demand management (TAMAKI, 2003):

- *Water bills:* issued by the public utility company, are the simplest tool from which the current month's consumption, the last six months' consumption and the average consumption can be obtained;
- *Readings:* as billing readings are done just once a month and there is a gap between the reading and the corresponding bill, the routine of *in loco* reading can be adopted;
- *Submetering:* aiming at increasing the relationship between the consumption and the consuming unit, submetering can be adopted - installation of other water meters besides the ones used by the public utility company for water billing purposes;
- *Remote Reading:* instrument of water demand management that works on:
  - *Data collection (Figure 1, left):* more reliable for collecting more data in real time, besides detecting anomalies faster, among which leaks (made explicit, for example, by high nighttime flow rates);

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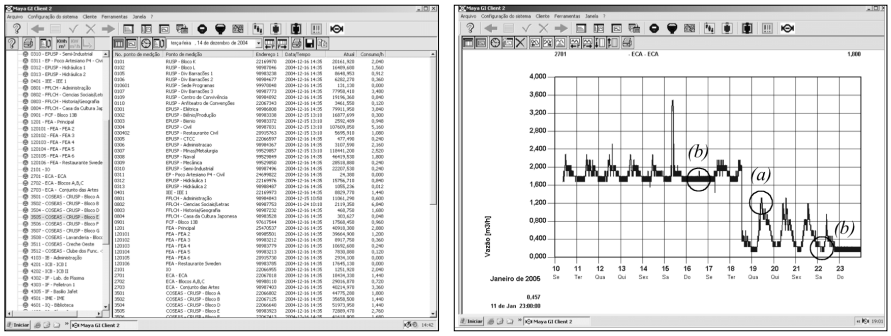

Figure 1 - Management application of a remote reading software

- *Determination of control parameters (Figure 1, right):* represents a significant advance in relation to instruments such as *in loco* readings, since it also provides flow rate profiles over the day, from which points of *maximum flows* (a) *and minimum flows* (b) can be seen, thus showing possible anomalous consumptions.

3 Remote Reading Systems - Technologies

With regard to the benefits of remote reading, it can also be mentioned the supply of information to the different kinds of users, be those the public utility company, the building systems managers or the end-users. Therefore, different needs can be met and routines can be created or improved, so as to save inputs and reduce costs.

A basic remote reading system is made up of (ROZAS, 2002):

- *Metering and Reading Unit:* the meter itself, which transforms the consumed physical magnitude into recordable and storable values. The basic adaptation of the conventional meters for remote reading is carried out by the simple input of counting devices of the emitter-receiver type. Modern electronic meters have a electronic circuit that, in addition to receive pulse sequence, process that information and convert it into total values and other facilities;
- *Meter Interface Unit:* the *MIU*'s function is the communication between the meter and the communication network, modifying the data provided by the meter in order to make them suitable to be transported by the communication network to the management center;
- *Communication Network:* means of data transmission from the meters to the management center;
- *Management Center:* its function is to receive, process, store and apply data from the several meters.

Today there are some remote reading technologies, among which radiofrequency (RF), power line carrier, public network of fixed and mobile telephony, cable TV, field-bus and hybrid systems.

3.1 Radiofrequency

The variety of the RF communication systems comes from the historic development of the employed technologies. The first systems, still in use, were based on portable readers with which the meter-readers, on foot, could establish communication with each meter and recorded the readings in their own equipment.

Today it is usual to adopt a structure made up by meter equipped with low power RF transmitters and receivers, primary concentrators located near groups of meters and fixed in structures and secondary concentrators that cover a set of primary concentrators and are connected to the management center.

As advantages of RF systems it can be mentioned that they do not need to share the network with other users, besides the low costs of the system elements and their implementation (*Figure 2*). On the other hand, they can not provide flow rate profiles, being more applicable to situations requiring only daily or monthly consumption values.

Figure 2 - Radio modules (for conventional meter), communication interface and data collector

3.2 Field-bus

The field-bus consists of a cable network that covers all the meters in a region. For analogical meters with pulsed signal output, this network links each meter with a signal concentrator, as well as this latter with other concentrators or a computer. The concentrator totals the pulses, converts them into measurement units and transmits them to the data application and storage computer. Characteristics of this solution are the low cost for implanting remote reading devices in the meters and the restriction of distances and information transmitted.

In the case of electronic meters with specific communication protocol (*Figure 3*), the communication network has a branch topology in which ever meter receive the same information at the same time. This topology has as characteristics the extremely simplicity of connections, as additional points can be put in the network by its mere enlargement. Others characteristics of this solution are: network stability even when a meter fails; degradation of the communication when many meters are added; and the necessity of addressed meters, since they share the same network - that means reading cycles and limitation of both meters and sent data.

The greatest drawbacks of systems based on the field-bus technology are the cost of installing a dedicated physical means (network) and technical problems that are often encountered (interferences with other utilities and buildings). Therefore, this is a restricted solution, suitable for specific sites, such as commercial condominiums, industrial plants, horizontal residential condominiums and university *campi*.

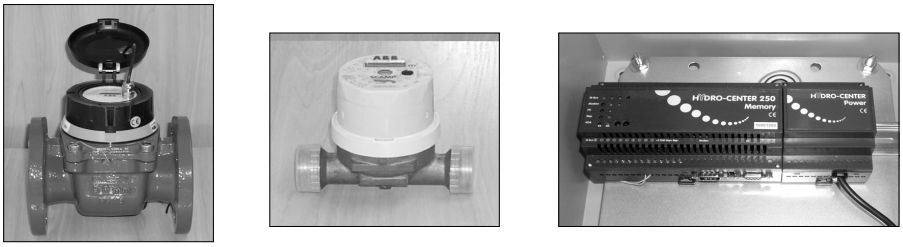

Figure 3 - Electronic water meters (DN50 and DN20 models) and signal amplifier/ regenerator

4 Remote reading systems - Implementation of the digital field-bus system

In this work it is presented the digital field-bus communication technology with Meter Bus (M-BUS*)* communication protocol.

4.1 M-BUS Standard

Data communication digital system made up by electronic water meters, communication network, a computer with specific program and network-computer communication interface. It is a local area system that adopts a bidirectional serial field-bus topology, i.e., all the points are connected to a common transmission line and receive the same message at the same time. Other elements can be incorporated to the system in order to improve safety, reliability and network range as a whole, such as signal amplifiers/regenerators and grounding system (*Figure 4*).

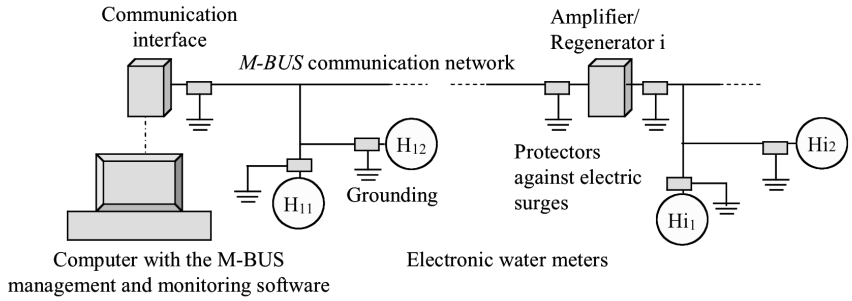

Figure 4 - Example of standard M-BUS remote reading system

It should be noticed that the range of the M-BUS network depends on a number of factors, the topology and network extent, the type of cable utilized, the speed of data transmission, the relative position of water meters in the network and the power of signal amplifiers and regenerators being the chief ones. The parameters of resistance, tension and network capacitance are the ones that can restrict the network extent and the maximum number of interconnected meters.

4.2 System Elements

4.2.1 Electronic water meters

These water meters have electronic register of extra-dry type, with magnetic coupling, which are jointly integrated or connectable to the meter chamber. They have microprocessors with functions such as totaling consumption and instant flow rate, data which can be collected at the spot on a liquid crystal display or remotely through a M-BUS two-way bus.

4.2.2 Communication network

The communication network consists of a branched cable network, which maintains the communication interface between the water meters and the computer, the signal amplification/regeneration and grounding system, these last two only when necessary:

- *Ducts and cables:* the cables used by the M-BUS system are the same that are used for fixed telephony, twisted pair type, each wire having a cross-section of 0.5 mm^2;
- *Communication interface, signal amplifiers/regenerators:* elements that suit the signals for passing through the net, allowing that they keep their original characteristics and in conditions good enough so as to establish the communication with all the water meters. Besides power feeding the meters, the interface has a built in program for converting the microcomputer serial *EIA* RS232 C to M-BUS standard, in both directions, thus allowing the communication between the computer and the water meters. Because of the dimensions and characteristics of the communication network, there can be a quality degradation of the M-BUS signal that make it impossible the direct communication with all the water meters, making it necessary the utilization of signal amplifiers or regenerators. These devices should be located at strategic points so as to serve different portions of the communication network, and be placed at regular distances between one another and an approximate similar amount of meters should be connected to them;
- *Grounding system:* due to the degree of exposition and the extent of the network, as well as the frequency of atmospheric discharges of the region, it may be necessary to implement a protective system for the equipment. This grounding system, which has to have performance requirements similar to the ones used for several types of electronic devices, can reduce the impact of a discharge on the remote metering system, thus restricting the number of burnt apparatuses (or even preventing the loss of a unit).

4.2.3 Remote reading management center

The management center is made up of a microcomputer with a program for supervision (communication and management of M-BUS system) and application. Next to the microcomputer, the communication interface between the computer and the communication network is installed.

The supervision program routines include the M-BUS system communication and management, i.e., communication with each meter installed according to the setup of the communication parameters (speed, reading frequency, order, etc), receiving and storing of a set of data in a database, making backup copies of the files, among other routines.

The effective use of the data is carried out by the routines of the management application module (*Figure 1*) and the data are presented in tables, graphs and plans, so as to make it possible the water demand management. These applications allow the checking of consumption variance, making comparisons of data (of different meters and periods), generating new consumption indicators and alarms for abnormal consumption occurrences and printing reports.

4.3 Implementation

A flowchart of the stages for implementing an M-BUS communication network is shown below (*Figure 5*).

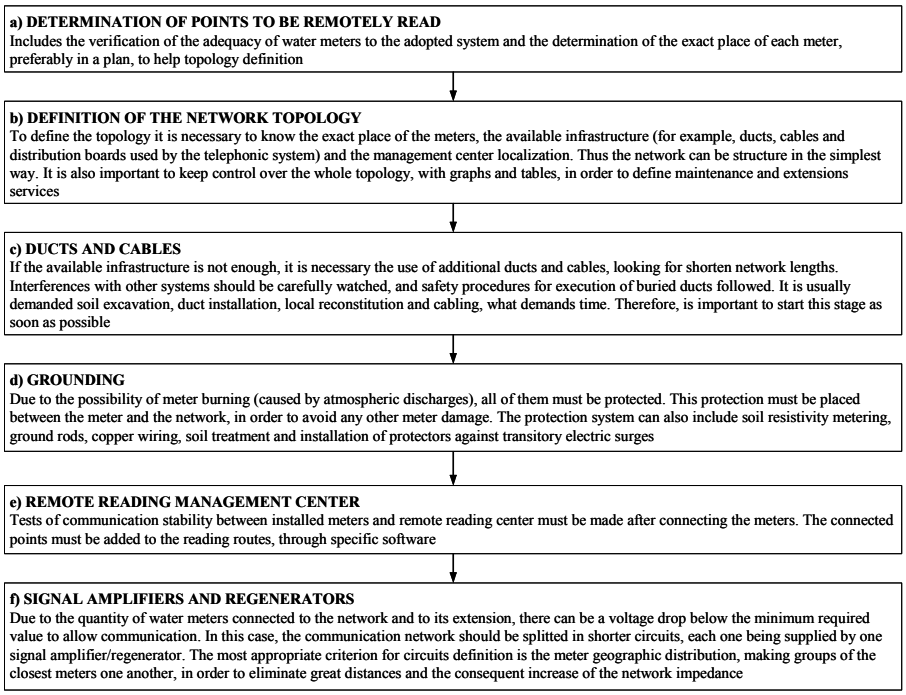

Figure 5 - Stages of M-BUS communication network implementation

5 Case study: Implementation and use of a digital field-bus system at the University of São Paulo

5.1 The University of São Paulo and the *campus Cidade Universitária*

The USP is the largest public university in Brazil and develops its activities of teaching, researching and extension in Units located in the Capital City of the State of São Paulo (internal and external to the *Cidade Universitária*) and in other Units in the interior of the State of São Paulo, besides research centers scattered in the State.

The *campus Cidade Universitária Armando de Salles Oliveira* - CUASO (*Figure 6*) has a fixed population of approximately 55,000 people, a built up area of almost 725,000 m^2, and a total of 214 buildings, according to USP (2003) & (EPUSP, 1998/2003). The CUASO, set up in 1944, occupies an area of approximately 3,600,000 m^2. One can see the existence of buildings of several ages, built according to the needs, technical and building cultures as well as knowledge and availability of resources characteristic of each period. Since their erection, most of the building systems have not undergone any significant interventions, and one can see several types of conceptions, installations and state of preservation of the buildings. Despite the age and diversity of the building plumbing systems, no efforts were made for maintaining,

improving or modernizing the systems, in a rational, systematic and structured way, with proper technical support and information recording. As for the operation and maintenance of the plumbing systems of the *campus*, the teams are small and there is no preventive maintenance apart from some individual initiatives of Facilities Management.

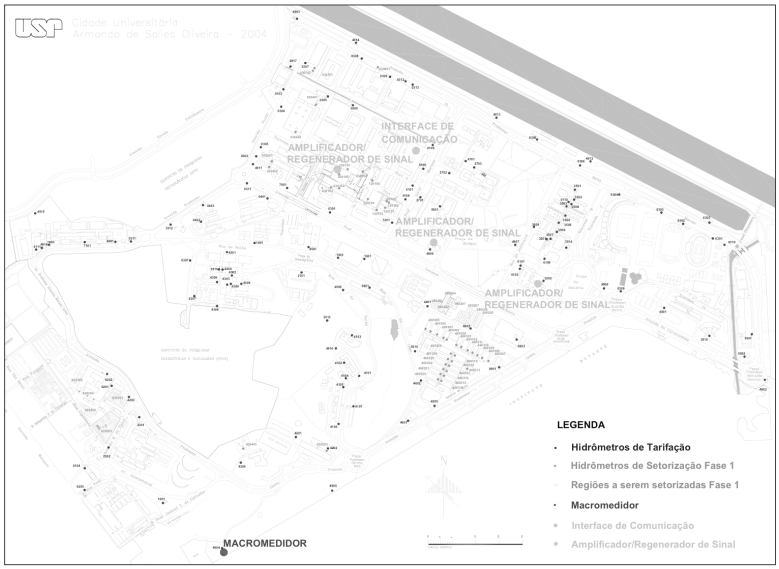

Figure 6 - Plan of *Cidade Universitária*

As characteristics of the cold water supply and sanitary equipment systems of the Units of the *Cidade Universitária* one can point out 19,181 points of use, 467 reservoirs, 36.8 km of external network registered (including the fire network) and a monthly water consumption of 137,881 m^3/month in the second half of 1998, according to EPUSP (1998/2003) & SABESP (1999/2002). All the water supply for the *campus* is carried out by the mains of the public company, which in the city of São Paulo is the *Companhia de Saneamento Básico do Estado de São Paulo* (SABESP). There are some artesian wells in the *campus* which are used only occasionally. This supply is carried out through a single water inlet pipe for the whole *campus*. The water distribution network, which once belonged to the University, is now run by SABESP, which, in 1992, installed more than a hundred meters all over the USP for billing purposes (additional to the only connection that existed until then).

5.2 The Water Conservation Program of the University of São Paulo

In 1998, in the context of the PURA Macro-program 6 - Specific Programs for Saving Water in Different Types of Buildings (non-habitational), the Water Conservation Program of the University of São Paulo - PURA-USP has begun as a case study in a university *campus*, made feasible through an agreement between the USP and the SABESP.

With the implantation of the Program, three were the main goals:
- To reduce the water consumption and keep this reduced consumption profile over time;
- To implant a structured water demand management system; and
- To develop a methodology that could be used in other places in the future.

The implantation of PURA-USP in the *campus* was carried out in two phases:
Phase 1 (7 Units - 1998 and 1999), first aiming at the biggest water consumers (50% of the *campus*) and presenting the different use typologies and Phase 2 (21 Units - 2000 and 2001).

The follow-up of consumption allowed to verify, as a Program impact, the impressive reduction in water consumption in the Units of the *Cidade Universitária*, even after the end of the interventions: 137.881 (2^{nd} half of 1998, except for July) down to 77.574 m^3/month (2^{nd} half of 2004). The PURA-USP has also led to a high net economic benefit for the University - savings in the order of US$ 20 million (1998/2003), according to simplified calculations.

According to SILVA; TAMAKI; GONÇALVES (2004), as example of the methodology proposed for implementation of a Water Conservation Program, the PURA-USP involved activities related to planning, pre-implantation, implantation and post-implantation, the two latter being the cause of the maintenance of consumption at reduced levels, especially the activities of water demand management. As instruments of this management, the bills/invoices, *in loco* readings and especially the submetering (detailed by TAMAKI, 2003) and remote reading were adopted at the *Cidade Universitária*.

5.3 The remote reading system of the *Cidade Universitária*

As objectives for adopting this system at the *Cidade Universitária*, TAMAKI (2003) lists the following:
- Need for better information about water demand (daily consumption and consumption profile over time) and its systematization;
- Evaluation of the impact caused by the interventions carried out by PURA-USP;
- Detection of consumption abnormalities such as leaks;
- Possibility of monitoring, in real time, a great number of consumers simultaneously.

Among the problems found in the implementation of the system the following are worth pointing out:
- Limitation of the range of the system: difficulty or impossibility of communication between the water meters and the remote reading center;
- Instability of some programs, especially the ones causing problems of database integrity;
- Need for replacing water meters: many of them have to be replaced due to humidity penetration, burning of electronic components and even acts of vandalism;
- Need for implanting the grounding system, that was realized only after several water meters and signal regenerators were burnt.

Table 1 shows a summary of the system implantation at *Cidade Universitária* in January 2005, where it can be seen that the remote reading system implanted in the *campus* had at that time 70 water meters which communicate in a stable way out of the 357 (122 for billing and 235 for submetering) to be monitored when the whole system of remote reading were completed.

Table 1 - Situation of the remote reading system of *Cidade Universitária*

Points	*Billing*			*Submetering*	*Total*
	Phase 1	*Phase 2*	*Subtotal*	*Phase 1* [(1)]	
Electronic water meters					
Foreseen	29	93	122	57	179
Installed and working	27	87	114	45	159
Communication network					
Ducts and cables	29	36	65	12	77
Communication interface	1 device (PURA-USP headquarters)				
Signal amplifier/regenerator	3 devices (DTe, EP-Electric, RUSP)				
Grounding system	29	78	107	19	126
Remote reading management center					
Water meters with remote reading	25	32	57	13	70

[(1)] Included only Submetering Phase 1 points. The number of points of Phase 2 is not determined yet, but according to preliminary studies, they would be 178, from which 1 is already working

Now some comments about the elements of the remote reading system at the *Cidade Universitária*:

- *Electronic water meters:* 114 billing water meters and 45 remote submetering meters (totaling 159) are installed and working, with nominal diameters of 20 to 100 mm and nominal flows of 1.5 to 60 m³/h, respectively. *Figure 6* shows a plan of the *campus* with the billing and submetering points of (Phase 1);
- *Communication network:* built according to the description in *Figure 5,* supported by the USP Division of Telecommunications (DTe). The telephone network infrastructure was used, but keeping the M-BUS network apart from the signals generated by the telephone system equipment. *Figure 7* shows in a schematic way, the characteristics of the implanted network;

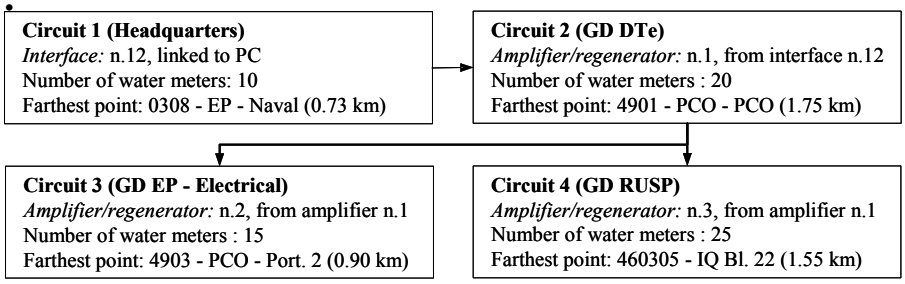

Figure 7 - Characteristics of the communication network circuits

- *Ducts and cables:* the new sections were made by extending a cable from the distributor to the external connecting box that was the closest to the meter box. PVC electro ducts were put in a trench between the connecting box and the meter box. The network is entirely underground, and extends for more than 10 km, considering only the telephone system sections,
- *Communication interface and signal amplifiers/regenerators:* the interface is installed at the remote reading management center and the signal amplifiers/regenerators are at the General Distributors (GDs),
- *Grounding system:* occurrences as burning of the communication M-BUS port and of the electronic register of the water meters were verified, and a protective system against transient electric discharges was installed in 2001;
- *Remote reading management center:* located at the headquarters of PURA-USP (*Figure 8*), is made up by a microcomputer with a program of supervision and management and next to which is installed the communication interface. Since 1998 some programs have been utilized, the current one in use having two main modules:
- *Server:* responsible for the communication between the water meters and the center, including the setup of the equipment parameters and communication with the remote reading network and with the module *Client*, and for managing the database.
- *Client:* interface through which the effective utilization of the data are made, allowing the visualization of the consumption data under tabular and graph form, the carrying out of logical operations and the incorporation of reference maps among other functions.

Figure 8 - Remote reading management center - PURA-USP headquarters

The program receives data from the water meters at every five minutes, what allows the generation of detailed flow rate profiles, through which consumption abnormalities can be identified (*Figure 1*). The follow-up of water meters profiles is performed everyday in order to identify possible consumption abnormalities, the most common being the occurrence of leaks, which can be identified by the sudden increase of the flow rate level or by the occurrence of flow during the night.

6 Final considerations

The implementation of remote reading of water meters, in the context of PURA-USP, became an instrument of water demand management to promote savings of the water supplied to the *Cidade Universitária*.

As reported in the case study, the actions of the water demand management have allowed the reduction of consumption levels, increasing the benefits attained by the interventions in the building systems:

- Reduction of 44% in water consumption - from 137.881 down to 77.574 m³/month (1998/2004);
- Total accrued benefit of US$ 22,7 million (1998/2003), an impressive value, especially when compared to the investment of US$ 2,6 million (1998/2003), from which US$ 170 thousand for the remote reading and submetering.

The implementation itself represented an opportunity for the Universidade de São Paulo to develop technical solutions for the remote reading of water meters, in face of the difficulties inherent to the innovation that they represent in university *campi*.

Many of the benefits gained by USP can be extended to similar situations of implementation of remote reading of water meters for purposes of water demand management, with the due care in observing all the considerations raised and the particularities of each application.

7 References

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8 Presentation of authors

Orestes Marraccini Gonçalves is Full Professor at the University of São Paulo, Department of Civil Engineering.

MSc Humberto Oyamada Tamaki is Engineer Conservation Program of the University of São Pa

MSc Gisele Sanches da Silva is Engineer Conservation Program of the University of São Paulo.

Fernando Rodrigues Tonetti is Civil Engineering Student at University of São Paulo.

The Multiple Functions of Irrigation Ponds in Japan

Kenta Fukagawa (1), Saburo Murakawa (2)
Daisaku Nishina (3), Yasuo Koshikawa (4)
(1) k-fukaga@it.hirokoku-u.ac.jp
(2) muraka@hiroshima-u.ac.jp
(3) nishina@hiroshima-u.ac.jp
(4) ykoshi@ hiroshima-u.ac.jp
Department of Socio-environmental Design, Hiroshima International Univ., Japan
Graduate School of Engineering, Hiroshima Univ., Japan

Abstract

According to the decline in the farming population, irrigation ponds are likely to lose its values. The values of irrigation ponds are not only for farming but also as a place of recreation, a place for the natural creatures and so on.

The purpose of this study is to clarify the functions of irrigation pond, based on the consciousness and the evaluation by the inhabitants living around the ponds.

In this paper, 10 irrigation ponds in Higashihiroshima city are focused on. The city is a place quickly being urbanized. To clarify the difference of inhabitant's consciousness among the irrigation ponds, some surveys were handled. The one of them is a questionnaire survey. The other one is water quality survey. To analysis the results, the statistical techniques were mainly applied.

As the results of this study, the factor that causes the inhabitant to decide the evaluation on categories was clarified. In addition, the functions of irrigation ponds which were not recognized before were perceived.

Keywords

Irrigation pond, Evaluation on Importance, Evaluation on the surroundings of the irrigation ponds, Factor loading matrix

1. Introduction

The irrigation ponds in Japan were constructed for the use of farming water, especially for rice cropping, since 8th century. However, according to the development of Japan to the industrial country, the way of using the water of irrigation ponds has largely changed. Some irrigation ponds lost its values and were filled to be used for the residential area. Some were just abandoned. Especially in the cities under the rapid urbanization, there are plenty of irrigation ponds which are likely to lose its values or already lost its values, such as the ones in Higashihiroshima city.

The values of irrigation ponds are not only for farming but also as a place of recreation, a place for the natural creatures, and so on. The purpose of this study is to clarify the effect of irrigation ponds in consciousness and physical elements to reconsider the way to apply the water of irrigation pond.

2. Outline of the researches on irrigation ponds

2.1 Outline of Higashihiroshima city

The data of Saijo-cho where is the main area of Higashihiroshima city is shown in Table 1 with the data of the year 1984. After the move of Hiroshima university from the center of Hiroshima city, finished moving in 1984, this city has developed very quickly. The population in 2003 is about 1.5 times more than the population in 1984. According to the rapid urbanization, especially the number of farmers decreased a lot. Then the square measure of agricultural land and the number of irrigation ponds decreased because of the decline in the farming population..

Table 1-Data of Saijo-cho in Higashihiroshima city

		In 1984	In 2003	Change ratio
Square measure		94.82		1.00
Total population		33,376	54,762	1.51
Density of population		2,262	1,406	1.51
Numbers of farmers		2,262	1,406	0.62
Agriculutral land in suquare measure	Rice field	1,618	1,222	0.76
	Crop field	57	44	0.77
	Silva	11	8	0.73
	Total	1,686	1,274	0.76
Total numbers of irrigation pond		2,181	2,038	0.93

2.2 Outline of Irrigation ponds

The data of targeted irrigation ponds and ground surface conditions of their surroundings are shown in Table 2. The 10 irrigation ponds are categorized into three kinds, such as the ponds situated in a hill side area, the ponds situated in urban area, and the ponds situated in suburban area, as the following.

a) Hill side area – Tabusa
b) Urban area –Isomatsu, Osawada, Karimata, Nanatsu, Shouya, Okuda
c) Suburban area – Shitami, Yoshigou, Osako

2.3 Outline of the measurement

The questionnaire survey to the people was done in September, 2003. The distributed questionnaires were 100 in each area of around the ponds, and the average ratio of

collected questionnaires was approximately 90%. The targets were the inhabitants living at the distance of within 500m in each irrigation pond. However, with Okuda, we could not find enough inhabitants with that distance and extended the distance to 1000m.

The method of distribution is that we visited every single house including apartment houses around each pond and asked to fill in the questionnaire. The inhabitants were given several days to fill it out. After several days, we revisited and collected the questionnaires.

The numbers of distributed were 1000, 100 in each area of the irrigation pond, and collected were 954. The numbers of valid collected questionnaires were 937.

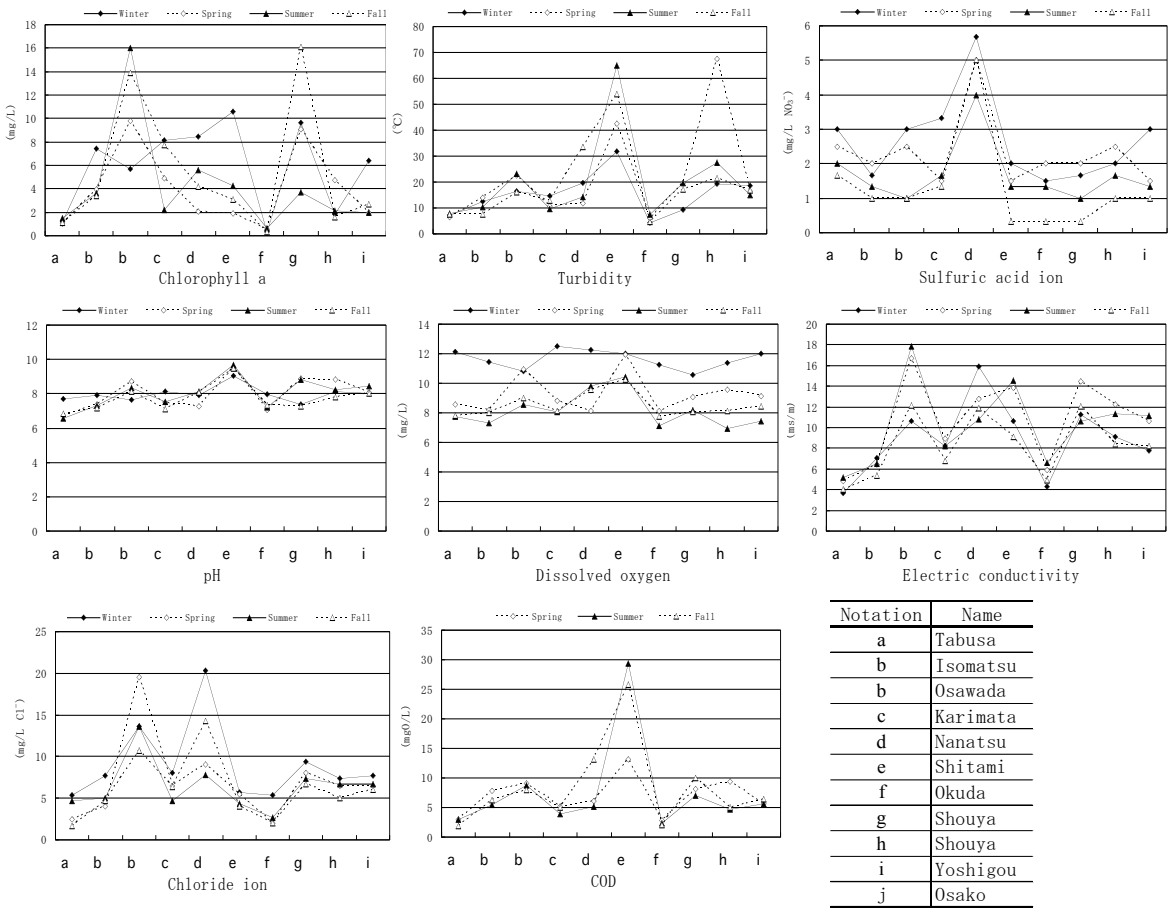
Table 2 - Data of irrigation ponds and ground surface conditions of their Surroundings (The surface ground conditions are calculated by dividing the air photos of each irrigation pond by 10m × 10m meshes from the edge of the water.)

Name of irrigation pond	Data of irrigation ponds						Percentage of ground surface conditions around irrigation ponds(%)					
	Total of bank length(m)	Height of bank top(m)	Width of bank top(m)	Volume of bank (1000 ㎥)	Volume of water storage (1000 ㎥)	Square measure of water(ha)	Architectural structure	Artificial ground surface	Silva	Crop and rice field	Bare and grass field	Water space
Tabusa	83	20.0	2.0	39.840	126.00	3.40	1.0	4.7	79.1	5.2	9.2	0.7
Isomatsu	66	5.1	2.8	2.060	41.00	1.14	20.2	46.5	21.8	0.3	11.2	0.0
Osawada	212	5.4	3.5	7.418	80.83	4.85	27.3	28.4	18.4	2.8	23.0	0.0
Karimata	96	6.8	4.0	13.000	94.00	4.42	10.7	21.4	55.0	3.7	9.2	0.0
Nanatsu	264	19.7	16.5	19.971	145.06	15.88	14.3	19.5	41.3	1.1	23.0	0.8
Shitami	275	3.1	3.0	3.170	17.40	2.90	10.7	30.6	3.5	32.5	22.7	0.0
Okuda	185	8.9	3.8	3.830	101.80	3.30	0.8	18.8	52.2	0.0	26.0	2.2
Shouya	164	5.9	6.3	1.889	10.90	1.70	16.3	16.6	3.8	53.3	10.0	0.0
Yoshigou	270	3.1	4.0	3.100	32.41	4.42	5.0	9.2	1.5	68.0	15.6	0.7
Osako	82	5.0	5.8	2.445	33.10	3.82	9.2	17.2	30.9	7.6	29.9	5.3

3. Water quality in each irrigation pond in each season

The actual state of water quality in each irrigation pond in each season is shown in Figure 1. In Tabusa, Isomatsu and Okuda, there is only a small difference in any measured items. However, in Nanatsu and Shittami, on the other hand, there is a large

Figure 1-Actual state of water quality in each irrigation pond in each season



Notation	Name
a	Tabusa
b	Isomatsu
b	Osawada
c	Karimata
d	Nanatsu
e	Shitami
f	Okuda
g	Shouya
h	Shouya
i	Yoshigou
j	Osako

water quality difference among the seasons. Especially in Nanatsu, the measured values of electric conductivity, chlorophyll a, sulfuric acid ion and chloride ion are very high in winter. This phenomenon might be caused by the sluice of the irrigation pond in October which probably causes the increase of the density of domestic wasted water.

4. Attributes of answerers at the total of 10 irrigation ponds

The attributes of answerers at the total of 10 irrigation ponds are shown in Figure 2. As it is shown in the items of gender and age, about 60% is female and about 40% is the age of more than 60. More than 90% of answerer is married and more about 45% of them has 3 or 4 people in family. The major house type is detached and more than 70% of the answerers is living in Higashihiroshima city more than 11years. The major occupation is house frau and only about 20% of the answerers farms on holiday.

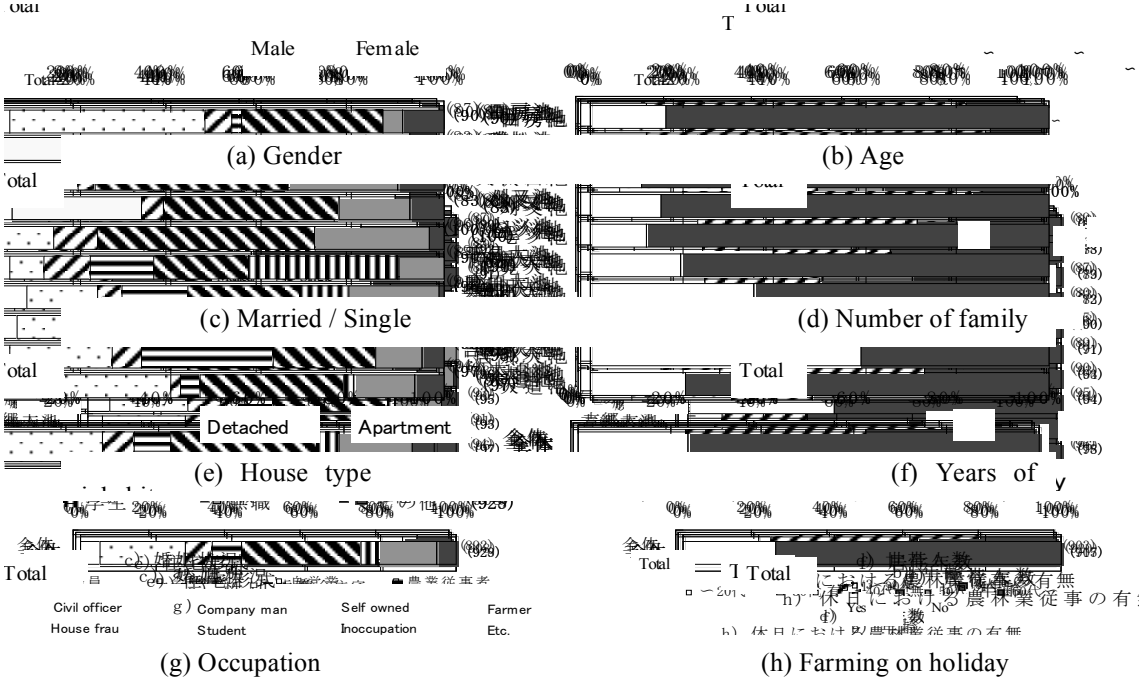


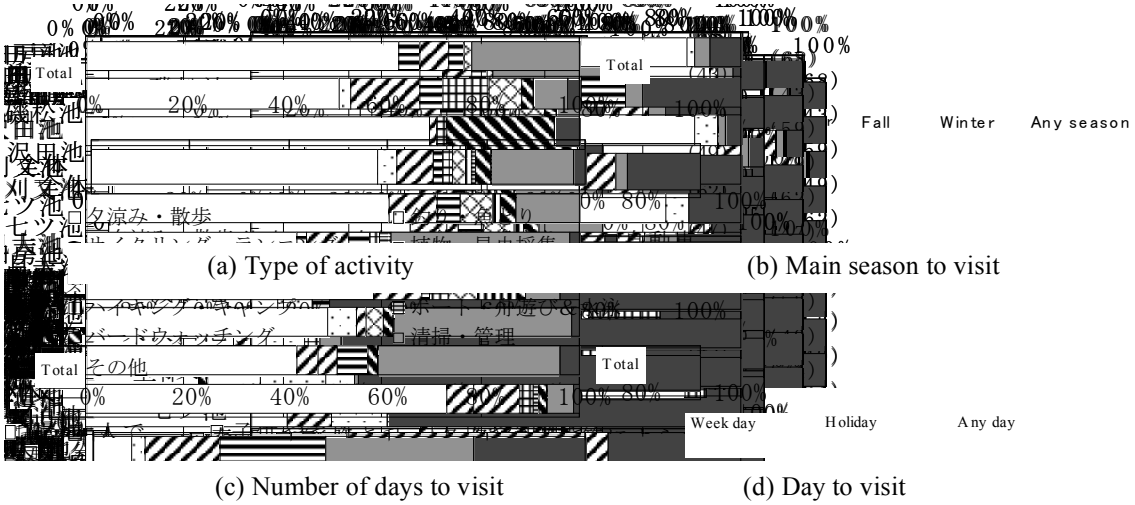
Figure 2-Attributes of answerers at the total of 10 irrigation ponds

5. Actual utilizations at the total of 10 irrigation ponds

The actual utilizations at the total of 10 irrigation ponds are shown in Figure 3. The utilization are analyzed by the question which asks the frequency of the answerers to go to irrigation pond, and when the selected answer of frequency is more than "some times go to irrigation pond", we embraced the answer.

The main activities done around irrigation ponds are cool off in the evening and scroll. For these kinds of activity, there is no special season. The second well done activity is cleaning/administration, and there is also no special season.

Looking at the frequency of visiting, more than 40% of irrigation pond users visits irrigation ponds at least 1 or 2 days a week. In addition, more than 50% of the users answered as it does not matter whether the day is week day or holiday.



(a) Type of activity (b) Main season to visit

(c) Number of days to visit (d) Day to visit

Figure 3- Actual utilizations at the total of 10 irrigation ponds

6. Evaluation on importance of irrigation ponds

The result of factor analysis for evaluation on importance of irrigation pond is shown in Table 3 as the factor loading matrix. At the 1st factor, the items, such as "For comfortable living environment", "For good landscape", "For culture and history of region", and so on, marked high score. Therefore the 1st factor is named as "Function for forming regional environment".

Table 3 - Factor loading matrix for evaluation of irrigation ponds on importance

Evaluation on importance of irrigation pond :Irrigation pond is important for.	1st Factor Function for forming regional environment	2nd Factor Function for utilization and fire control	3rd Factor Function for inhabitation of creature
For comfotable living environment	0.812	0.331	0.094
For good landscape	0.803	0.308	0.062
For culture and history of region	0.604	0.387	0.324
For place of education for children	0.603	0.209	0.529
For place of community	0.596	0.362	0.366
For place to stroll around	0.589	0.076	0.452
For controling microclimate	0.576	0.481	0.281
For exixstence of biogeocenosis	0.567	0.288	0.400
For preventing water damage	0.347	0.702	0.133
For infilitation of water to ground	0.341	0.613	0.344
For agriculture	0.271	0.597	0.031
For emergency life water	0.181	0.567	0.271
For fire control water	0.154	0.546	0.206
For fishing	0.183	0.202	0.580
For place to cultivate fish and aquatic plant	0.096	0.424	0.437
contribution ratio (%)	25.319	19.426	11.687
accumulative contribution ratio (%)	25.319	44.745	56.432

The factor loadings of more than 0.4 are closed in square

At the 2nd factor, the items, such as “For preventing water damage”, “For infiltration of water to ground”, “For agriculture”, and so on, marked high score. The 2nd factor is assessed as the function which reflects the inhabitant’s consciousness that the irrigation ponds well works for agriculture and preventing floods or controlling fire. Therefore the 2nd factor is named as “Function for utilization and fire control”.

At the 3rd factor, the items, such as “For fishing”, and “For place to cultivate fish and aquatic plant” marked high score. According to the functions, the factor is named as “Function for inhabitation of creature”.

As the result of this analysis, the functions above are extracted when the evaluation of irrigation ponds is focused on its importance from inhabitant’s consciousness.

7. Evaluation on environment of irrigation ponds and their surroundings

The result of factor analysis for evaluation on environment of irrigation ponds and their surroundings is shown in Table 4 as the factor loading matrix.

At the 1st factor, the evaluation items, such as “Preferable atmosphere”, “Good scenery”, “Richly endowed with nature”, and so on, marked high score. Therefore the factor is named “Efficiency of naturalness”.

At the 2nd factor, the evaluation items, such as “Needed administration of pond by inhabitants”, “Needed familiarity”, and “Preservation of culture and history of region” marked high scores, the factor is named “Commonality consciousness of region”. This factor reflects the inhabitant’s consciousness of that the irrigation pond supports forming the community of region nearby.

At the 3rd factor is named “Efficiency of sanitation” because of the high scored evaluation items, such as “No smell from irrigation pond”, “No noise”, “No insalubrious place around”, and “A lot of moisture”.

At the 4th factor, the items, such as “Can be used for recreation”, “Can be used for event”, and “Can be used as educational place for children”, marked high score. Therefore the factor is named “Efficiency of utilization”.

The 5th factor is named “Efficiency of easing temperature” by the evaluation items marked high score, such as “Can be well ventilated”, “Makes micro-climate cooler in summer”, and “Makes to feel liberating”.

The 6th factor is named “Efficiency of cleanliness” by the evaluation items which are “Can be used for living life water” and “Water is clean”.

The 7th factor is named “Efficiency of safety” because the evaluation items, “Less vulnerable to floods” and “Water accident measure is taken”, which are all relating to safety of irrigation pond.

The 8th factor is named “Efficiency of cultivation” by the evaluation items relating to food productivity, such as “Can alimentate ground water” and “Can help cultivation”.

The 9th factor is named “Efficiency of water utilization” because the high scored evaluation items, such as “Can be used for fire controlling water”, and “Can be used for agriculture”, are both relating to the utilization of water.

As the result of this analysis, 9 efficiencies of irrigation ponds and their surroundings are extracted from inhabitant’s consciousness, and the indices which have relations to the efficiencies were clarified.

Table 4- Factor loading matrix for evaluation on environment of irrigation pond and including its surroundin gs

Evaluation items (About irrigation pond and its surroundings)	1st factor Efficiency of naturalness	2nd factor Commonality conciousness of region	3rd factor Efficiency of sanitation	4th factor Efficiency of utilization	5th factor Efficiency of easing temperature	6th factor Efficiency of cleanliness	7th factor Efficiency of safety	8th factor Efficiency of cultivation	9th factor Efficiency of water utilization
Preferable atmosphere	0.737	-0.023	0.072	0.037	0.082	0.070	0.182	0.130	-0.011
Good scenery	0.720	0.149	0.001	0.050	0.238	0.062	0.157	0.146	-0.012
Richly endowed with nature	0.644	0.132	-0.028	0.176	0.076	0.064	0.013	0.036	0.162
Sylvan	0.619	0.112	-0.002	0.057	0.076	0.223	0.038	0.007	-0.046
Change of water quality and quantity	0.355	0.257	-0.266	0.026	-0.154	0.036	0.074	-0.045	0.128
Stopover of migratory birds	0.284	0.117	-0.067	0.200	0.046	-0.234	0.064	0.082	0.251
Needed Administration of pond by inhabitans	0.119	0.533	0.001	0.078	0.174	0.075	0.068	0.098	0.089
Needed familiarity	0.336	0.531	0.030	0.355	0.230	0.081	0.143	-0.031	-0.056
Preservation for culture and history of region	0.303	0.459	0.175	0.184	0.237	-0.072	0.060	0.081	0.171
No nuisance	-0.011	-0.382	0.338	-0.057	0.069	0.008	-0.007	0.108	-0.049
Forming peculier landscape	0.307	0.359	0.041	0.194	0.278	-0.031	0.176	0.277	0.064
No influence to water quality by discharged water	0.059	-0.284	0.266	-0.014	-0.062	0.258	0.138	-0.119	0.038
No smell from irrigation pond	0.053	-0.033	0.719	0.095	0.088	0.350	-0.153	-0.023	0.024
No noise	-0.069	0.084	0.549	-0.073	0.012	-0.010	-0.186	0.042	0.023
No insalubrious place around	0.149	-0.082	0.478	-0.080	0.071	0.326	0.164	-0.043	0.086
A lot of moisture	0.057	0.005	-0.405	0.025	0.040	0.047	-0.198	0.159	0.158
No destruction of nature	0.011	0.004	0.301	-0.020	-0.026	-0.086	0.059	-0.050	0.062
Can be used for recreation	0.115	0.224	-0.001	0.724	0.012	0.004	0.070	0.075	0.180
Can be used for events	0.088	0.078	-0.126	0.634	0.080	0.204	0.058	0.165	0.010
Can be used as educational place for childeren	0.350	-0.014	-0.072	0.443	0.286	0.098	0.111	0.161	-0.069
Can be well-ventilated	0.143	0.137	-0.011	0.043	0.632	-0.095	0.033	0.040	0.241
Makes micro climate cooler in summer	0.244	0.293	0.009	0.086	0.536	0.243	0.172	0.150	0.132
Makes to feel liberating	0.386	0.287	0.120	0.129	0.453	-0.130	0.203	0.144	0.065
Makes micro-climate warmer in winter	0.011	-0.009	-0.015	0.108	0.252	0.048	0.218	0.223	-0.099
Can be used for living life water	0.068	0.203	-0.057	0.165	-0.099	0.603	0.066	0.164	0.059
Water is clean	0.331	-0.100	0.072	0.133	0.067	0.557	0.161	0.153	0.071
Abundance of water quantitiy	0.140	-0.016	0.151	0.079	0.259	0.327	0.007	-0.071	0.301
Less vulnerable to floods	0.176	0.073	0.100	0.032	0.142	0.049	0.791	-0.035	0.206
Water accident measure istaken	0.162	0.083	-0.065	0.096	0.054	0.101	0.516	0.057	-0.055
Can alimentate ground water	0.090	0.214	-0.068	0.089	0.095	0.017	-0.003	0.614	0.079
Can help cultivatation	0.126	-0.166	-0.179	0.187	0.046	0.130	-0.006	0.493	0.065
Conciousness for conservation by inhabitants is high	0.187	0.111	0.109	0.138	0.109	0.131	0.202	0.221	0.092
Can be used for fire controlling water	-0.026	0.064	0.012	0.094	0.156	0.096	0.030	0.061	0.588
Can be used for agriculture	0.147	0.341	0.067	-0.070	0.003	0.061	0.084	0.326	0.421
contribution ratio (%)	9.002	5.273	5.106	4.720	4.519	4.178	4.080	3.506	2.962
accumulative contribution ratio (%)	9.002	14.275	19.382	24.102	28.620	32.799	36.879	40.385	43.347

8. Correlation coefficients between "Evaluation on importance of irrigation ponds" and "Evaluation on environment of irrigation ponds and their surroundings"

Table 5 shows the correlation coefficients between 3 extracted functions on importance and 9 extracted efficiencies on the evaluation of irrigation ponds and their surroundings.

Focusing on the functions of importance, "Function for forming regional environment" has positive relation with "efficiency of naturalness" and has negative relation with "Efficiency of water utilization". Therefore, when the surroundings of irrigation ponds are richly endowed with nature, and there is less opportunity for "the utilization of agriculture" and "the utilization of fire controlling water", the function as water space is well recognized in the inhabitant's consciousness.

The 2nd factor "Function for utilization and fire control" has negative relation with "Efficiency of utilization" and has positive relations with "Efficiency of cleanliness", "Efficiency of cultivation", and "Efficiency of water utilization". According to this result, when an irrigation pond is not well arranged for recreation, it well recognized as its birthright.

The 3rd factor "Function for inhabitation of creature" has positive relation with "Efficiency of utilization" and has negative relations with "Efficiency of safety", "Efficiency of cultivation", and "Efficiency of water utilization". This means even the irrigation pond which neither functions as filtration of water nor cultivation, it is recognized as important for the creature to inhabit.

As the result of this analysis, the relationship between the evaluation on importance and the evaluation on the environment was clarified.

Table 5 - Correlation coefficients between "Evaluation on importance of irrigation pond" and "Evaluation on environment of irrigation ponds and their surroundings

Evaluation factors on irrigation enviromnet \ Evaluation factors on importance of irrigation pond		1st Factor Function for forming reginal environment	2nd Factor Function for utilization and fire control	3rd Factor Function for inhabitation of creature
1st factor	Efficiency of naturalness	0.883 **	-0.005	0.153
2nd factor	Commonality conciousness of region	0.371	0.182	0.133
3rd factor	Efficiency of sanitation	-0.434	0.143	-0.185
4th factor	Efficiency of utilization	0.447	-0.472	0.535
5th factor	Efficiency of easing temperature	0.361	0.334	-0.318
6th factor	Efficiency of cleanliness	0.020	0.548	0.000
7th factor	Efficiency of safety	0.243	0.380	-0.589
8th factor	Efficiency of cultivation	-0.316	0.764 *	-0.814 **
9th factor	Efficiency of water utilization	-0.538	0.579	-0.637 *
Numbers of samples		10	10	10

9.Correlations between inhabitant's consciousness and physical indices

To clarify the relationship between inhabitant's consciousness and physical indices, correlation analysis was applied for as water quality and surface ground conditions.

9.1 Correlations between water quality and "evaluation on environment of irrigation ponds and their surroundings"

The correlation coefficients between water quality and "evaluation on environment of irrigation pond and including its surroundings" are shown in Table 6.

From the result, it is clear that the 6th factor "Efficiency of cleanliness" has the highest correlation with water quality. In addition, the items marked more than 0.5 on correlation coefficients are "Electric conductivity", "Dissolved oxygen", "pH", "Chloropyll a", "C1-", and "COD". Therefore, it is clear that "Efficiency of cleanliness" is improved by amelioration of water quality, the color of water, and less sewage contamination.
With "Efficiency of water utilization", the factor has positive relation with "Turbidity" and has negative relations with "NO_3" and "$C1^-$". Referring to figure 1, "Turbidity" especially in fall is very high in Shitami and Yoshigou, and in Tabusa and Okuda, on the other hand, "Turbidity" is very low. According to this matter, there is a positive

relation occurring at the correlation coefficients.

Table-6 "Correlation coefficients between water quality" and "evaluation on environment of irrigation ponds and their surroundings"

Measured items of water quality / Factors of evaluation on irrigation enviromnet		Electric conductivity	Dissolved oxygen	pH	Chlorophyll a	Turbidity	NO_3	Cl^-	COD
1st factor	Efficiency of naturalness	0.064	0.121	-0.074	-0.233	-0.043	0.277	0.177	-0.213
2nd factor	Commonality conciousness of region	-0.169	0.071	-0.393	-0.133	-0.381	0.462	0.003	-0.080
3rd factor	Efficiency of sanitation	-0.076	-0.111	0.107	-0.109	0.390	-0.171	-0.148	-0.026
4th factor	Efficiency of utilization	-0.026	-0.224	-0.256	0.086	-0.463	-0.020	0.234	-0.461
5th factor	Efficiency of easing temperature	0.396	0.132	0.427	0.191	0.239	-0.337	0.054	0.111
6th factor	Efficiency of cleanliness	-0.822 *	-0.530	-0.612	-0.596	-0.486	-0.368	-0.755 *	-0.533
7th factor	Efficiency of safety	0.073	0.162	0.136	-0.376	0.155	0.425	-0.068	0.269
8th factor	Efficiency of cultivation	-0.227	-0.100	0.154	-0.456	0.447	-0.238	-0.533	0.160
9th factor	Efficiency of water utilization	-0.232	0.165	0.400	-0.356	0.570	-0.521	-0.687 *	0.488
Numbers of samples		10	10	10	10	10	10	10	10

9.2 Correlations between surface ground conditions and "evaluation on environment of irrigation pond and including its surroundings"

The result of correlation analysis between surface ground conditions and "evaluation on environment of irrigation ponds and their surroundings" is shown in Table 7.

Focusing on the items that mark more than 0.5 on coefficients of correlation, the 1st factor has negative relation with "Artificial ground surface" and has positive relation with "Bare and grass field". From this result, it is possible to say that the construction of artificial surface ground affects the evaluation of "Efficiency of naturalness" by the increase and decrease of each surface ground condition.

The 6th factor "Efficiency of safety" has negative relations with "Artificial structure" and "Artificial ground surface" and has positive relation with "Silva". This is according to the apprehensiveness of inhabitants on the degradation of water quality by the destroying "Silva" and constructing "Artificial structure" and "Artificial ground surface"

The both 3rd factor "Efficiency of utilization" and 8th factor "Efficiency of cultivation" have positive relation with "Crop and rice field". However, the 4th factor "Efficiency of utilization", on the other hand, has negative relation with "Crop and rice field" and has positive relation with "Bare and grass field".

As the result of this analysis, there is a capability of improving the evaluation of irrigation ponds on utilization by arranging either effective and attractive grass or bare field beside irrigation ponds where the irrigation ponds users can organize some kinds of recreation.

Table 7 - Correlation coefficients between surface ground conditions and "evaluation on environment of irrigation ponds and their surroundings"

Evaluation factors on irrigation enviromnet \ Evaluation factors on importance of irrigation pond		Architectural structure	Artificial ground surface	Silva	Crop and rice field	Bare and grass field	Water space
1st factor	Efficiency of naturalness	-0.346	-0.515	0.399	-0.275	0.609	0.411
2nd factor	Commonality conciousness of region	-0.152	-0.209	0.655 *	-0.474	-0.173	0.064
3rd factor	Efficiency of sanitation	-0.138	-0.172	-0.325	0.599	-0.374	-0.241
4th factor	Efficiency of utilization	0.067	0.016	0.326	-0.552	0.506	0.351
5th factor	Efficiency of easing temperature	-0.167	-0.489	-0.332	0.479	0.414	0.373
6th factor	Efficiency of cleanliness	-0.752 *	-0.543	0.646 *	-0.089	-0.297	0.251
7th factor	Efficiency of safety	-0.265	0.066	0.000	-0.039	0.298	0.055
8th factor	Efficiency of cultivation	-0.534	-0.290	-0.318	0.747 *	-0.277	-0.193
9th factor	Efficiency of water utilization	-0.376	0.019	-0.423	0.635 *	-0.233	-0.061
Numbers of samples		10	10	10	10	10	10

10. Conclusions

This survey was carried out to clarify the functions of an irrigation pond by the inhabitant's consciousness and the statistic analysis was applied for that purpose. The list of the clarified knowledge is as the following.

1) There are some differences on water quality of some irrigation ponds in each season.
2) The evaluation on importance of irrigation pond is mainly composed by 3 factors and each factor emphasis the functions of the irrigation pond recognized evaluated by the inhabitants.
3) The evaluation on environment of irrigation ponds and their surroundings is mainly composed by 9 factors. In addition, the evaluation is effected by the physical elements, such as water quality, ground surface conditions, and so on.
4) The relations of inhabitant's consciousness and physical indices have positive and negative relations. They affect the evaluation results and are intricately interrelated.

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The authors wish to express the gratitude for the subsidy of science research by "The Kajima Foundation" from the year 2002 to 2003 (Head investigator: Saburo

Murakawa).

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Main author presentation

Kenta Fukagawa is the Research Associate at Department of Socio-environmental Design, at Hiroshima International University. His special field is the multiple functions of irrigation pond.

Examination of Rain Water Use System in House in Consideration of Infiltration and Reservation

Hiyoruki Kose [(1)], Kuniharu Yoshimoto [(2)] and Koshiro Nakajima [(3)]
(1) hkose@eng.toyo.ac.jp, Toyo University
(2) yoshi@eng.toyo.ac.jp, Toyo University
(3) nakajima016@sekisui.jp, Sekisui Chemical Co., Ltd.

Abstract

The necessity of utilizing the rainwater effectively as water source of one own expense heightens, when they worry about fresh water materials shortages of the world. In the rainwater utilization, it is necessary to also examine the water quality with the demand and supply balance of rainwater. Then, the result of simulation on quantity of water balance and residence time of rain water at rain water infiltration and reservation system in use of single-family house, while the outline of "Center for Regional Industrial Symbiosis Research, Toyo University (CRIS)" which the practical research project realizes the circulation society and society system, is reported in this study. In assumed house, the calculation was carried out by two cases in supplying the rainwater in case only the toilet and toilet and washing application. And, the evaluation index for 1 year variously was obtained in the case in which the rainwater infiltration rate is made to change at 0.0-1.0 and the capacity of rainwater storage tank is made to change in 1.0-10.0 m^2. As the result, the effectiveness of attempting the rainwater utilization, while it makes the rainwater filtration a basis, could be confirmed. In the future, it is necessary that it carries out the simulation in each utilization condition and each place, while measured data are collected by the field experiment, and evaluates the effectiveness of rainwater utilization system many-sided.

Keywords

rainwater, simulation, regional industrial symbiosis

1. Introduction

According to reduction of CO_2 emission for prevention from global warming and heat island of the city, the necessity of utilizing water resources in cities such as the rainwater effectively heightens more and more. And, in the city, it is, while the drought of the dam which is a water source frequently occurs, and the runoff of the untreated sewage to rivers, etc. in the combined sewerage becomes a problem with the river rapidly rising in the heavy rainfall, and the city flood arising. It becomes that these problems are synthesized like **Figure 1**, and the improvement on the aqueous environment through storage and infiltration and utilization of rainwater in the region is expected. And, the utilization as urgent resources in the disaster is expected stored water.

In addition, the waterfront environment such as amenity water facilities and biotop has been introduced into the architecture outside space from the increase of recovery of the natural ecosystem in the city and environment consciousness of the citizen. And, it contributes to the improvement in the amenity of the region with introducing natural energy such as wind force and solar light with the annexing to this space, and utilizing it as a core of the region community.

Though the rainwater utilization contributes to the region regeneration by using efficiently, maintenance of the appropriate water quality is necessary, when effective utilization and environmental improvement are advanced.

From these backgrounds, in the Center for Regional Industrial Symbiosis Research, Toyo University (CRIS) which was started in the 2004 , the research is carried out for the purpose of clarifying evaluation in introducing the distributed infrastructure system that the rainwater is stored and infiltrated and utilizes variously and introduction effect to the region in the building such as the detached house. And, the schema of evaluation item scheduled with installed experimental facility “circulations and purification type natural regeneration demonstration facility in water resources” is shown in **figure 3**, and the field photograph is shown in **photo 1**.

In this paper, the result of quantity of water balance and evaluation on residence time, etc. for carrying out basic study on a series of research, while simulation program of rain water storage and infiltration compatible rain water utilization system in the housing is developed, is reported. In addition, this paper is created based on the reference (1).

2. Simulation condition

2.1 Installation condition

In this paper, the evaluation program of rain water storage and infiltration and utilization system considering application independent water use in the housing was made. The following are shown in **figure 4** : Building and condition of rain water utilization system as a premise of the simulation of this paper. The system, which gave priority to the infiltration that it collects the rainwater from the roof and passes through infiltration trench and seepage pit in the underground from the gutter, that it accumulates in the rainwater storage tank, was assumed. It was set the rainwater storage tank the

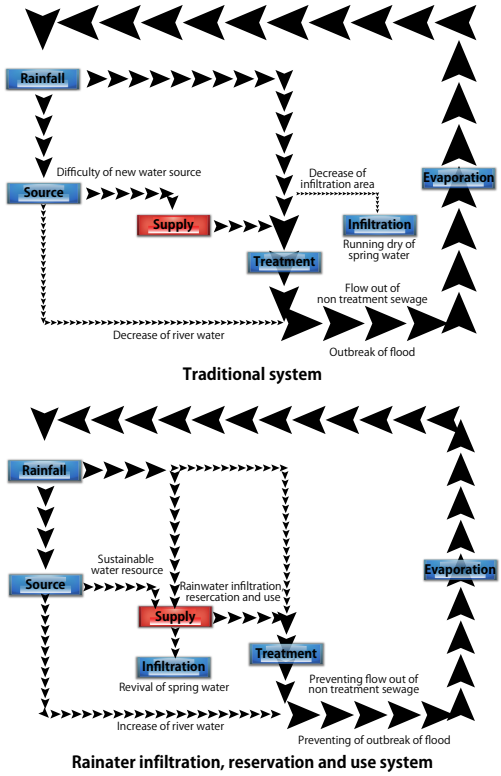

Figure 1 - The paradigm shift of water cycle in the city

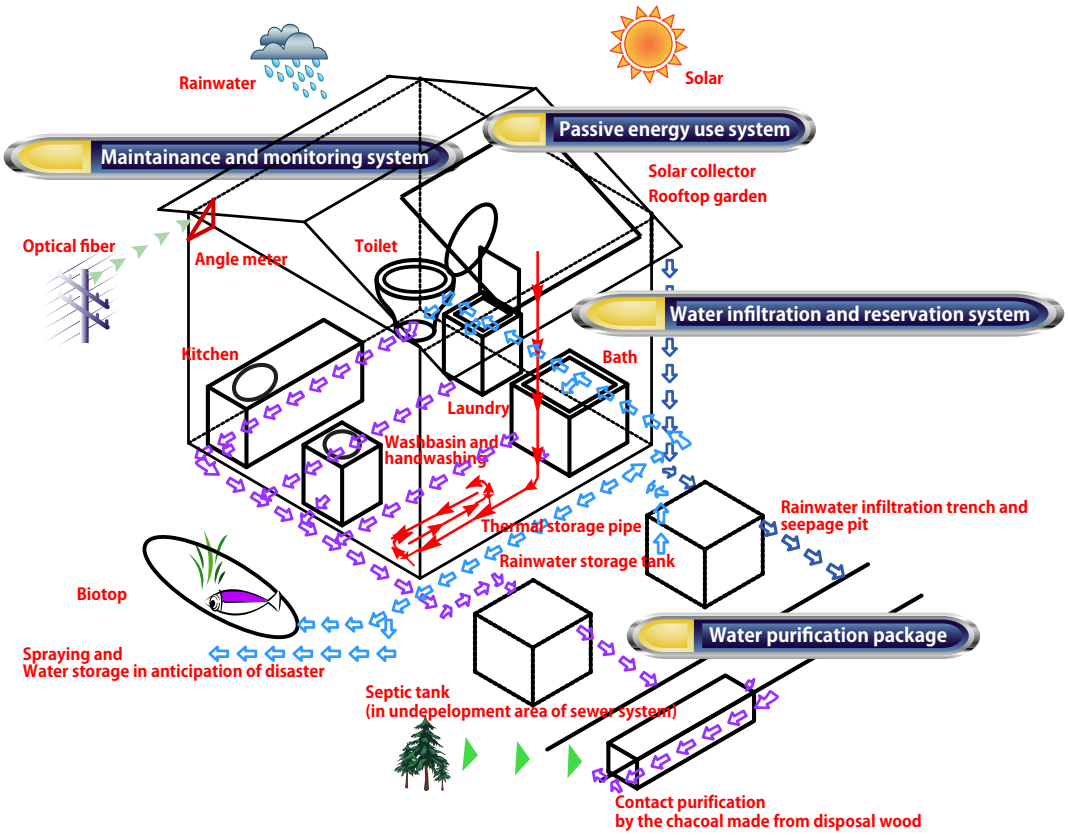

Figure 2 - The technology development element of the distributed infrastructure in CRIS

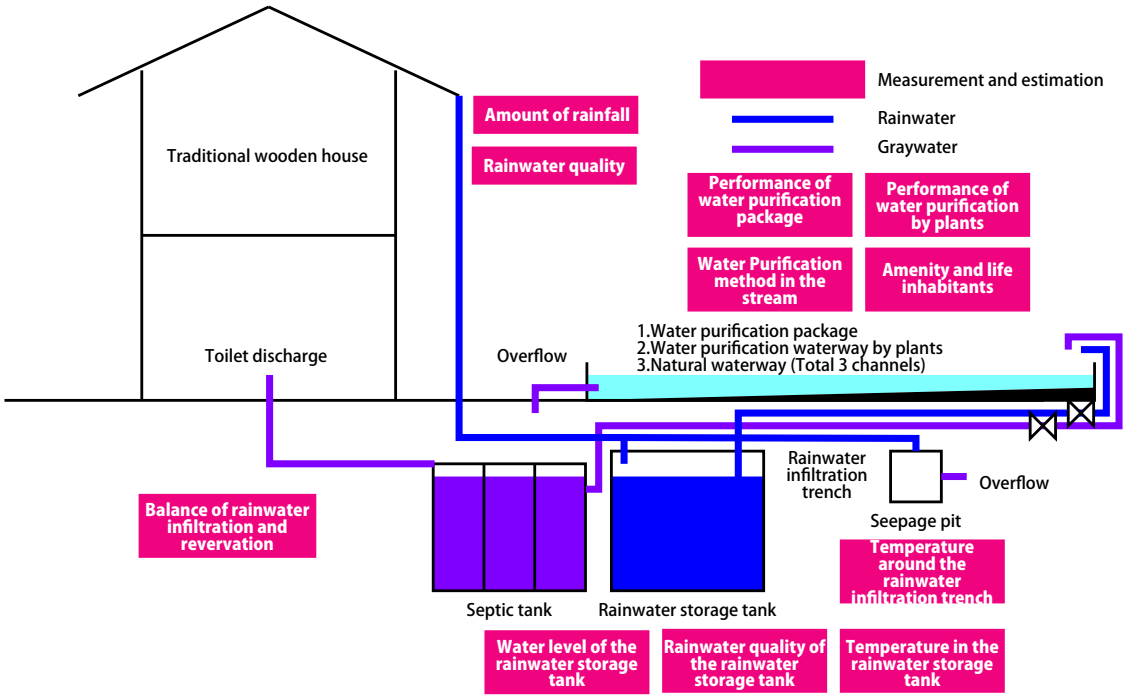

Figure 3 - The schema of experimental facility and evaluation element scheduled

Photo 1 - The laboratory of CRIS

makeup water comes in the makeup water place, and in order to makeup water stop at the stopping water level. And, it should be overflowed, when an effective capacity of the rainwater storage tank was exceeded. In this paper, catchment area was made to be $100m^2$ as initial condition, and water consumption in each day was made to be 1000L as a standard water consumption of the 4 house group. And, the discharge coefficient of rainwater was made to be 0.9, and initial rainfall elimination quantity was made to be 0.5mm.

2.2 Evaluation method

An effective capacity of the rainwater storage tank was made to change from $1.0m^3$ to $10.0m^3$, and rainwater infiltration rate of rainwater infiltration tranch and seepage pit was made to change from 0.0 in 1.0, and the simulation was carried out. Using water consumption and rainfall data in every 1 hour, the following were obtained. Annual frequency of overflow, replenishment frequency of the tap water, average water exchange days, water substition rate by use of rainwater, rainwater use rate for recycled water, overflow rate in each case. The definition of each evaluation index is shown at **Table 1**.

And, in this paper, the simulation was carried out on the assumption of only the toilet using or, rainwater for toilet and washing by estimating extension within the water usage application of the future rainwater utilization, and it compared the result.

2.3 Rainfall data

In this paper, rainfall data from November 2003 in October 2004 observed in Kawagoe City, Saitama Prefecture, which left 4km from the Kawagoe Campus of Toyo University almost, was used (**Figure 5**). There is hardly the precipitation from January over February in the winter, and there is small precipitation on this rainfall from the June over July, which is the rainy season from common year, and it is observation historically maximum precipitation in this region in October. Still, the annual precipitation becomes the common year ordinary.

2.4 Water consumption according to the application of the housing

In this paper, it was to multiply contribution ratio of each water usage application (kitchen , bath, washbasin, handwashing, laundry and toilet) in 24 dwelling unit in every hour of whole dwelling unit of research object (the summer weekday) which reference 2) show (**Table 2**) by water consumption in each day, and application independent water consumption was calculated. Though it is a typical pattern on the order of 8 o'clock and 21 o'clock with the peak of the load, the water consumption rate of the toilet is lower than that of the data, which is general with 14.0%. However, what will be considered in future, when the popularization of the water saving type stool is considered, seems to be appropriate. By assuming that the water usage was done in the every day equal pattern in this paper, the simulation was carried out.

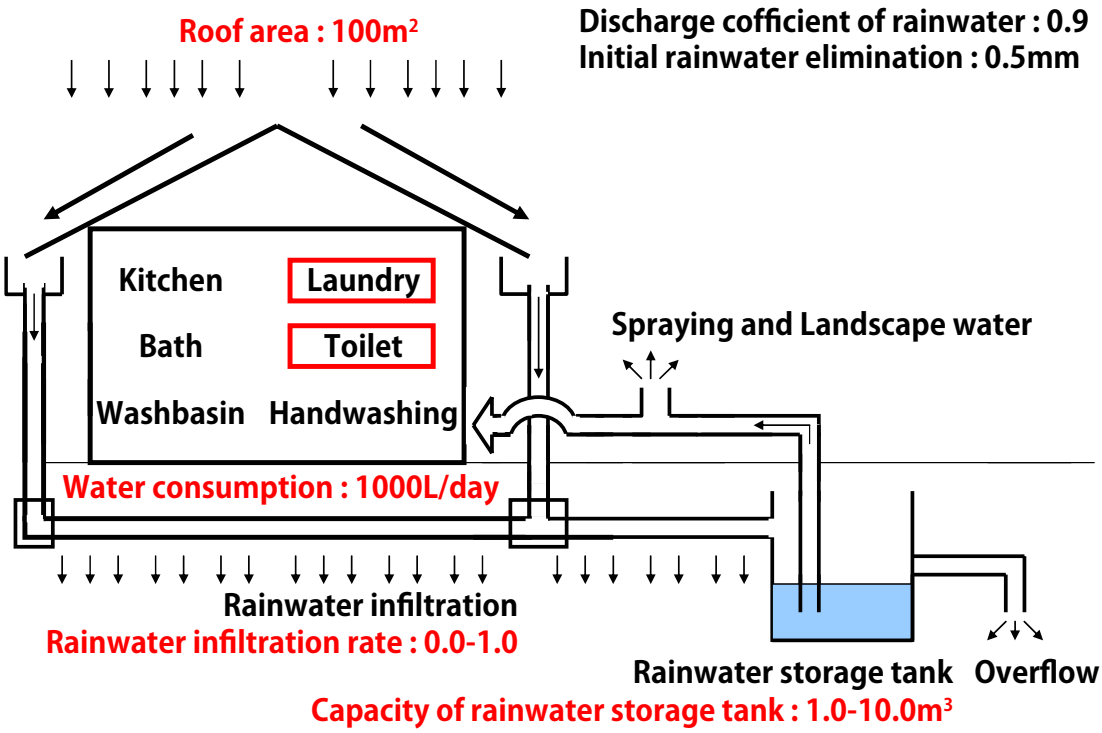

Figure 4 - Setting condition of rainwater utilization system

Table 1 - The definition of each evaluation index

Overflow rate[%]	Accumulated overflow / (Accumulated filtration + Accumulated overflow) * 100
Water substition rate by use of rainwater[%]	Accumulated rainwater consumption / Accumulated water consumption * 100
Rainwater use rate for recycled water[%]	Accumulated rainwater consumption / Accumulated recycled water consumption * 100
Frequency of overflow	Over frequency of rainwater storage tank capacity
Frequency of replenishment	Replenishment frequency of tap water on account of under water replenishment level in the rainwater storage tank † Stopping level of replenishment water is 1/3 of rainwater storage tank capacity. Replenishment level of tap water is 0.5m³ in case of over 1.0m³ of rainwater storage tank capacity, and else 1/2 of rainwater storage tank capacity.
Average water exchange days	366 / (Accumulated rainwater consumption / Average water reservation amount of 1 year in the watar storage tank)

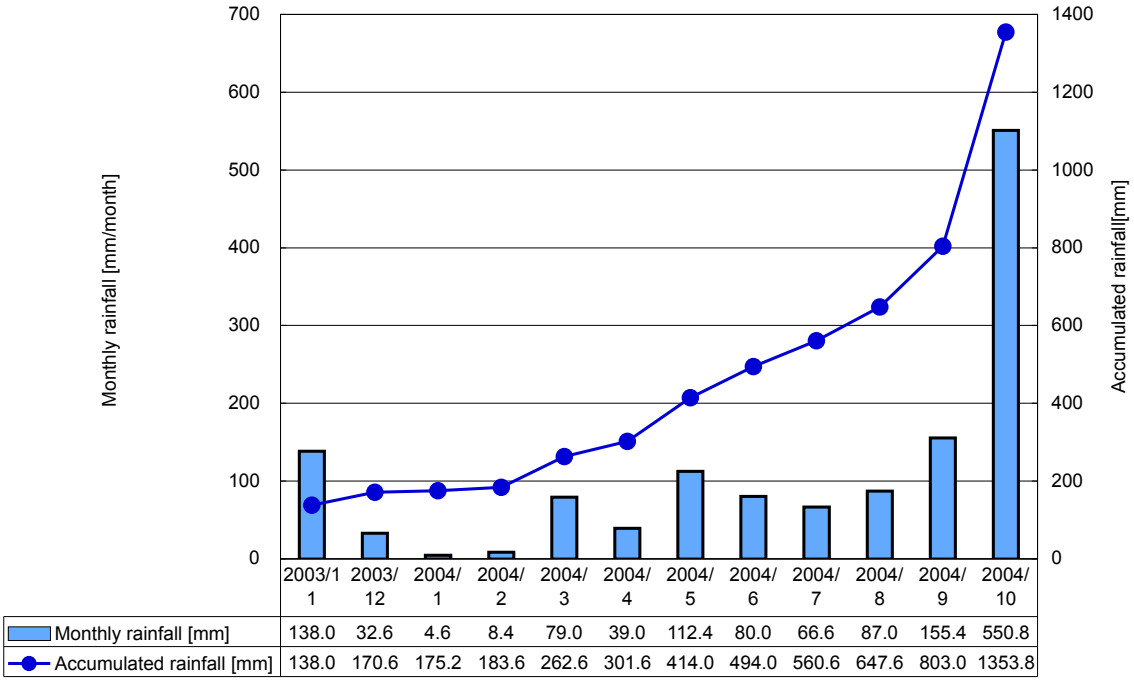

Figure 5 - Rainfall data

Table 2 - The water consumption data according to the application

Hour	Kitchen	Bath	Washbasin	Handwashing	Laundry	Toilet	Total
0	0.44%	2.15%	0.30%	0.04%	0.07%	0.70%	3.71%
1	0.37%	1.23%	0.35%	0.05%	0.11%	0.56%	2.67%
2	0.28%	0.59%	0.32%	0.02%	0.16%	0.41%	1.78%
3	0.12%	0.20%	0.11%	0.02%	0.11%	0.27%	0.82%
4	0.12%	0.22%	0.07%	0.01%	0.10%	0.21%	0.74%
5	0.13%	0.22%	0.05%	0.01%	0.03%	0.22%	0.67%
6	0.31%	0.36%	0.18%	0.03%	0.15%	0.46%	1.48%
7	1.20%	2.02%	0.63%	0.06%	1.13%	1.26%	6.30%
8	1.08%	2.08%	0.83%	0.17%	2.91%	1.25%	8.30%
9	0.93%	0.47%	0.47%	0.07%	3.74%	1.00%	6.67%
10	0.92%	0.26%	0.22%	0.09%	2.41%	0.48%	4.37%
11	0.52%	0.41%	0.36%	0.05%	0.93%	0.47%	2.74%
12	0.82%	0.54%	0.25%	0.03%	0.70%	0.48%	2.82%
13	0.93%	0.59%	0.28%	0.03%	0.54%	0.45%	2.82%
14	0.73%	0.21%	0.17%	0.04%	0.54%	0.39%	2.08%
15	0.69%	0.28%	0.37%	0.02%	0.46%	0.48%	2.30%
16	0.64%	0.36%	0.36%	0.02%	0.50%	0.50%	2.37%
17	1.03%	0.43%	0.33%	0.07%	0.93%	0.53%	3.34%
18	1.73%	0.67%	0.27%	0.04%	1.25%	0.49%	4.45%
19	1.95%	1.82%	0.30%	0.06%	1.40%	0.55%	6.08%
20	1.78%	3.20%	0.50%	0.07%	0.93%	0.64%	7.12%
21	1.81%	5.85%	0.40%	0.20%	1.21%	0.60%	10.08%
22	1.56%	4.77%	0.25%	0.16%	0.74%	0.74%	8.23%
23	1.45%	4.69%	0.32%	0.08%	0.65%	0.89%	8.08%
Total	21.56%	33.59%	7.67%	1.46%	21.68%	14.04%	100.00%

3. Results

3.1 Change of the each evaluation index by the change of the tank capacity

The simulation of each evaluation index calculated it as an effective capacity of the rainwater storage tank is made to change from 1.0 m^3 to 10.0 m^3 at every 0.5 m^3. The result is shown in **Figure 6** and **Figure 7**. This figure is an analytical result in making the rainwater infiltration rate to be 0.2. For the reference, the example of quantity of water variation in the rain water storage tank is shown in **Figure 8**. It tended to stabilize the each evaluation index, when 4.0m^3 at the rain water tank capacity was exceeded. In comparison with the case (**Figure 6**) in which the application used for the recycled water utilization was used only for the toilet and case (**Figure 7**) in which it was used for toilet and laundry, Though the overflow decreases, it is got as the 35.7% half in which the water substition rate by use of rainwater is the sum total water consumption proportion of toilet and laundry, and the makeup water quantity increases. The capacity of rainwater storage tank is shown by the intensiveness of the result in 3.0 m^3 and the case in which the rainwater infiltration rate was made to be 0.2 in **Table 3** and **Figure 9**.

3.2 Change of the each evaluation index by the change of the rainwater filtration rate

The change of each evaluation index as the rainwater filtration rate is made to change from 0.0 to 1.0 is shown in **Figure 10**. This figure is a result in making the rain water utilization application to be toilet and washing as rain water tank capacity 3.0m^3. Though the water substitution rate by use of rainwater greatly does not decrease, even if the rain water filtration rate is increased, the overflow rate greatly decreases. Therefore, flood countermeasure in the city and effectiveness to the groundwater recharge to the region can be expected by doing the rain water filtration rate in about 0.5, while the rain water utilization is retained.

4. Conclusion

Using the data in every 1 hour, this paper quantitatively evaluated the rainwater utilization system from each evaluation index for 1 year, while simulation program of infiltration and storage compatible rainwater utilization system in detached house was constructed. In the future, it is necessary that it carries out the simulation in each utilization condition and each area, while measured data are collected by the field experiment, and evaluates the effectiveness of rainwater utilization system from the possibility of advantage utilization by the building to introduction effect by the region level many-sided.

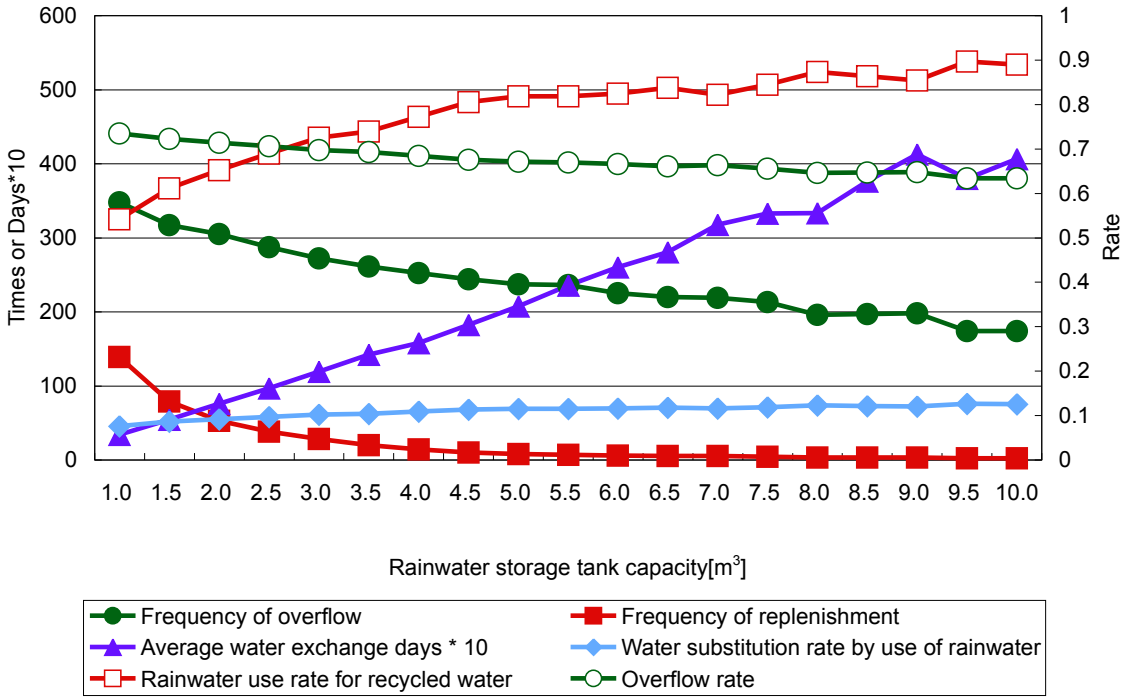

Figure 6 - The evaluation by the change of capacity of rain water storage tank (the case in which the rain water utilization is toilet only)

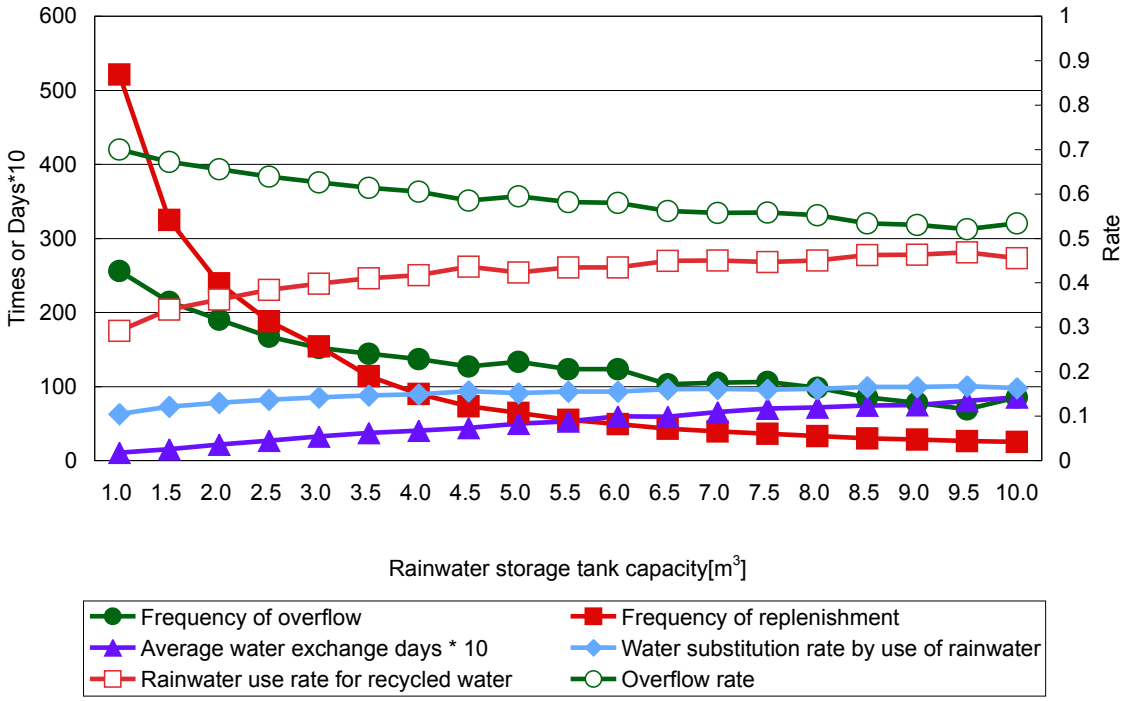

Figure 7 - The evaluation by the change of capacity of rain water storage tank (the case in which the rain water utilization is toilet and laundry)

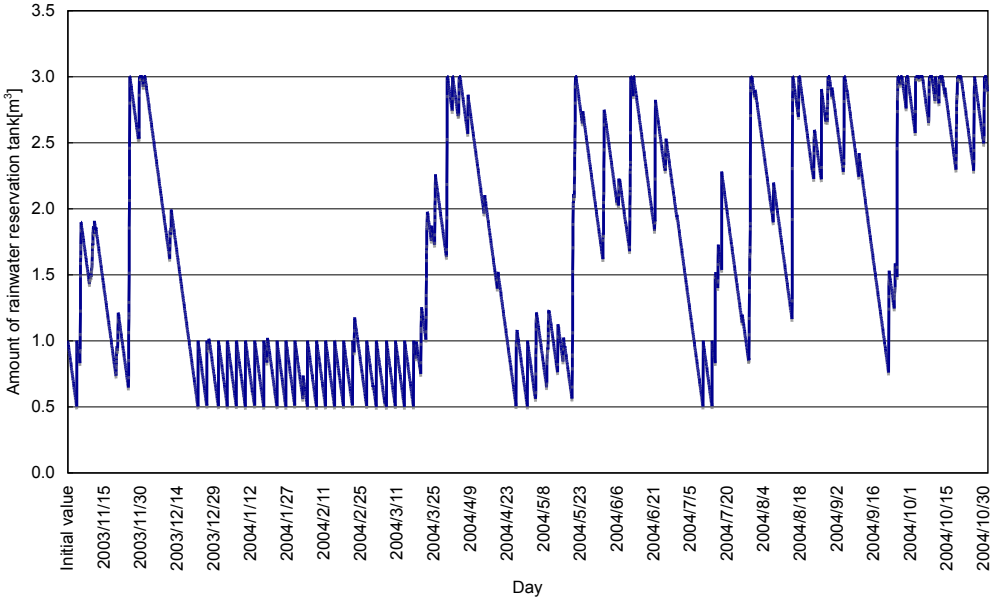

Figure 8 - The example of quantity of water variation in the rain water storage tank (the case in which the capacity of rain water storage tank is 3.0m^3)

Table 3 - The comparison of the simulation result
by the recycled water application
(Capacity of rainwater storage tank is 3.0m^3 and rainwater infiltration rate is 0.2.)

A	Accumulated rainfall[㎜]	1353.8
B	Accumulated drain[㎜]	121.84
C	Accumulated early rainfall elimination[m^3]	6.63
D	Accumulated rainwater infiltration[m^3]	23.04
E	Accumulated water consumption[m^3]	366

	Use of recycled water	Toilet only	Toilet and Laundry
F	Accumulated overflow[m^3]	53.01	38.53
G	Overflow rate[%]	69.7	62.6
H	Accumulated collected rainwater[m^3]	39.16	53.64
I	Accumulated tap water route consumption[m^3]	314.61	235.25
J	Accumulated recycled water route consumption[m^3]	51.39	130.75
K	Accumulated replenishment of tap water[m^3]	14.12	78.79
L	Accumulated rainwater consumption[m^3]	37.27	51.96
M	Accumulated tap water consumption[m^3]	328.73	314.04
N	Water substitution rate by use of rainwater[%]	10.2	14.2
O	Rainwater use rate for recycled water[%]	72.5	39.7
P	Frequency of overflow	272	152
Q	Frequency of replenishment	28	154
R	Average water exchande days	11.9	3.2

†Initial condition : Collected rainwater Area 100m^2, Water Consumption 1000L/day,
Rainwater storage tank capacity 3.0m^3, Water drain rate 0.9,
Amount of early rainfall elimination 0.5mm. Rainwater infiltration rate 0.2

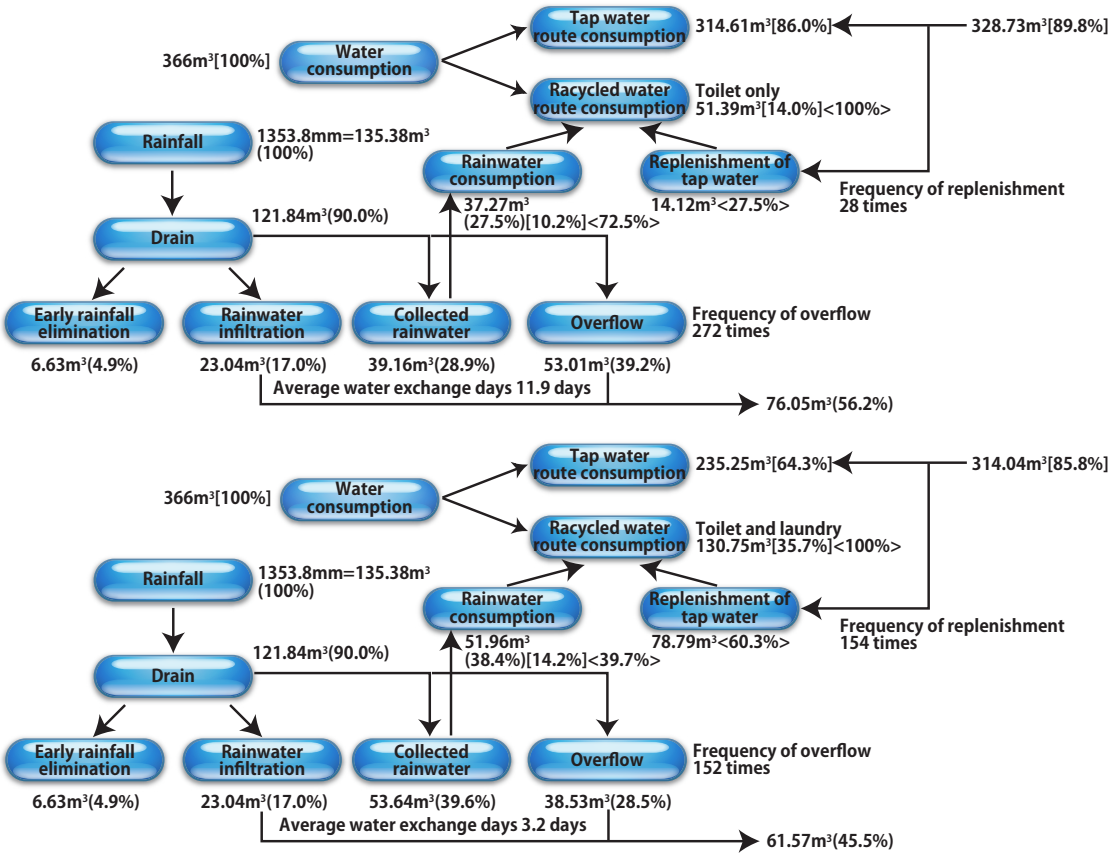

Figure 9 - The comparison of quantity of water balance by the recycled water application (Top is toilet only. Bottom is toilet and washing.)

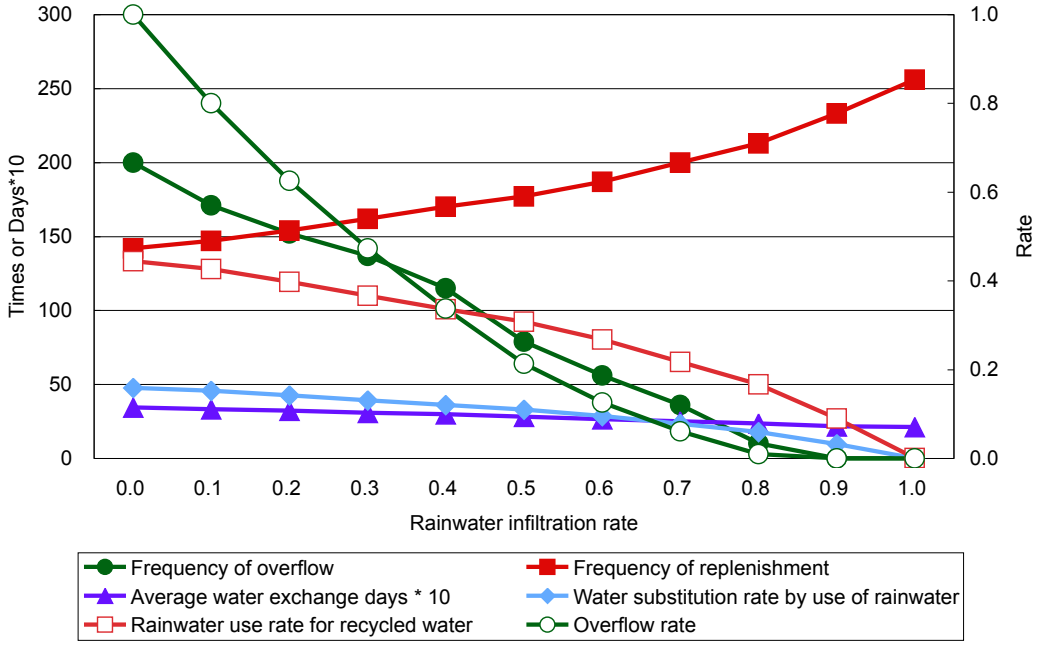

Figure 10 - The change of each evaluation index by the change of the rain water infiltration rate (Capacity of rainwater storage tank is 3.0m^3 and recycled water application are toilet and washing.)

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The cooperation of Tomoki Hirata which was the Toyo University graduate was got, when this study was advanced. The gratitude is expressed.

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Main author presentation

Hiroyuki Kose is the Associate Professor at Toyo University, Department of Civil and Environmental Engineering, Faculty of Engineering. Special fields of study are plumbing engineering, environmental city planning, and environmental design. Since this year, it is engaged in landscape reconstruction on Yamakoshi area of Nagaoka City which received large damage in the Niigata Chuetsu Earthquake on October 23, 2004.

Sustainable approach of existing building rainwater system from drainage to harvesting in Taiwan

M.C. Liao, Mr. (1), C.L. Cheng, Dr. (2), Y.C. Liu, Mr. (3) J.W. Ding, Mr. (4)
(1) D9213109@mail.ntust.edu.tw
(2) CCL@mail.ntust.edu.tw
(1)(2)(3)(4) National Taiwan University of Science and Technology, Department of Architecture, 43 Keelung Road Sec.4, Taipei, Taiwan, R.O.C.

Abstract

This research focuses on reuse mechanism of rainwater drainage system in existing building of Taiwan. The current design methodology of roof construction for rainwater plumbing system would be reviewed. We set up a framework of design process in rainwater plumbing system, critical factors including financial and technical issues must be under consideration. Furthermore, in succession to the investigation of existing buildings last year, those cases would be applied to demonstrate the rationality of this framework. The critical aspect was how to integrate present rainwater plumbing system, and transferred to rainwater harvesting system. Finally, this paper would rearrange design methodology of rainwater plumbing system and also perform a case study as the verification.

Keywords
Rainwater use, water conservation, sustainable approach, evaluation system.

1. Introduction

Due to the precipitation distributed unequally in time and space, water resource had become embarrassing problems in Taiwan in recent years. Besides droughts and floods, over-developing the hill areas gave rise to cutting down operating efficiency and period of the reservoirs. These water shortages have resulted in an anxious public consciousness to existing water supplies and created an economic barrier to development. Consequently, it is clear that alternative water resources must be investigated to alleviate the water shortage problem in urban areas. Rainwater use as a supplement to the potable water supply in Taiwan has been demonstrated a practical and promising alternative where traditional groundwater or surface water is limited.

Key concepts of rainwater utilization would be dispersing the risk of water shortages. The operating mechanism of rainwater harvesting system could be like mounts of small reservoirs distributed in urban areas. They could diminish the damage in urban floods, and supply parts of substitute daily water when lower precipitation. (Figure 1)

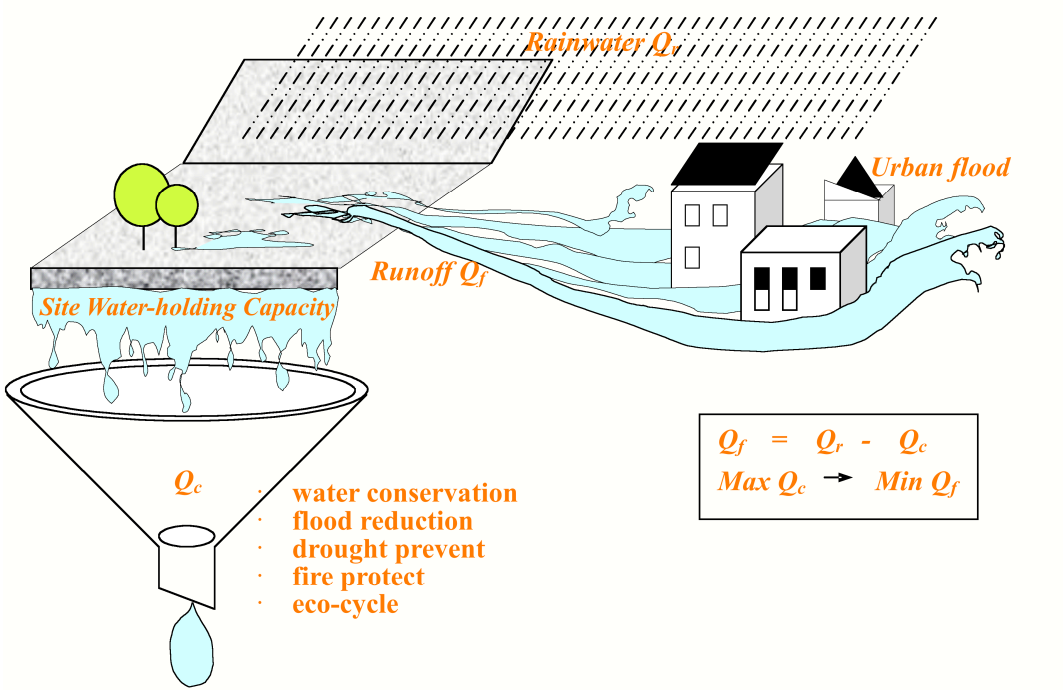

Figure 1 - Rainwater utilization conception chart

2 Modes of rooftop rainwater harvesting system

2.1 Description of study object

A new rainwater use guideline that had been linked to building code offers an easy approach to the evaluation of water conservation and a rainwater use system for architectural planning in Taiwan currently. However, these rainwater use system guideline mostly were conducted for new constructions and rare to mention about the large number of existing buildings. It is noteworthy that setting rainwater harvesting system in existing buildings.

The existing buildings are the majority object of constructions, which occupy more than 98% of the constructions in Taiwan. The total efficiency of rainwater utilization in existing buildings would be much better than in new constructions. There might be rainwater drainage piping system in existing buildings presently. It could be applied to rainwater utilization system partly, and lower the budget for setting. As the circumstance observation of practical problems about maintenance, many roof drainage gutters suffer plugged in our previous investigation. We have to check up the rainwater drainage system and maintain steadily if we want to set rainwater utilization system.

However, there were several limited factors concerned. First one is the original roof drainage systems, which are including collecting area, plumbing piping, collection installations, driving out and etc. Accordingly, we need adequate space for the facilities like storage tank, settling tank, filter tank, and the additional facilities. The other issues that we also need to consider are including delivery piping system, long-term water-saving efficiency and the financial supporting. Furthermore, the existing structure system must to be verified for affording the additional load of rainwater use system.

2.2 Modes conception

Large divergence in main concepts was between roof drainage system and rainwater utilization system. Diving out rainwater dropping on the roof rapidly was the critical function of roof drainage system. On the contrary, rainwater utilization system tended to collect rainwater and transfer to substitute water use, like toilet flushing, washing, irrigation, and etc. To clarify the rainwater harvesting system, it could classify into four categories, collecting area, plumbing piping, diving out, and utilization. (Figure 2)

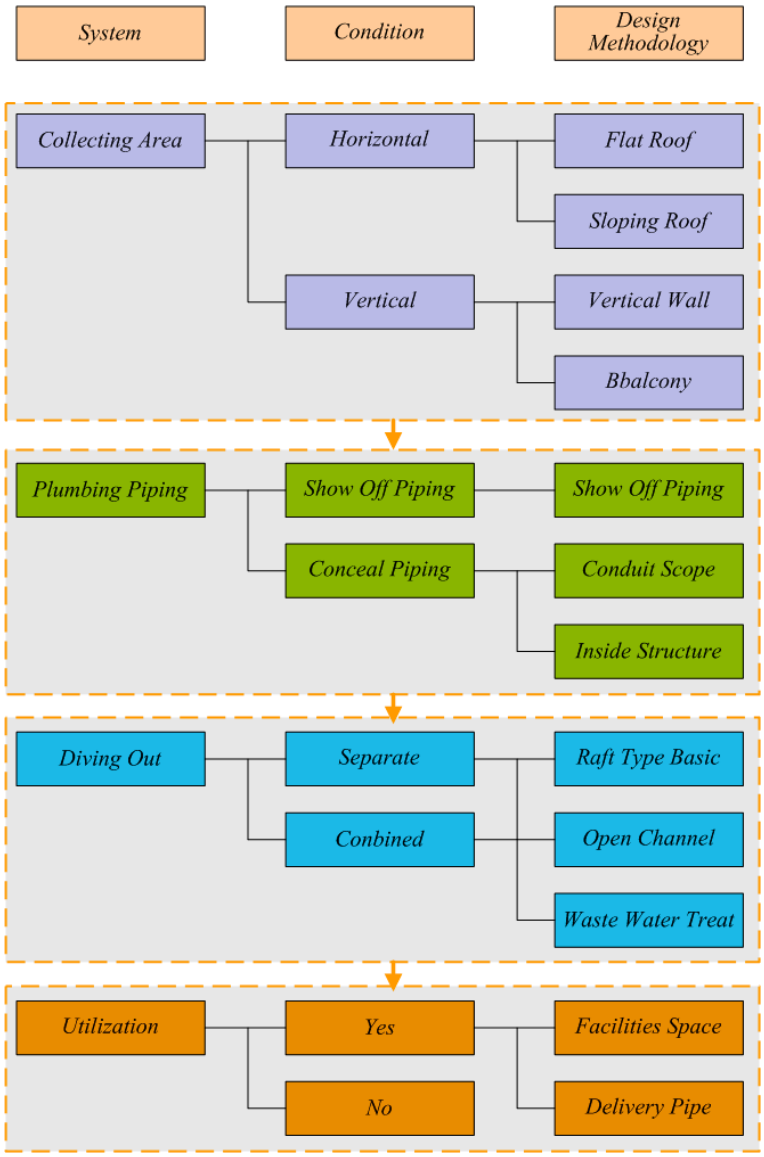

Figure 2 - Rainwater harvesting system classification

Figure 3 shows the typical type of water supply and roof drainage system in buildings. There were two separate systems. Water supply system delivers clean water for all purposes, like kitchen, bathing, drinking, flushing, and etc. Roof drainage system was conducted into common sewer with waste water.

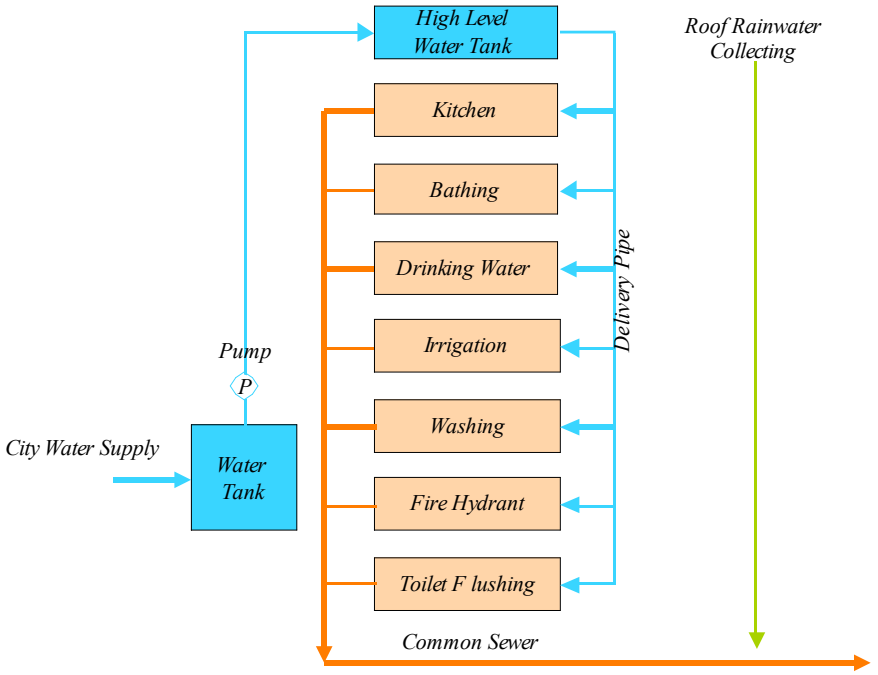

Figure 3 - Typical type of water supply and roof drainage system

Figure 4 shows rainwater utilization system type I. After collecting, settling, and filtering, rainwater was delivered to high level rainwater tank for substitute water use. It would supply clean water if rainwater was used up. It must be noted the security of structure system.

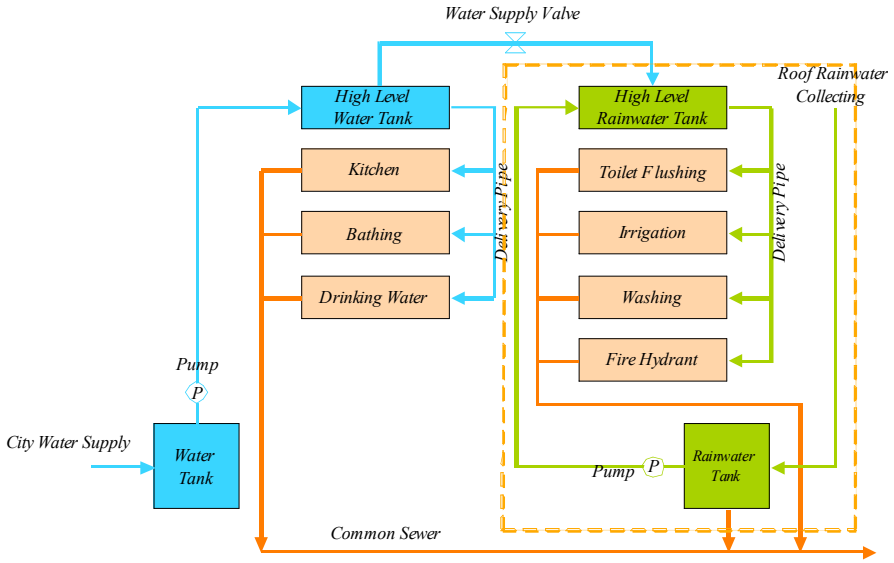

Figure 4 - Rainwater utilization system type I

Figure 5 shows rainwater utilization system type II. After collecting, settling, and filtering, rainwater was delivered to small feed tanks in every residence unit for substitute water use. Similarly, it would supply clean water if rainwater was used up.

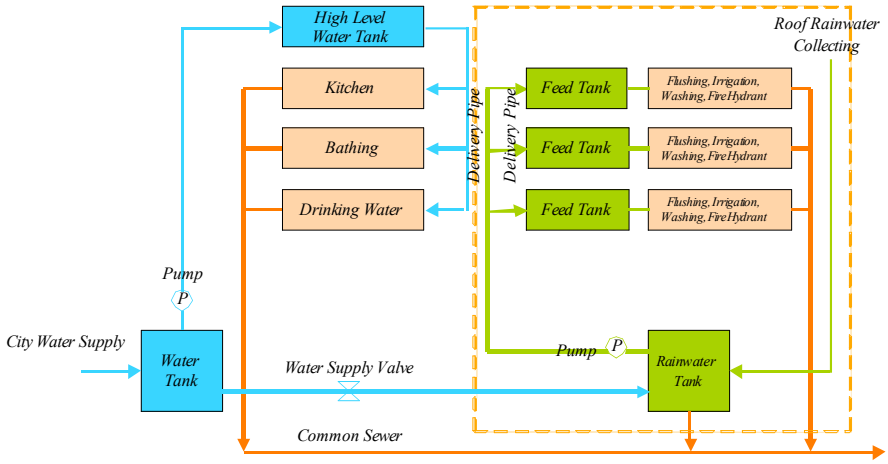

Figure 5 - Rainwater utilization system type II

Figure 6 shows rainwater utilization system type III. Rainwater was delivered immediately to feed tanks in every residence unit, so it wouldn't have to set rainwater storage tank in underground floor. Taking account of the security of structure system, the capacity of feed tank was suggested under 500 L.

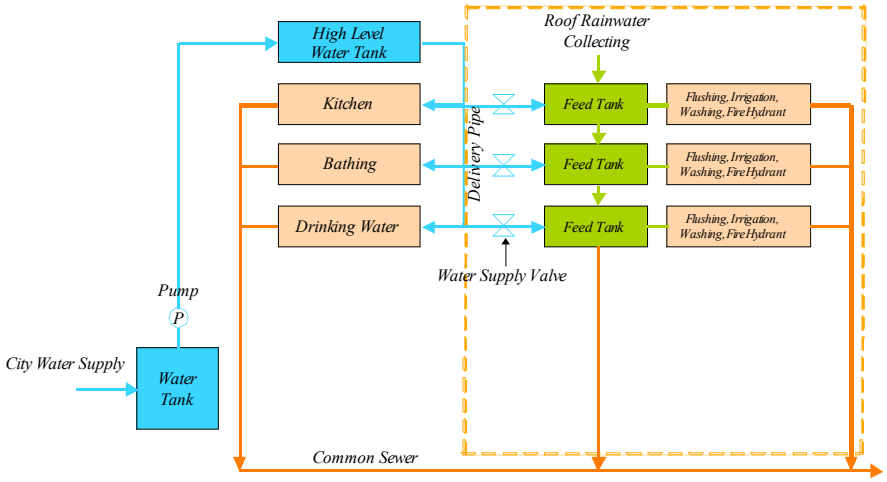

Figure 6 - Rainwater utilization system type III

Basing on the three types, we tried to offer 5 practical modes of rainwater utilization in existing buildings. They could be applied reasonably in accordance with situations and requirements. (Figure 7)

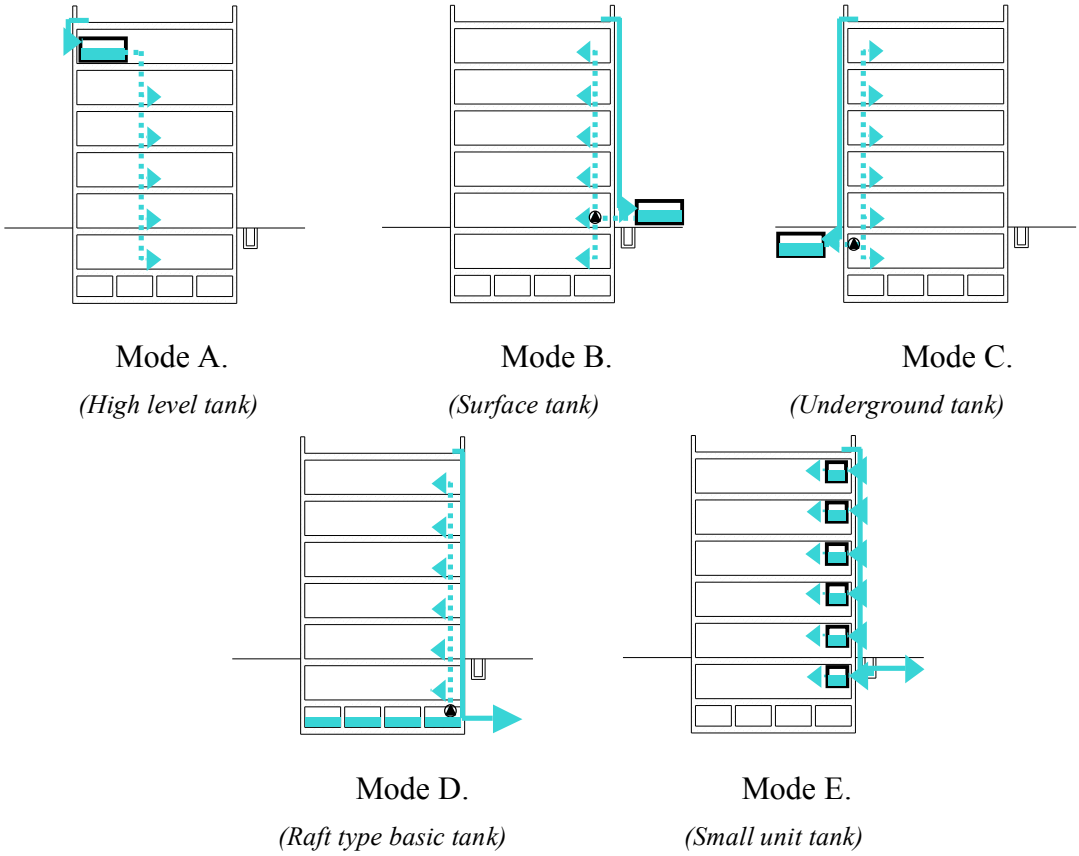

Figure 7 - Rainwater utilization applied modes

2.3 Practicability

Due to multifarious situations in realistic application, there were some limitations in each mode. Table 1 shows practicability of rainwater utilization modes in accordance with situations. In our previous study, we had investigated 97 cases on roof drainage system in Taipei. Table 2 shows practical cases in each model on rainwater utilization.

Table 1 - Practicability assessing on rainwater utilization

System	Conditions	A	B	C	D	E
Collecting Areas	*Flat roof with collection installations*				◎	
	Flat roof with additional drainage piping	◎	◎	◎		◎
	Additional steel roof frame	◎	◎	◎		◎
Plumbing piping	*Conceal piping*				◎	
	Show off piping	◎	◎	◎		◎
	Drain directly	△	△	△		△
Driving Out	*Open channel*	△	△	◎		△
	Drain directly	△	△	△		△
	Raft type basic				◎	

□ = Practical □ = Practical partly

Table 2 - Practical cases on rainwater utilization

Rainwater utilization models	Mode A	Mode B	Mode C	Mode D	Mode E	Unable
Practical cases	*0*	*39*	*39*	*33*	*41*	*37*
Percentage	*0%*	*40.20%*	*40.20%*	*34.02%*	*42.27%*	*38.14%*

3 Case study

For evaluating the efficiency of rainwater utilization, in this study, we investigated an example in Taipei city. There were three buildings involved in this case. (Figure 8) Building A was a 12F building with 600 tons raft type basic water tank. (Mode D) The storage tank would provide WC flushing water for Building A, Building B, and Building C. The simulation time would be 20 years (1984-2003). Related information were in Table 3 and Table 4.

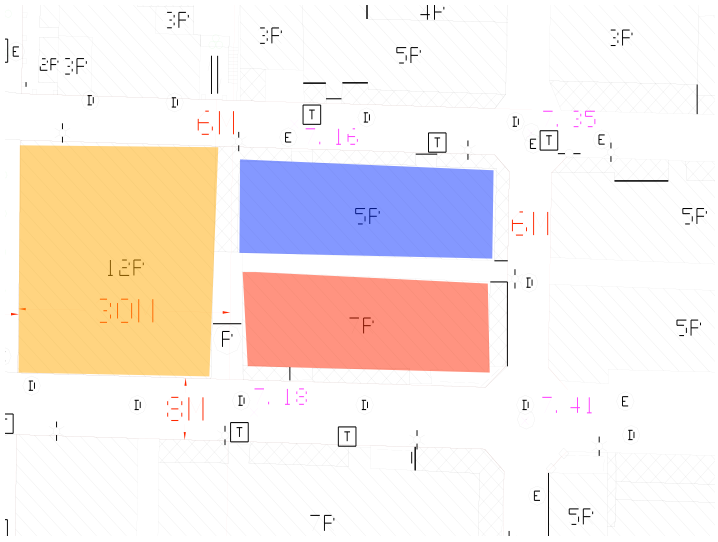

Figure 8 – Sampling case

Table 3 – Background information of sampling case

Building	Building floors	Residence numbers	Collection area(㎡)	WC flushing water consumption per day(m³)
Building A	*12F, with 600 tons raft type basic water tank*	*82*	*721*	*19.68*
Building B	*5F*	*20*	*337*	*4.80*
Building C	*7F*	*28*	*322*	*6.72*

Table 4 - Yearly precipitations of Taipei (1984-2003)

1984	*2711.3*	**1989**	*2268.6*	**1994**	*2043.7*	**1999**	*1958.1*
1985	*2487.9*	**1990**	*2913*	**1995**	*1716.7*	**2000**	*2744*
1986	*2605.6*	**1991**	*2215.9*	**1996**	*2253.1*	**2001**	*2862.1*
1987	*2219.1*	**1992**	*2391.9*	**1997**	*2595*	**2002**	*1346.4*
1988	*2821.2*	**1993**	*1745*	**1998**	*4404.7*	**2003**	*1192.5*

3.1 Water-saving percentage and yearly precipitations

Water-saving percentage was the most critical data to respond efficiency of rainwater utilization. In the study, water-saving percentage raised corresponding to the yearly precipitations. The value was between 2.84% - 10.75%, and average value was up to 5.77%. Concretely speaking, we could namely retrench 2743 tons of clean water per year.

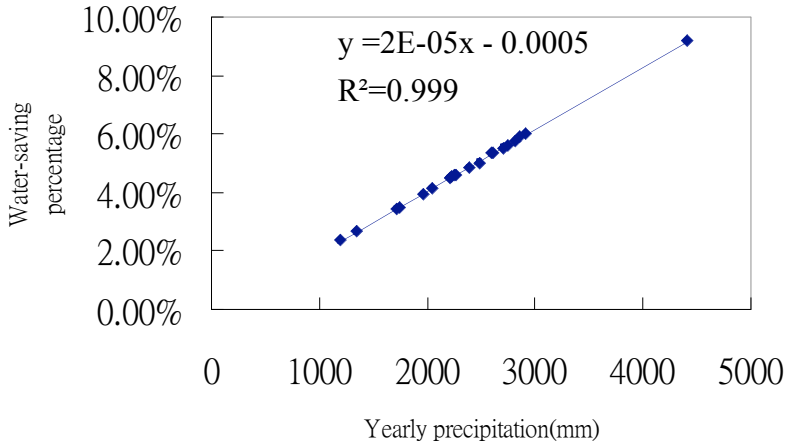

Figure 9 – Water-saving percentage and yearly precipitations

3.2 Rainwater collecting percentage and storage capacity

Figure 10 shows the relation between rainwater collecting percentage and storage capacity. There was an immediate sharp increase when the storage capacity was less than 100 tons. Putting it plainly, the efficiency of rainwater collecting was close to 90%. It could afford to treat most part of rainwater. The storage capacity between 100-600 tons could be considered urban flood controlling, particularly in typhoons or rainstorms.

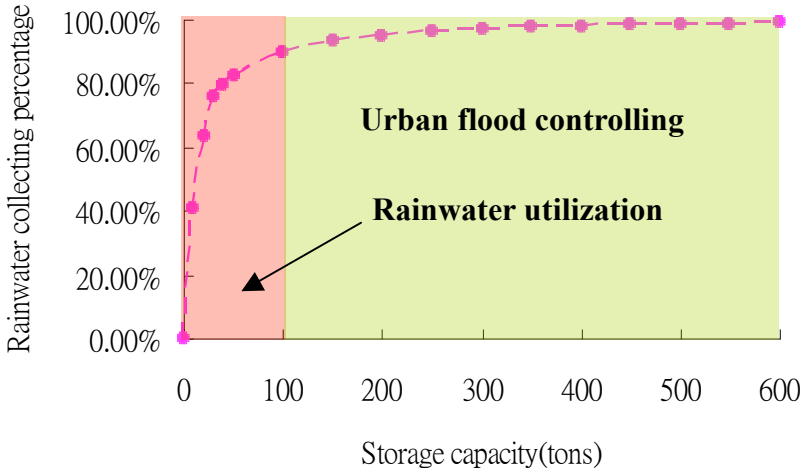

Figure 10 – Rainwater collecting percentage and storage capacity

4. Evaluation and verification

4.1 Evaluation Tool

Existing rooftop rainwater harvesting system is an acceptable solution for alleviating the water shortage problem in urban areas. However, practical performance need functional tool to make the real progress for the publics. Herein, we developed a practical evaluation tool in the research. We transfer the calculation to be dynamic simulation through commercial software Visual Basic. The partial results and the application are offered in network at present. Figure 11 shows the entrance page for practical evaluation of existing rooftop rainwater harvesting system.

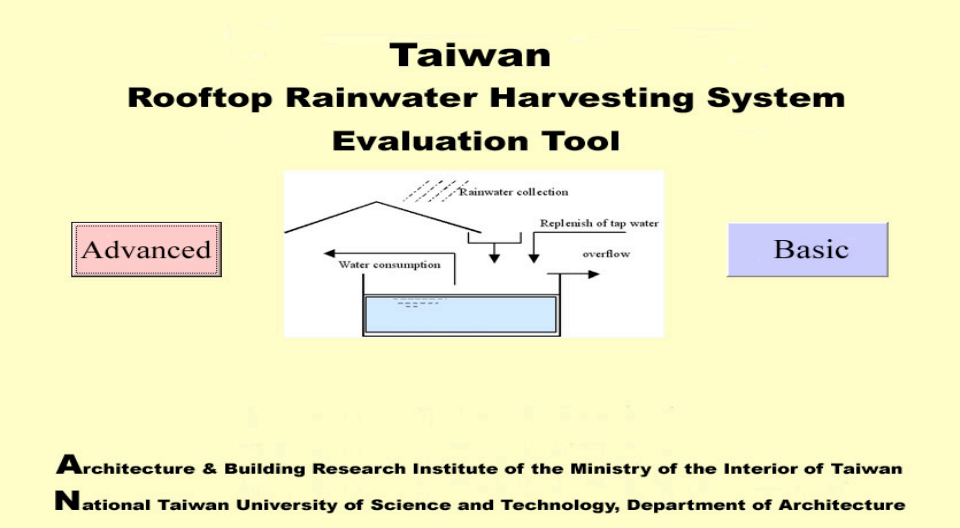

Figure 11 – Entrance page of the evaluation tool

4.2 Conditions analyzing and issues identification

We also found several critical problems on conducting rainwater utilization in existing buildings, and classified into six categories:

(1) Maintenance of collecting areas and installations
Collecting areas and installations were the point of departure on rainwater utilization. Keeping them clean and working well would be contributed to improve the efficiency of rainwater utilization system.

(2) Plumbing piping design – show off piping or conceal piping
Generally speaking, conceal piping always had problems of maintenance, and was difficult to transform into rainwater utilization system. Show off piping work might be the fitting way.

(3) Combined or separate drainage system
Combined drainage system always intermingle waste water with rainwater, and would influence the water quality. Separate drainage system shows more suitable for rainwater utilization system.

(4) Driving out
The outlets of rainwater drainage system would connect with the facilities of rainwater utilization system, and concern the modes choosing.

(5) Optimized space for the facilities
Providing enough space for the facilities of rainwater utilization was a critical issue in our investigation, and the security of structure system would be taken into account.

(6) Delivery piping system
After collecting and treating, how to deliver rainwater to users would be a great problem. Revising the delivery piping system usually occupied a part of budget.

5. Conclusions

In this study, we set up a framework of design process in rainwater utilization system, critical factors including financial and technical issues must be under consideration. The critical aspect is how to integrate present rainwater drainage system, and transferred to rainwater harvesting system. We concluded 5 practicable modes for existing buildings. There still have much potential development for rainwater utilization system in urban areas, and more researches need to be conducted in the future.

6 Acknowledgments

The authors would like to thank the Architecture & Building Research Institute of the Ministry of the Interior of Taiwan (ABRI) for financially supporting this research.

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5. Liao, M.C., Cheng, C.L., Liaw, C.H., Chan, L.M. "Study on Rooftop Rainwater Harvesting System in Existing Building of Taiwan", CIB-W62 International Symposium, Paris, France. 2004.09.

8 Presentation of Author

Ming-Cheng Liao is a Ph.D student majoring in rainwater harvesting system at National Taiwan University of Science and Technology, Department of Architecture. He is also interested in ecological ponds and urban water.

Proposal of a Hybrid Drainage System that Enables Free-plan Housing Technology

MASAYUKI OTSUKA (1), YUSUKE MINAM I (2)
(1) dmotsuka@kanto-gakuin.ac.jp
(2) d0343001@kanto-gakuin.ac.jp
(1) Prof., Dept. of Architecture, College of Engineering Kanto-Gakuin Univ., Dr. Eng.
(2) Graduate School of Architectural department Engineering Kanto-Gakuin University Graduate Student, M. Eng.

Abstract

CO_2 emissions produced in Japan place the country fourth in the world and the construction industry is responsible for one-third of the total CO_2 emissions. CO_2 emission control therefore needs to be in place. The “scrap and build” approach has conventionally been applied to housing construction but the perspective of “long-lasting and versatile housing” has gradually been recognized to become the main axis of housing policies by promoting the reduction and renewal of construction and demolition waste. Moreover, long-lasting and versatile housing can be realized by the construction of houses that are designed with flexibility to meet different lifestyles, enabling the designing and modification of infill drainage space. The development of plumbing engineering, which is adaptable to such houses, also plays an important role. Problems arise however particularly related to infill drainage. Infill drainage for ordinary houses employs a gravity drainage system using the effect of natural gradient. This method is accompanied by two issues.

Firstly, there is normally not enough space under the floor (underfloor space) to install a long horizontal branch pipe to connect sanitary equipment and a drainage stack. Inadequate space cannot secure the appropriate pipe gradient, thus hindering smooth drainage. Secondly, the extension and/or modification of an infill space requires a considerable degree of construction work.

This paper focuses on the development of a horizontal branch pipe system that is designed to respond flexibly to the modification of water distribution of infill space. To be more specific, a new horizontal branch pipe system still adopts the conventional gravity drainage system while incorporating a force drainage system using a pressure pump, which flexibly responds to the extension and modification of infill drainage space. This paper also examines and evaluates the performance and practicality of this hybrid drainage system.

Keywords

Long-lasting and versatile housing, hybrid drainage system, horizontal branch pipe system, force drainage system using a pressure pump

1. Introduction

1.1 Underfloor space and the installation of horizontal branch pipes

When constructing a new high-rise housing complex in Japan, horizontal branch pipes are normally installed along residential floor surfaces. **Fig.1** shows three different sections where horizontal branch pipes are installed; above the slab (SL), below the finished floor (FLU) and the finished floor surface (FL), in relation to the gap space. The gap space between SL and FL (underfloor space) is particularly important in designing horizontal branch pipes and it is normally 150 – 180mm for ordinary high-rise housing complexes. Drainage stacks are typically installed vertically through infill sections, connected to horizontal branch pipes along floor surfaces.

The latest development is the SI (Skeleton and Infill) method by which housing complexes are constructed with an underfloor space of 250 – 300mm, much more generous than conventional, and a drainage stack installed in shared sections of housing complexes, as shown in **Fig.2**. This method has improved the securing of the appropriate pipe gradient, plus the installation of drainage stacks in shared sections rather than in private infill sections of housing complexes has drastically reduced complications involved in drainage maintenance (upgrading and cleaning), which is a significant benefit brought by the method.

1.2 Promotion of "free-plan housing"

There are two main requests shared by residents of high-rise housing complexes regarding infill drainage facilitation, which also trigger some points to be considered.
(1) Easier access to toilets for those in care (**Figure 3**)

Going to the toilet is a very hard task for elderly people who are in nursing care; the process of getting out of bed and walking a long distance for them to reach the toilet causes a considerable degree of discomfort. Many therefore request the conversion of fitted storage space in their rooms to toilets so as to create easier access.

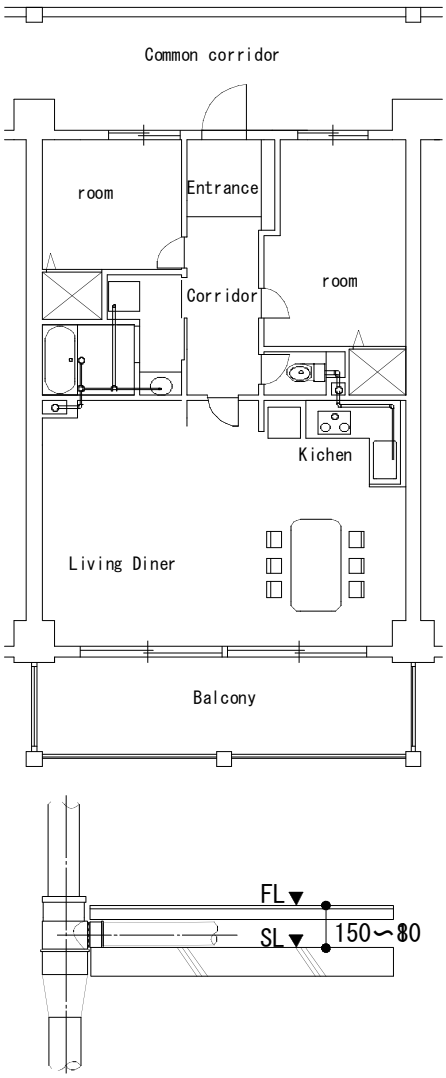


Figure 1 - Ordinary housing complex

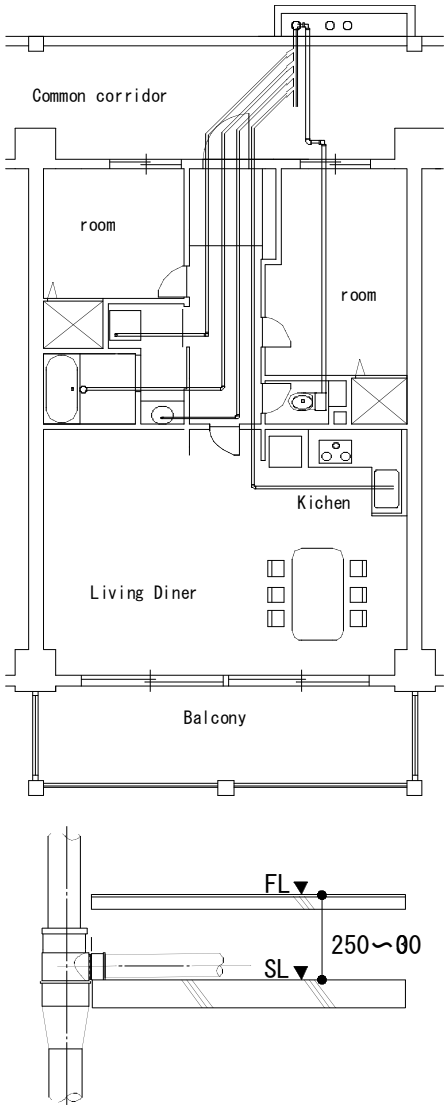
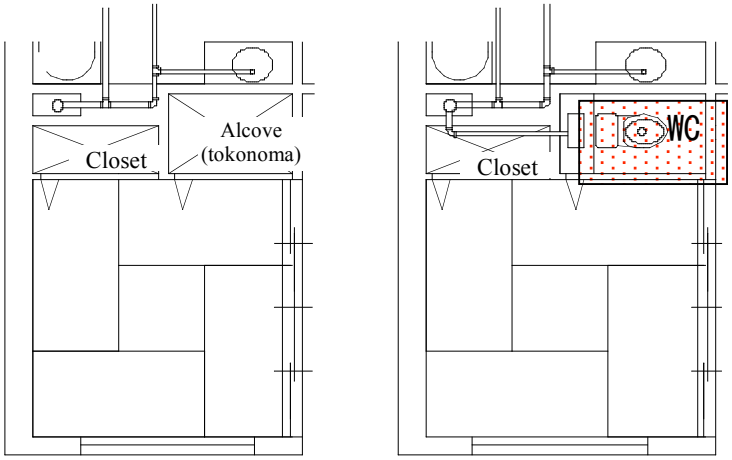


Figure 2 - SI-housing



Before renovation After renovation

Figure 3 - Installation of a toilet for people in care

However, such renovation involves a substantial degree of demolition and replacement of floor and construction materials, not to mention the reinstallation of horizontal branch pipes.

(2) View baths (**Fig.4**)

In Japan when designing the layout of residential space for a high-rise housing complex, the living room is normally positioned facing outside the building and the bathroom and toilet are often concentrated in the infill drainage section (with no windows). However, it would be much better, in terms of refreshing oneself in open space, if the bathroom is located adjacent to the living room, for instance, overlooking pleasant scenery. Such a bathroom is called a "view bath" and it requires a very long horizontal branch pipe to connect a view bath to the infill drainage point, thus making it impossible to secure the appropriate pipe gradient.

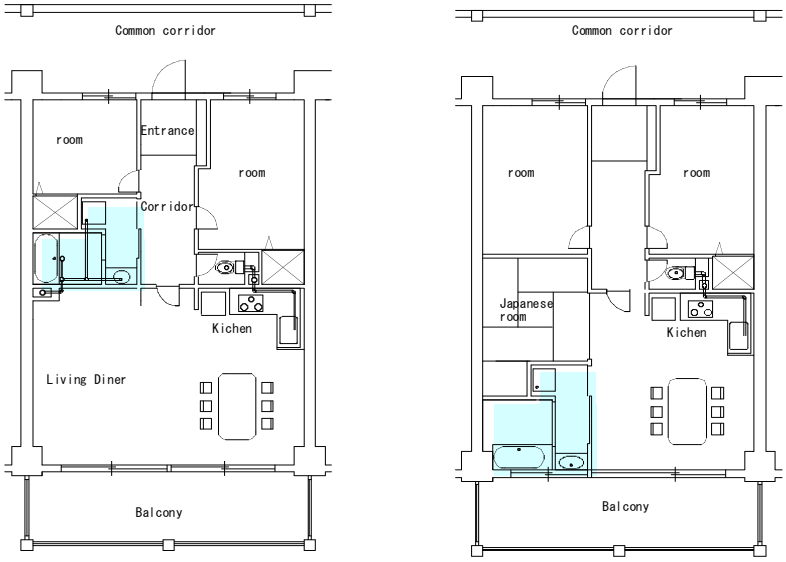


Figure 4 - Installation of a "view bath"

1.3 Hybrid drainage system

In order to realize “free-plan housing” as mentioned in 1.2, the authors propose a horizontal branch pipe system as illustrated in **Fig.5**. According to its concept, with a drainage stack as the basing point, room enough to install a gravity drainage system is determined within the underfloor space already provided. Meanwhile, a force drainage system is also installed with a pressure pump attached to a plumbing fixture in case of a need for installing a toilet for people in care or a view bath. This double system is called “hybrid drainage system” in this paper. The concept of the hybrid drainage system is identical to that of a ventilation system, in terms of ventilation and air-conditioning, which operates by coordinating natural ventilation and power ventilation.

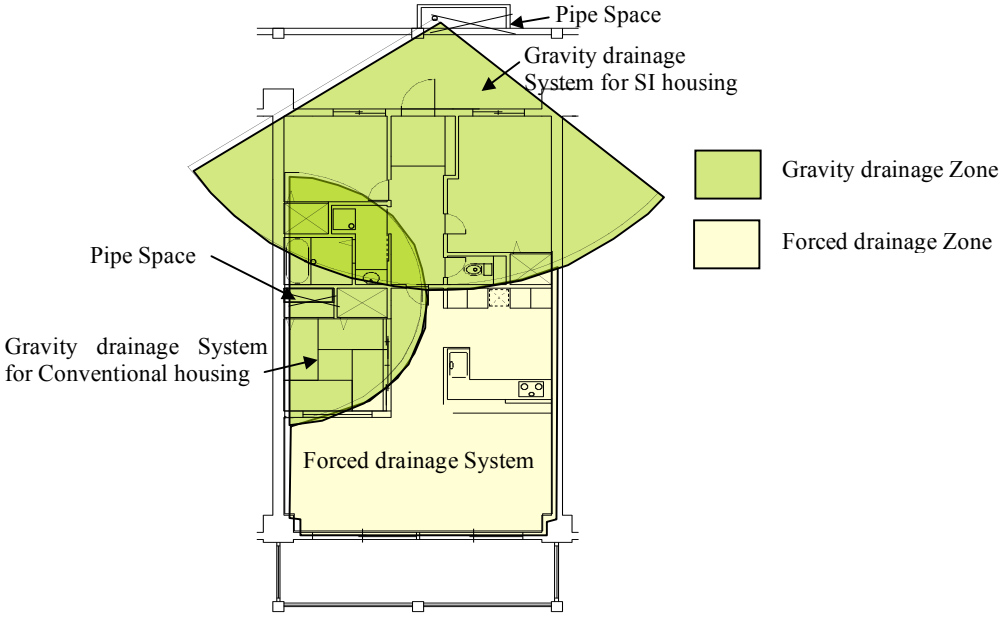


Figure 5 - Concept of the hybrid drainage system

2. Overview of the experiments

2.1 Drainage performance of the force drainage unit with a pressure pump

A siphon toilet and a barrier-free bathtub were used as plumbing fittings for examining drainage characteristics of the force drainage unit with a pressure pump. As shown in **Fig.6**, two types of pressure pump units (A and B) were used for the experiments. Incidentally, Unit A was for the toilet and Unit B was for the view bath. **Fig.7** shows the measuring device for identifying drainage characteristics and the plumbing layout. The diameter of the pipes connected to the pressure pump units is 20mm. For the pipes used with the gravity drainage system, the diameter is 75mm for the toilet pipe and 50mm for the bath pipe, both of which can be reduced. The experimental branch pipe was installed taking two different routes; through the underfloor space (horizontal plumbing) and up

to the ceiling (ceiling plumbing). Unit A has one fixed pump speed pattern and Unit B has three different pump speeds of 1500rpm, 2500rpm and 3500rpm. Photo1 exemplifies underfloor unit installation.

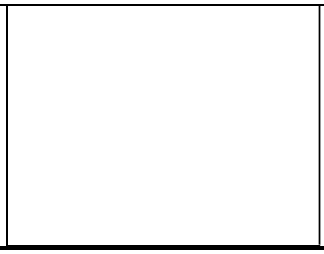
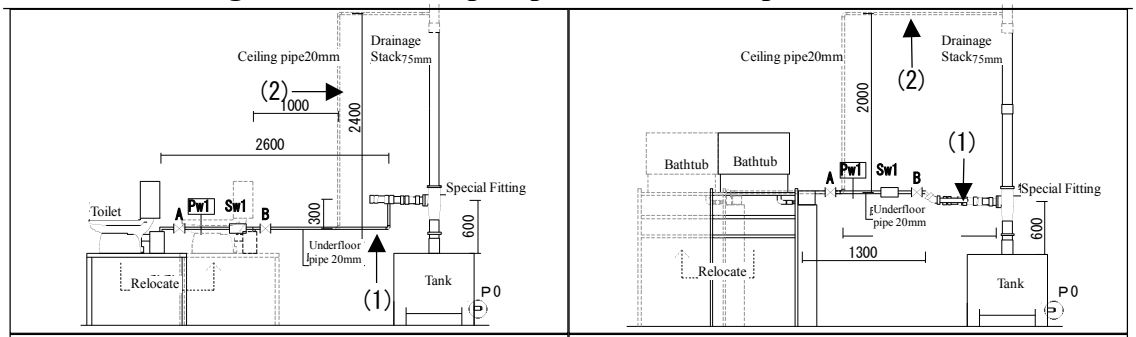
Photo		
Type	A	B
Intended use	Seeage Water/Waste Water	Waste Water
Capacity	Top lift 3.5m	5.3m (with invert Control)
Voltage	100V	100V

Figure 6 - Pressure pump units for the experiments



Toilet drainage system [horizontal (1) ceiling (2)] | Bathtub drainage system [horizontal (1) ceiling (2)]

Figure 7 – Experimental apparatus for drainage characteristics

2.2 Load influence on the drainage capacity of the stack system

The environmental experimental construction simulation tower at Kanto Gakuin University, where the authors are based, was used for this experiment. **Fig.8** illustrates the schematics of the experimental drainage stack system (pipe diameter: 100mm). The stack system employs a special-coupling drainage system equipped with A and B-type pressure pump systems. Drainage load was applied according to three different patterns; to the conventional gravity drainage system only, to the forced drainage system only, and to the hybrid drainage system, which is a cross between the gravity drainage system and the forced drainage system. **Table1** shows the conditions for the drainage stack system and **Table2** shows the experiment patterns by which drainage load was applied using the experimental plumbing fittings. Three different floors of the simulation tower between 6^{th} floor and 8^{th} floor were used to apply drainage load according to the patterns shown in **Table2**; 8F, 7F+8F, 6F+7F+8F. **Table3** shows items to measure and measuring methods. Incidentally, the pressure fluctuation, the valuation basis, is

±400[Pa] compliant with the SHASE-S218 standard.

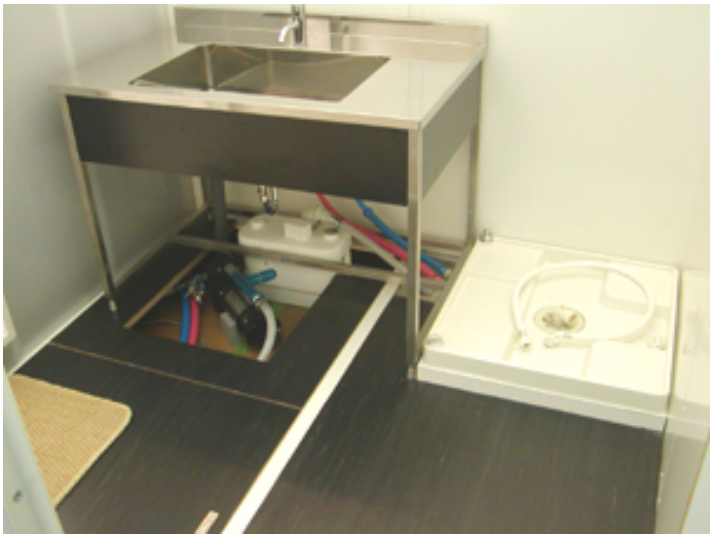


Photo 1 - Underfloor installation

Table1 - Conditions for the stack system

horizontal Branch	Gravity Drainage	75mm
	Forced Draiange	20mm
Drainage Stack		100mm
House Drain		125mm
Load	1Floor	8F
	2Floor	8,7F
	3Floor	8,7,6F

Table 2 - Experiment patterns

Load No	drainage					
	Toilet (S type)	Bathtub: forced			Toilet (P-type): forced drainage	
		Conventional	Underfloor	Ceiling	Underfloor	Ceiling
1	○					
2		○				
3			○			
4				○		
5					○	
6						○
7	○	○				
8	○		○			
9	○			○		
10	○				○	
11	○					○
12	○	○			○	
13	○		○		○	
14	○	○				○
15	○		○			○

Note: Bathtub pump speeds: 1500, 2500 and 3500rpm.
Drainage load: applied by the pattern (8F, 7F+8F, 6F+7F+8F)

Table 3 - Criteria

Item to measure	Symbol	Measuring method
Stack velocity	W	With an anemometer attached to the extension stack
Stack pressure fluctuation	Pn	With a compact semiconductor pressure sensor attached to the branch pipe 500mm away from the stack center. Compliant with SHASE-S218 and based on Psmax and Psmin of the pressure
Bathtub trap fluctuation and seal loss	⊿h	Compliant with SHASE-S218, ensuring that the seal loss is not below the half or less of the seal depth.

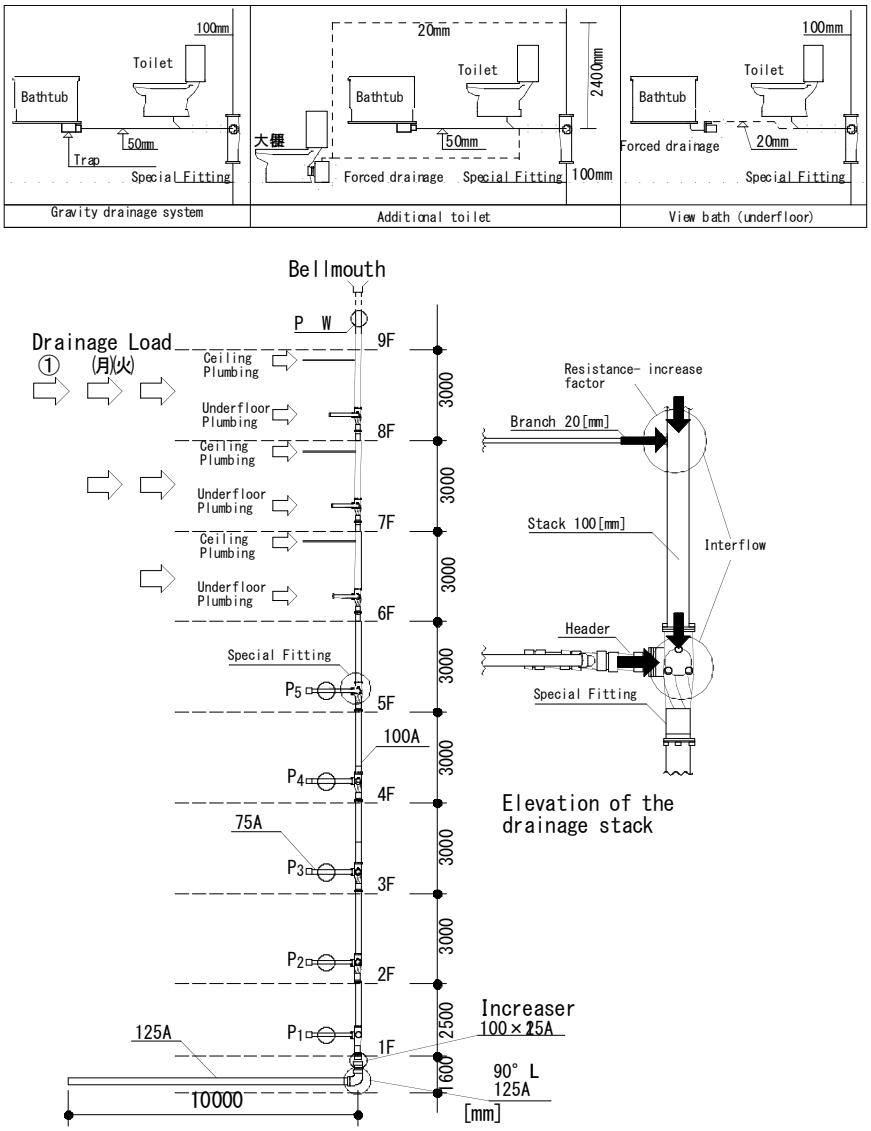


Figure 8 - Experimental stack system

3. Results and considerations

3.1 Drainage performance of the force drainage unit with a pressure pump

(1) Drainage characteristics - toilet

Fig.9 shows curves that represent different drainage flow rates when the toilet was drained using the experimental apparatus which is illustrated in **Fig.7**. It is evident that the maximum value of each flow rate fluctuation is lower with the pressure drainage method than with the gravity method. Especially when using the ceiling plumbing, the actual pump head is 25kPa and the hydrostatic pressure is 2.4mAq and these considerably high values create a significant degree of resistance, thus, making the

discharge flow rate low. **Fig.10** shows head capacity curves and resistance curves during drainage. When the flow rate is 54.7[L/min] (0.91[L/s]) using the horizontal plumbing, it is 36.1[L/min] (0.6[L/s]) with the ceiling plumbing while the drainage load flow rate added to the drainage stack decreases. Finally, **Table4** summarizes drainage characteristics identified by toilet drainage, where it is clearly shown that the average drainage flow, the qd value, which is used for the drainage load calculation, decreases by approx. 60% from 1.06[L/s] with the gravity drainage system to 0.68[L/s] with the ceiling plumbing.

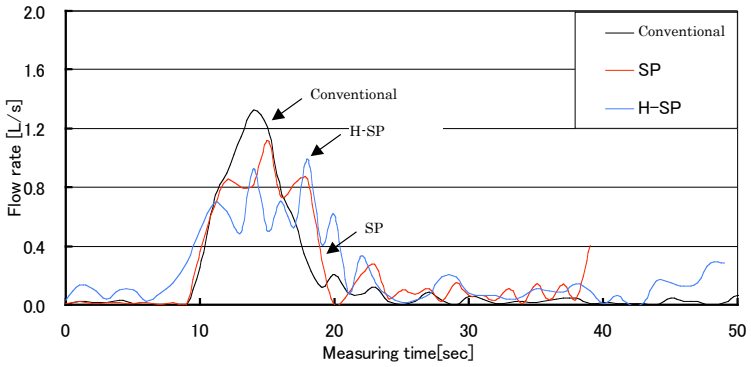


Figure 9 - Tank flow rate

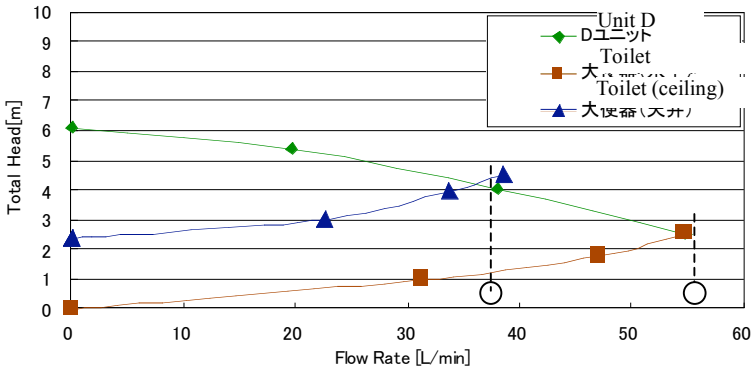


Figure 10 - Drainage characteristic curves - toilet

Table 4 - Drainage characteristics - toilet

Type		Drainage volume W (L)	Required drainage time T(sec)	Drainage time Td(sec)	Average drainage flow rate qd(L/sec)	Instantaneous maximum flow rate qmax (L/sec)	Average flow rate balance qw (L/sec)
Toilet	Conventional drainage	8.26	100.0	4.7	1.06	1.33	0.72
	Horizontal	8.05	40.0	5.0	0.97	1.12	0.87
	Ceiling	7.33	50.1	6.5	0.68	0.99	0.75

(2) Drainage characteristics - bathtub

Fig.11 shows curves that represent different drainage flow rates when the bathtub was drained using the experimental apparatus which is illustrated in **Fig.7**. Three different pump speeds; 1500rpm, 2500rpm and 3500rpm, were used during the experiment. When using the ceiling plumbing at 2500rpm approx., the maximum drainage flow rate is almost identical to that when using the gravity drainage method. This becomes doubled when using the horizontal plumbing at 3500rpm. As shown in **Fig.12**, the trap caused an overflow when using the ceiling plumbing at 1500rpm, making drainage impossible. The flow rate becomes 20.4[L/min] (0.34[L/s]) at 2500rpm. The qd value is 0.52[L/s] using the gravity method and increases by 0.24 - 0.58[L/s] at this pump speed. Table 5 - Summarizes drainage characteristics identified by the bath drainage.

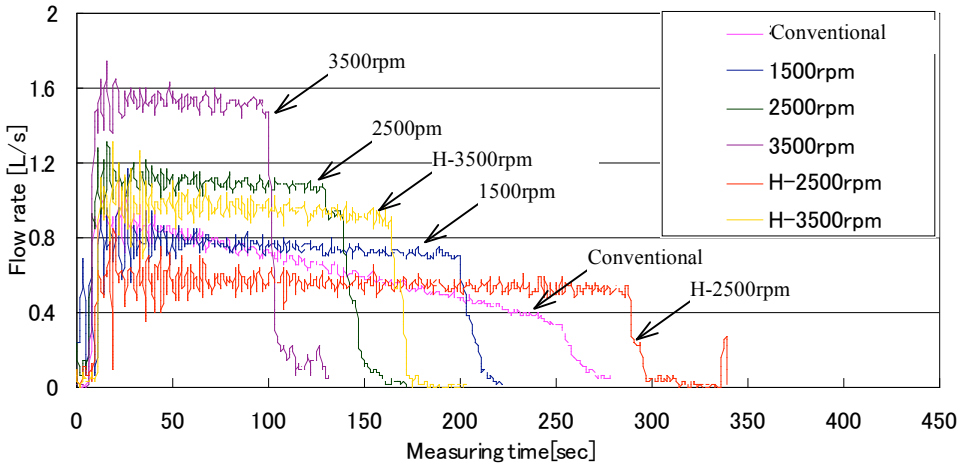


Figure 11 - Drainage tank flow rate

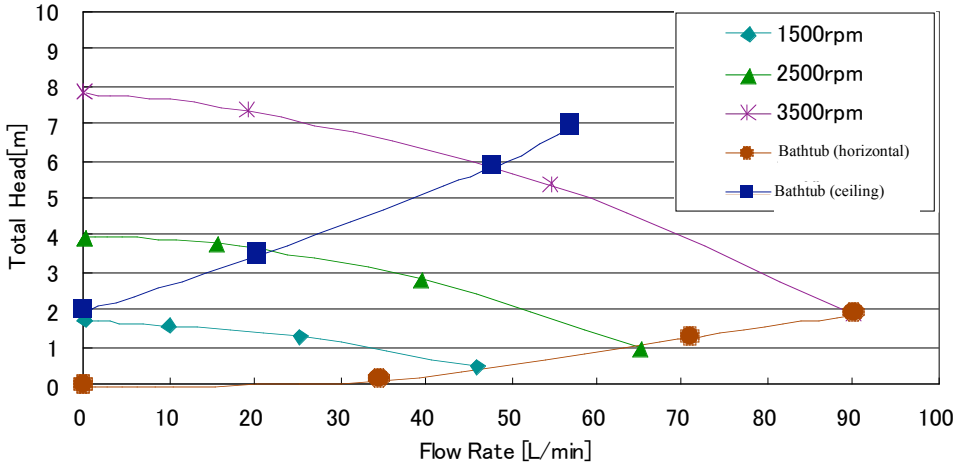


Figure 12 - Drainage characteristics curves - bathtub

Table 5 - Drainage characteristics – bathtub

Type			Drainage volume W (L)	Required drainage time T(sec)	Drainage time Td(sec)	Average drainage flow rate Qd(L/sec)	Instantaneous maximum flow rate Qmax (L/sec)	Average flow rate balance Qw (L/sec)
Bathtub	Conventional drainage		149.50	279.0	135.6	0.66	0.85	0.99
	Horizontal	1500	146.80	214.6	116.5	0.76	1.17	0.99
		2500	149.50	178.5	81.6	1.10	1.32	1.21
		3500	148.00	130.2	58.1	1.53	1.74	1.65
	Ceiling	H-2500	158.68	264.7	169.3	0.56	0.83	0.75
		H-3500	151.76	179.5	94.8	0.96	1.27	1.11

3.2 Load influence on the drainage capacity of the stack system

(1) Influence on the pipe pressure

Fig.13 (1) shows pipe pressure distributions (maximum value: Pmax, minimum value: Pmin) according to the experiment pattern, No.14 in **Table2**, with an additional toilet connected to the gravity drainage system when drainage was performed simultaneously from 6th, 7th a d 8th floors. The drainage load pressure ranges roughly from –190[Pa] to 100[Pa] using the gravity drainage system solely, whereas the negative pressure is –450[Pa] as the drainage load from the ceiling plumbing increases by the forced drainage system, going slightly below the criterion –400[Pa]. Meanwhile, the trap seal loss of 20mm approx. is retained, not causing complete breakage.

Considering that according to the previous study (4), the physically feasible drainage for a 8-storey standard building under actual harsh drainage load conditions is from the maximum of two upper floors, the pressure value is –350[Pa] approx., which satisfies the criterion. Furthermore, the underfloor plumbing hardly requires the actual pump head and therefore, the drainage flow rate and the negative pressure were initially predicted to increase. On the contrary, the negative pressure is –320[Pa], moderate compared to the value recorded with the ceiling plumbing, meeting the criterion of –400[Pa].

These results were reached seemingly because, as shown in **Fig.14**, the drainage stack had three additional inlets to it using the ceiling plumbing, doubling the number of what it would have had when using the conventional underfloor plumbing, and consequently the interflow increased air-flow resistance.
Fig.13 (2) presents pressure distributions (Pmax and Pmin) when a bathtub for SI

housing was modified to a view bath (horizontal plumbing). The drainage pressure before modification ranges between –180[Pa] and 100[Pa] and when the pump speed is changed to 2500rpm the negative pressure becomes –380[Pa] approx., satisfying the criterion of –400[Pa]. At 3500rpm, however, the maximum value (Psmax) becomes –500[Pa], going below the criterion. Hence, a pump speed of around 2500rpm is considered to be appropriate.

(2) Drainage capacity and applicable floor levels

Fig.15 shows the relationship of the Σqd value, the total of qd values, average rates of drainage flows that flow into the drainage stack, with Pmax and Pmin. Drainage characteristics are different between the plumbing fittings but in terms of the criterion of ±400[Pa], the special-coupling drainage system enables drainage capacities up to 8.0[L/s].

Fig.16 shows the relationship of applicable floor levels based on what is shown in **Fig.15** with drainage load flow rates and drainage capacities. It has been found that when an additional toilet is installed for those in care and the bathroom is relocated to become a view bath, the special-coupling drainage system can cope with high-rise housing buildings with a height of 45m above ground level using 100mm-diameter pipes, and super-high-rise housing buildings with a height of 120m above ground level using 125mm-diameter pipes.

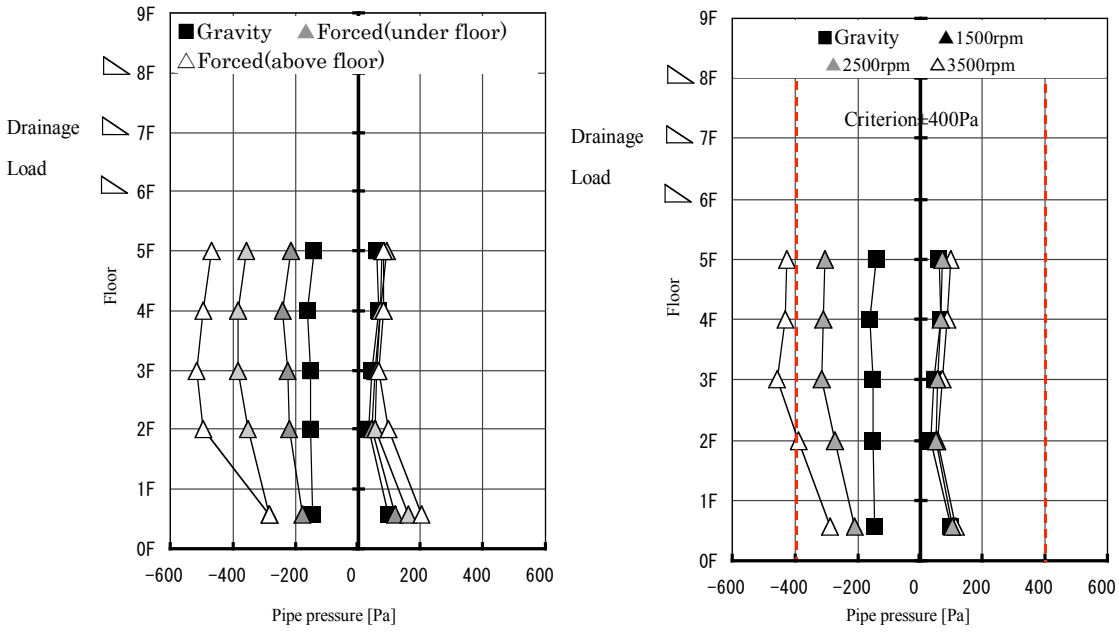


Figure 13 - Pressure distribution

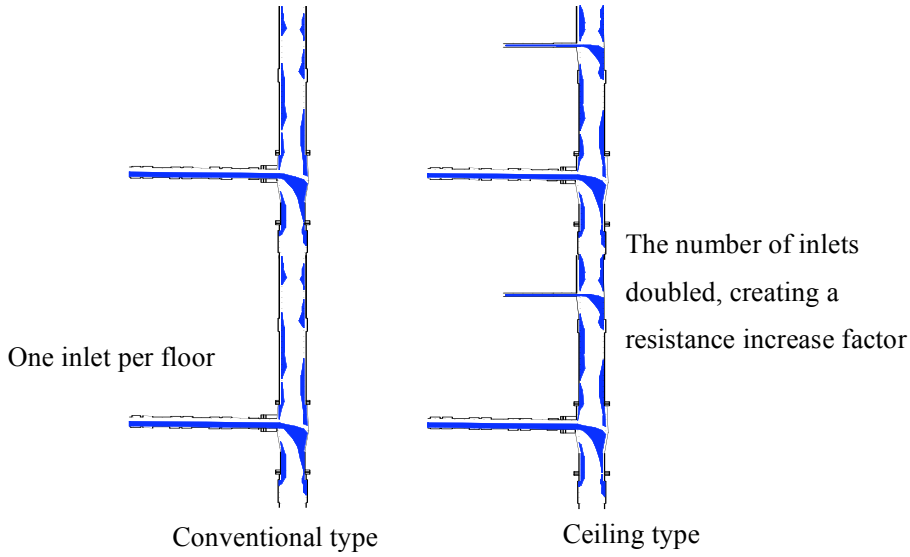


Figure 14 - Air-flow resistance increase factor

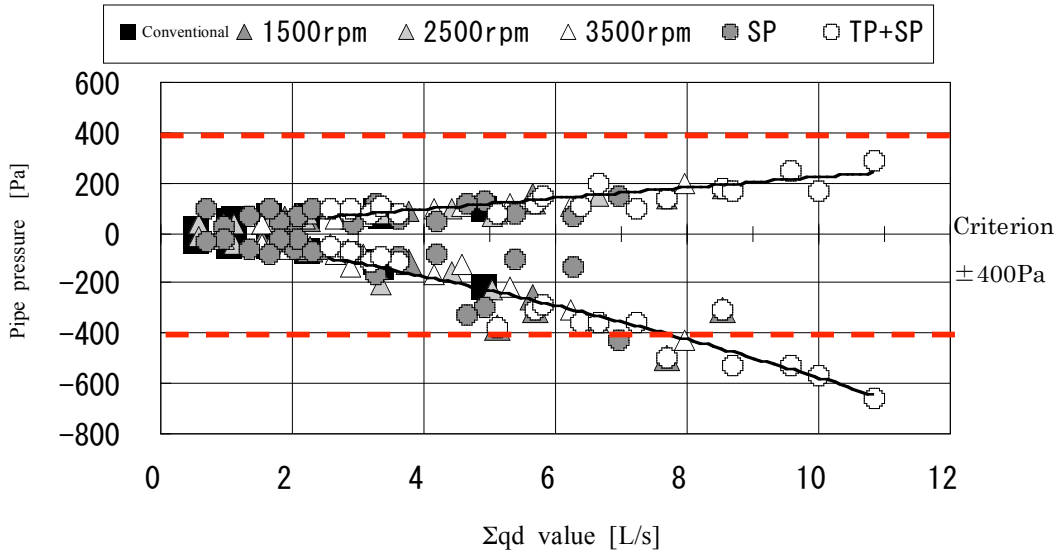


Figure 15 - Σqd values and pipe pressure

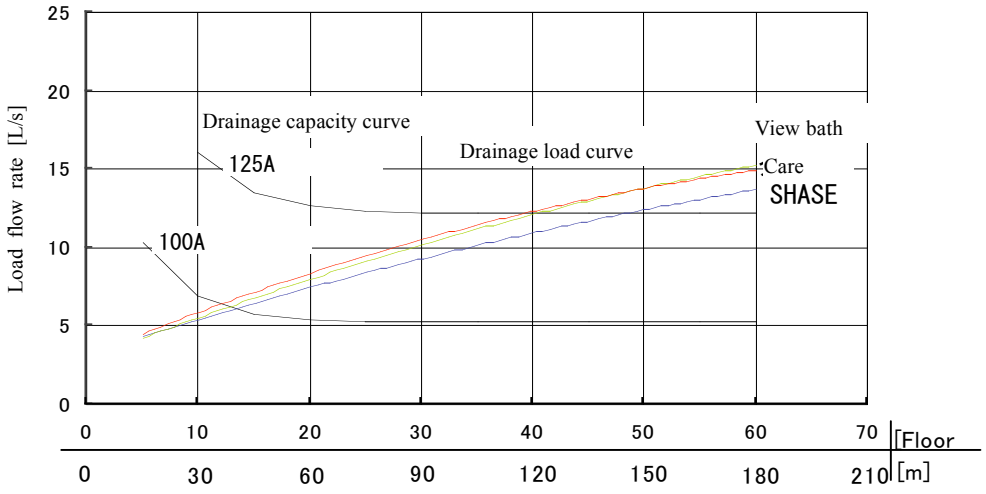


Figure 16 - Suitable drainage height and load flow rate

4 Summary

With the intention of realizing “free-plan housing”, the “hybrid drainage system”, a cross between the gravity drainage system and the forced drainage system, has been proposed and performance testing has been conducted by which the following conclusions have been acquired.

(1) The proposed hybrid drainage system contributes to the widening of construction design options including the installation of toilets for those in care and view baths.

(2) When using ceiling plumbing the drainage system appears to create a greater influence on the pipe pressure than when using horizontal plumbing. The reason is believed to be because of the increased number of inlets to the drainage stack, which increases inflow resistance. Hence, the further development of a coupling which is capable of moderating inflow resistance will be a future issue.

(3) The drainage capacity of the proposed hybrid drainage system, when applied to a typical special-coupling drainage system, has successfully been identified in reference to the SHASE-S218 criterion. Applicable floor levels have also been identified, although roughly. Subsequently it suggests that the hybrid drainage system can be adopted for super-high-rise housing complexes.

(4) Measures for emergencies, such as power cuts, will be a future issue to be discussed.

Acknowledgement

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Personal date of authors

Masayuki Otsuka is a professor at the Department of Architectural Environmental Engineering, Kanto Gakuin University. He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). Current Research interests are performance of plumbing systems, drainage systems with food waste disposers in high-rise apartment houses and drainage piping system for SI (Support and Infill) housing.

Yusuke Minami is a graduate student (doctor course of second) of the Graduate School of Architectural Engineering Department, Kanto Gakuin University. He conducts the research on the drainage performance evaluation of the drainage system with a food waste disposer grinder (food waste grinder).

Research of infection spread risk evaluation in building drainage system

C.J. Yen. (1), C.L. Cheng. (2), J.R. Ho. (3)

(1) D9313006@mail.ntust.edu.tw

(2) CCL@mail.ntust.edu.tw

(3) M9313212@mail.ntust.edu.tw

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

Abstract

Traditionally, the building's drainage is mainly to discharge fecal sewage. However, the infection incident of a high-rise in Hong Kong during the 2002 SARS outbreak has gained international attention over the drainage system's ability to prevent infectious diseases from spreading into a building. The loss of seal water in trap of any given plumbing system is likely to disseminate air-born diseases inside a building, causing an outbreak. In this study, the various drainage systems of the Taiwan buildings were examined and the infection carrier dissemination factor of the existing drainage systems was identified by applying weighting coefficient. An initial investigation shows infection factors include traps, drainage pipes, interior ventilation and system maintenance. The measuring approach explored in this study would used to develop the evaluation scheme for determining the risk of infection factors of air-borne diseases in a building's drainage system.

Keywords

drainage system, infection evaluation system, weigh coefficient

1 Introduction

The most important function of architectural drainage systems is to allow the contained materials to free-fall into the collection area with the help of gravity. To make sure that the drainage system can carry the materials with ease is an important subject that cannot be neglected. Other is to avoid the contaminants air and infection spread into living room by drainage plumbing system. Owing to the piping is not isolated but directly link the room space and the sewage treatment equipment. The only prevention is the trap which can easy depletion by flush water and vaporization. Not only the Crowded, highly tendency the housing building but also non-natural ventilation design plan can improved the risk of infection.

The infectious disease mainly is penetrates certain dissemination ways to cause the disease which the person infects. Take drainage system as an example (Figure 1), when patient go to use the toilet. If unfortunately the seal water in trap with function of failure, the faeces will become the source of infection because of the pathogen which can infected through the route of drainage system. During 2003 Coronal virus erupts the period, the whole world altogether has 8,098 people to suffer from the SARS sickness and 774 dead. In Taiwan, there are 73 dead. The infection incident of a high-rise in Hong Kong during the 2002 SARS outbreak has gained international attention over the drainage system's ability to prevent infectious diseases from spreading into a building. This research mainly aims at the drainage system to make the discussion, its main dissemination risk factor includes: The terminal appliance, the plumbing system, the spatial environment and the use maintenance.

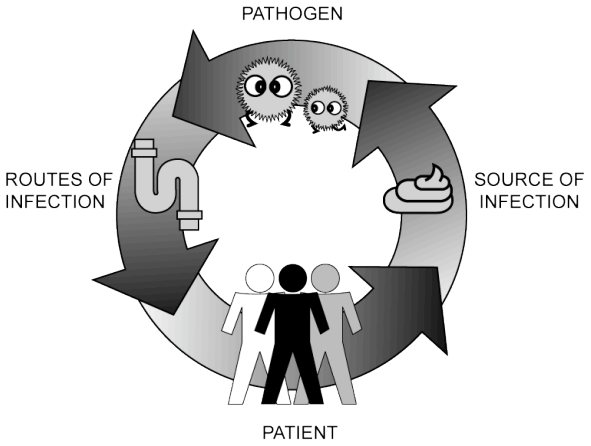

Figure 1 - Infectious Diseases spread Diagram

2 Building drainage System

2.1 Mechanism description

An actual discharge of vertical drainage stack has a complex phenomenon and may consist of triple phase flow feature with incorporated solid, liquid and air. The mechanism of flow within vertical drainage is now schematically understood (figure 2 and figure 3).

S1 is located at the upstream part of the stack vent from the discharge entry; therefore it only consists of airflow. Airflow in the drainage stack is promoted by through-flow mixing and the friction interaction between falling water and air. S4 the seal because of the traction of falling water will producing negative pressure and pull water seal try to balance the air in pipe. Until the water flows goes to S6 the main horizontal pipe, because of the stack transition the falling water became a water curtain air in the pipe goes back to lower floor drain to liberate the pressure. When the water seal can't keep off air pressure that will causes the water seal lose. In figure 3, it shows if plumbing system use double-pipe, the part of air pressure can inhale or liberate from the air pipe.

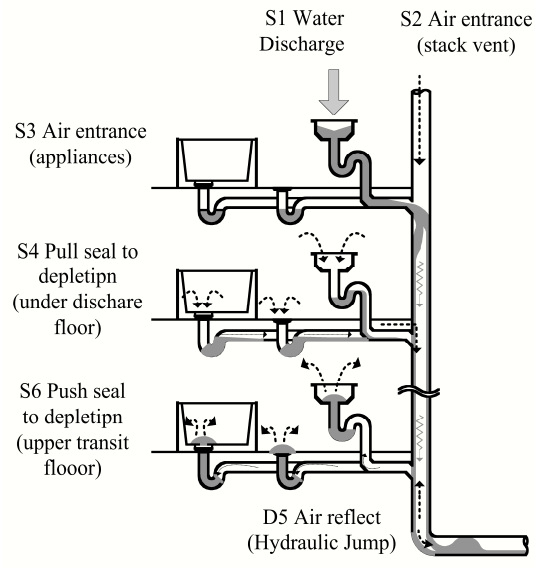

Figure 2 – Air flow in single-pipe drain

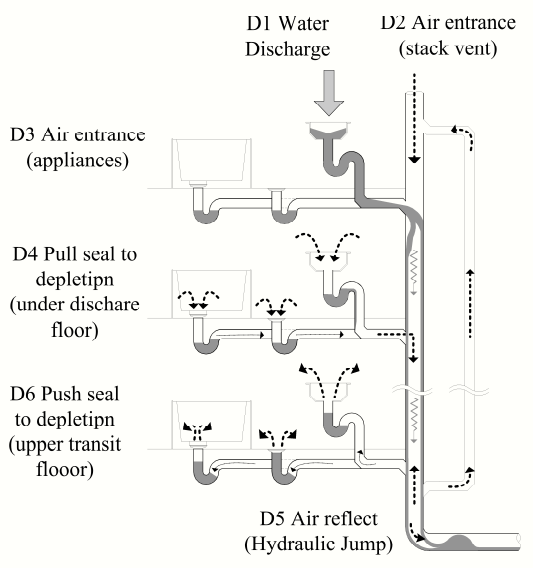

Figure 3 - Air flow in double-pipe drain

2.2 Design method

Drain components can divide into Drain System, Zoning Method, and Connection Method. Vent components can divide into Stack Vent, Yoke Vent, Loop vent, and endmost vent.（Figure 4）

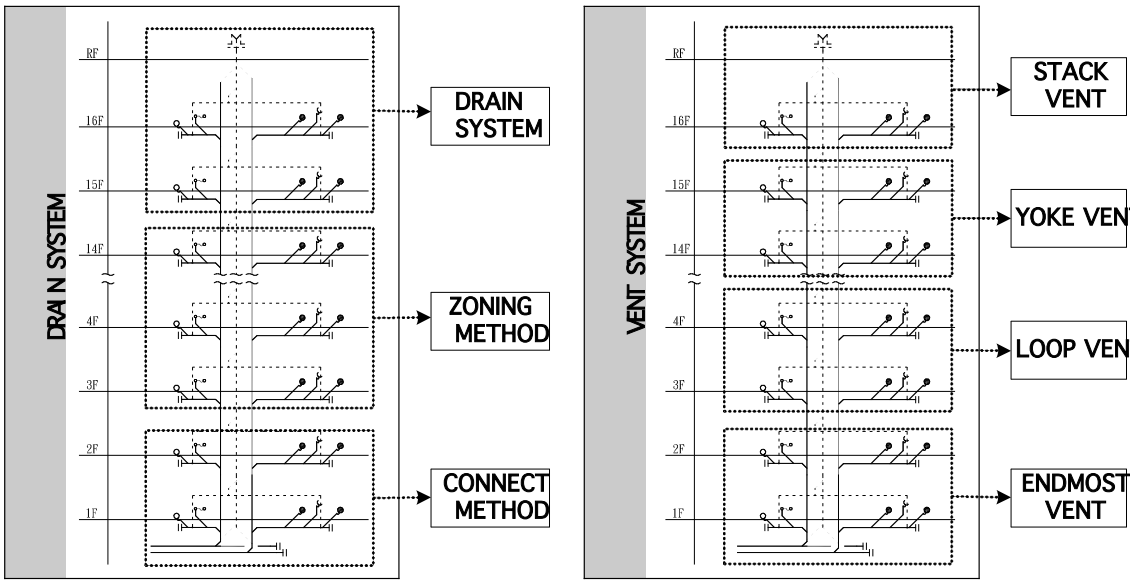

Figure 4 – Drainage system classification

3 Evaluation of infection spread risk

3.1 Methodology and evaluation system

The drainage system risk evaluation trying to use Failure Mode Effect Analysis (FMEA) to reveal the factor which influence of drainage system may cause the infection spread risk and applying weighting coefficient. The appraised table can give the prevention by showing the risk value of drainage system and may help to discover essential factor of the influence risk value by items.

The FMEA process was originally developed by the US military in 1949 to classify failures "according to their impact on mission success and personnel/equipment safety". Failure Mode and Effects Analysis is systematized technique which identifies and ranks the potential failure modes of a design or manufacturing process in order to prioritize improvement actions.

This risk evaluation system penetrates situation examination table and carries on the appraisal. The first investigation case with basic document includes location, the

building usage, building type, building scale and the floor, and obtain drainage plan. After the examination of floor drain, we follow the drainage plan to look up the plumbing system and also evaluate the space and environment.

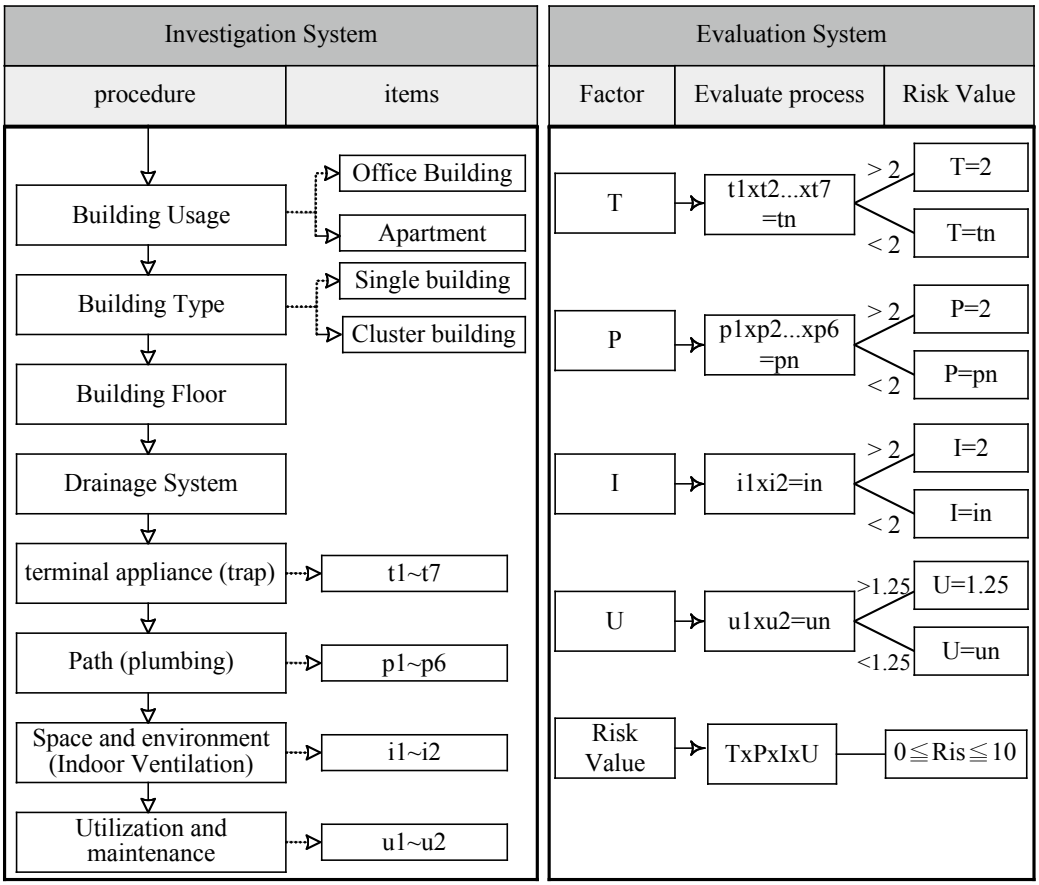

Figure 7 – Investigation system and Evaluation system illustration

In order to detect the effects infection factor cause by malfunction drainage system. This research penetrate risk assessment table obtains dissemination risk value Ris. The formula 1 its value is multiplications the value of four risks influences factor obtained weight and limits scope from 0 to 10. Value smaller expression risk lower, otherwise, then is higher. Penetrates this appraisal table to be possible to be separately systematic and the individual influence factor makes the discussion. Understood Taiwan drainage system design method to disseminate risk of value the infection carrier, and discovers in the system harm the existence, so may give the system remedial treatment and the design appraisal reference.

$Ris=T\times P\times I\times U(0\leqq Ris\leqq 10.0)$……..（1）

Figure 7 illustrates the relationship of investigation and evaluation system. The drainage system influence factor is: The terminal appliance, plumbing system, the spatial

environment and use maintenance, and its factor and risk coefficient appraisal table as the following content.

3.2 Terminal appliance (trap)

The terminal appliance means to collect the sanitary sewage to discharge building drainage system, such as water closets, urinals, bidets, and floor drain. They are use to discharge and prevent the noxious gas into interior by water seal. When water seal depletion by air pressure or vaporize to dry that will easy to form way of infection. The experimentation of the floor drain has to be taken due to the invisible water seal of floor drain to make sure the capability.

Most of the sanitary fixture had their own trap inside, could easy to examine but floor drain can highly discard by construction and may cause the mainly infection. And the
The tendency of seal water vaporizing rate and the relation between seal water depth and strength had been confirmed the depletion time between 9days to 23days. According to the 10mm water depth experiment, the limitations of pressure is about 90pa (-9mmAq). When floor drain experiment operates gives the slow pressure up to 20pa until the instrument data steady and then the pressure can keep for 10 minutes. If there is no pressure can keep and then have to make sure the trap existence by fill water so that finding out the cause is long time unused or without it.
The trap weighting coefficient is shown on table-1, the totally product of the entire terminal appliance cannot exceed 2.

Table 1 –Trap weigh coefficient

Factor	Sanitary fixture	Examine items	Provided	Unprovided
t1	water closets	Trap with water seal	1.0	1.5
t2	urinals	Trap with water seal	1.0	1.5
t3	basin	Trap with water seal	1.0	1.5
t4	bidets	Trap with water seal	1.0	1.5
t5	floor drain	Trap with water seal and prevent device	1.0	2
t6	mop basin	Trap with water seal and prevent device	1.0	1.5
t7	not in used	prevent device	1.0	1.5

$T=t1 \times t2 \times \ldots t7$ ，If $T > 2.0$, then $T = 2.0$---------- （2）

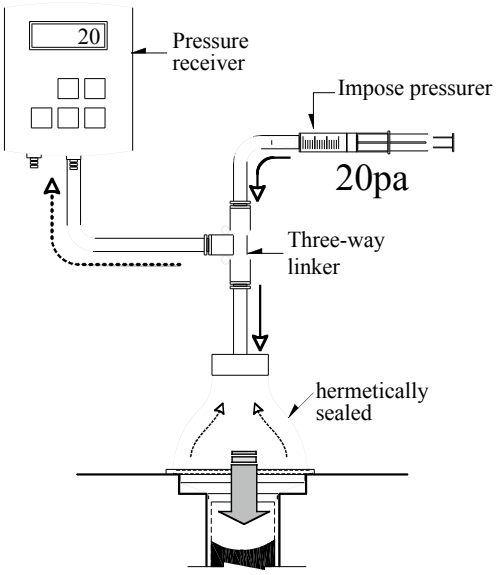

Figure 5 – Pressure measurement

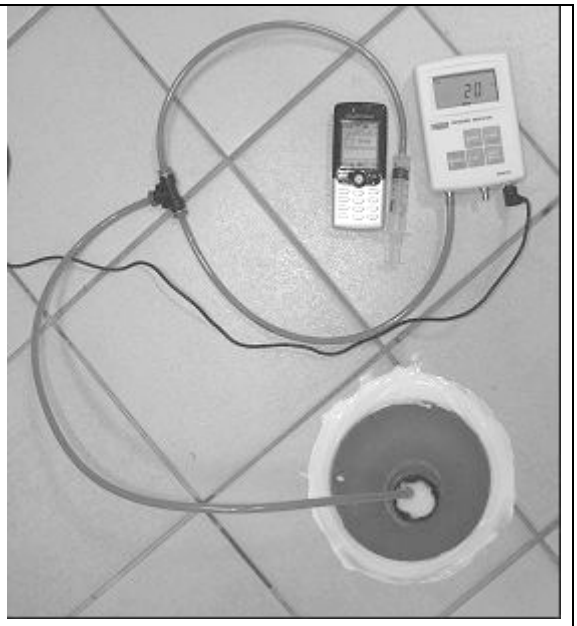

Figure 6 – Floor drain examination

3.3 Path (plumbing)

At present Taiwan existing drainage system is used the single-pipe system for lower floor and the double-pipe system for higher floor but yet used separately system. The sanitary drainage and feces sewer need to separately by regulations. Table-2 shows the path factor weighting coefficient.

Table 2 –Path factor weighting coefficient

Factor	System select		Floor			
			Under 7F	8~15F	16~29F	Over 30F
p1	Single-pipe system	General joint	1.0	1.1	1.3	1.5
		Special joint	1.0	1.0	1.0	1.2
p2	Double-pipe system		1.0	1.1	1.2	1.3
p3	Loop vent system		1.0	1.1	1.2	1.3
p4	Triple separate system		1.0			
p5	separate system		1.3			
p6	combined		1.5			

P=p1×p2×…p6，If P＞2.0, then P＝2.0----------（3）

3.4 Space and environment (Ventilation)

Ventilation condition included natural and mechanical. Natural ventilation according to ventilate the area and the floor area takes the weight. But mechanical ventilation if auxiliary by import fresh air may reduce the partial weights otherwise it will increase risk. Table-3 shows the space and environment weighting coefficient.

Table 3 – Space and environment weighting coefficient

Factor	System select	Ventilated condition				
i1	Positive ventilation	Living room all can ventilated	90% floor area ventilated	80% floor area ventilated	60% floor area ventilated	Under 60% floor area ventilated
i2	mechanical ventilation	Import fresh air to ventilated	Import fresh air	Over 50% Import fresh air	Under 50% Import fresh air	Non fresh air import
		0.8	1.1	1.2	1.3	1.5

I=i1×i2×…i3，If I＞2.0, then I＝2.0----------（4）

3.5 Utilization and maintenance

Drainage system after 15 years operation the performance and the security have to examine urgently. This research takes the risk factor based on the equipment life cycle and the use maintenance. Table-4 shows the utilization and maintenance weighting coefficient.

Table 4 – Utilization and maintenance weighting coefficient

Factor	Utilization condition	New	In 5years	6-10years	11-15 years	16-20 years	Over 21 years
u1	equipment life cycle	1.0	1.05	1.1	1.15	1.2	1.25

Factor	Maintenance condition	Excellent	General	Bad
u2	Quality of construction and maintenance	1.0	1.1	1.2

U=u1×u2，If U＞1.25, then U＝1.25----------（5）

4 Analysis and verification

4.1 Case study and ranking frame

After 30 random observations, we could make up chart which related to the connection between to drainage disease and separation up to 4 individual sections. By investigating each sections, the chart will eventually tells the observatory personal which drainage system will have instant higher chance to get effect and more dangerous become one of the drainage system which transmitting the virus. Accordingly, it would help to defend if system is in well shape or not, so it eventually could be applied and getting improved.

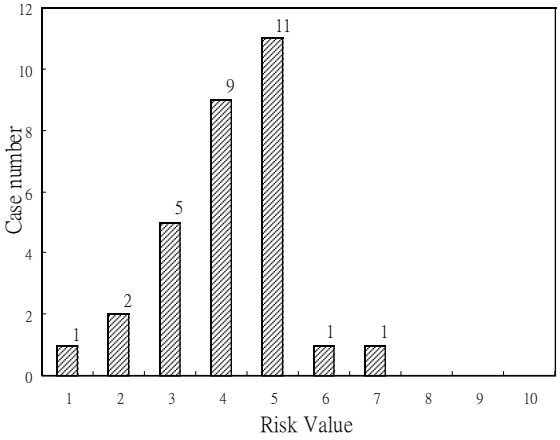

Figure 8 – Case distribution of risk value

Figure-8 shows the case distribution of risk value. In the drainage system the risk influence factor, affects the weighting following chart to show the terminal appliance equally is 1.7, plumbing system equally is 1.365, space and environment equally is 1.316, utilization and maintenance equally is 1.222 as shown as Figure-9.

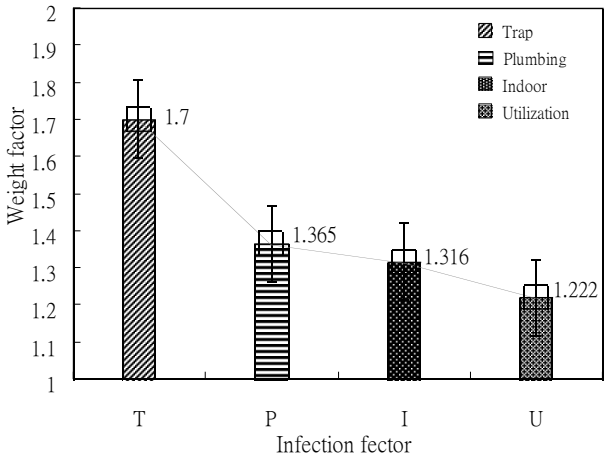

Figure 9 – The mean of each factor weighting coefficient

According to the case verification distribution, the risk value group could divide into five ranks by risk value low rank one to high rank five as shown as Figure-10.

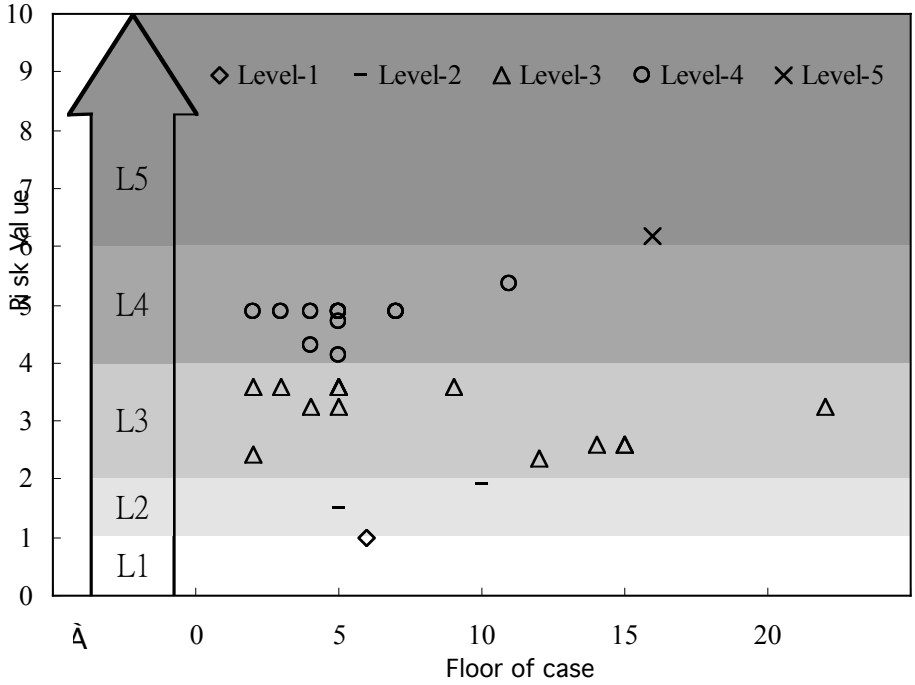

Figure 10 – The verification results of practical cases

According to the risk value characteristic, each level can be defined as the adequate description. Figure 11 shows the risk level diagram which illustrates the risk value and the according definition.

Risk Level Diagram					
Risk Level	1	2	3	4	5
Risk Value	0~1 point	1~2 point	2~4 point	5~6 point	6~10 point
Defination	Designs good, non- infection risk.	Risk value permissible , may examine with the auxiliary means.	Risk value medium, may sense the system problems.	Risk value high, with stench and obvious low design quality .	Risk value extremely high, with high-infection risk

Figure 11 - Risk level diagram and definition

4.2 Discussion

In this research investigation discover 73.3% floors drain is abnormal or not set up initially, especially the buildings over age 15 years are the majority. It demonstrated the early drainage system had not considered the necessity of the floor drain. But still had the extremely low ratio to demonstrate if they had their own floor drain, then it might cause the risk value to be low.

Concerning the ventilation in the building environment, 60% need auxiliary mechanical ventilation. The inadequate ventilation environment is still extremely easy to causes the air be detained and enhanced the dissemination risk. According to the drainage system life cycle consideration, the risk factor weighting influence is smaller and the dissemination risk regarding this influence is also small. Through the observation fo 30 cases appraisals, the risk value mostly are around 4~5 points with 66.6% which belong to the risk value of medium. Consequently, the assessment proposal of risk ranking system is proved to be practicable for evaluating the infection risk of building drainage system.

5 Conclusion

In Taiwan, lower story building mainly use single-pipe system, medium-high and high-rise buildings adopt dual-pipe as the drainage system. In this study, the various drainage systems of the Taiwan buildings were examined and the infection carrier dissemination factor of the existing drainage systems was identified by applying weighting coefficient. An initial investigation shows infection factors include traps, drainage pipes, interior ventilation and system maintenance. The measuring approach explored in this study would used to develop the evaluation scheme for determining the risk ranking of infection factors of air-borne diseases in a building's drainage system.

Accordingly, we created an infection spread risk evaluation system for building drainage system in this research. Using the quantitative risk ranking value, this paper establishes the drainage system risk assessment system and enables the drainage system to be reviewed from overall and the individual influence factors. As the result, the assessment tool may provide the designer and the occupant could fast and precisely to judge drainage system performance in either new construction or the existing building.

6. Acknowledgements

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8 Presentation of Author(s)

Chia-Ju Yen is a Ph.D student majoring in drainage system at National Taiwan University of Science and Technology, Department of Architecture. She is also interested in sustainable building.

Identification of possible cross contamination scenarios facilitated by building drainage and ventilation systems, and the contributory role of modelling positive transient pressure propagation

Dr L.B. Jack[1], Professor J.A. Swaffield[2], Mr S. Filsell[3]

1. l.b.jack@hw.ac.uk
2. j.a.swaffield@hw.ac.uk
3. sf3@hw.ac.uk
Drainage Research Group, Heriot-Watt University, Edinburgh, EH14 4AS, Scotland.

Abstract

The route of transmission of the SARS virus through the building drainage ventilation system of the Hong Kong Amoy Gardens housing complex, that resulted in 42 fatalities in March 2003 is now well known and well documented. As well as raising the general level of awareness of the possibility of disease transmission via drainage pipework, this event also prompted a re-evaluation of the impact of the overall transient pressure response of the system in either enhancing or inhibiting the movement of contaminant or virus-laden air. Although in the case of Amoy Gardens, the dominant factors contributing to transmission were determined by (mechanically) forced airflow and by buoyancy effects on the exterior surface of the building, it will be appreciated that there exist a range of further possible contributory mechanisms, where these are primarily determined by the system design, operation and maintenance, and where the occurance of positive or surcharge pressures can enhance 'reverse' or upwards airflow.

This paper identifies the individual factors that lead to the transmission of SARS in Amoy Gardens, and in doing so, presents an initial assessment of risk, focusing on the potential contribution of the generation and propagation of positive air pressures. The paper also addresses how research investigations and modelling techniques have enhanced understanding of system response when the network is subject to either sustained or short duration positive air pressures.

Keywords

Pressure transients, drainage system, modelling, cross contamination

1. Introduction

The role of drainage ventilation pipework within the overall services provision for buildings is seldom recognised as a vital component in retaining appliance trap seal levels that in turn ensure protection from the miasma present within the network and connected sewer system. Until recently, under-performance of this ventilation system was typically characterised by the ingress of foul odour – an occurance that, although unpleasant, does not introduce any real risk to health. However, transmission of the SARS virus through the drainage system of the Amoy Gardens housing complex in March 2003 – an event that resulted in 42 fatalities - prompted a re-assessment of the design and operation of systems in order that the risk of transmission of similar airborne viral diseases under both normal and extreme system operating conditions may be determined. To enable an understanding of the factors contributing to a risk assessment of this kind, the flow mechanisms that underpin the pressure response of the system require definition, as these both inhibit and enhance air movement capable of carrying either disease or contaminant.

2. System Flow Mechanisms

Discharge flows from sanitary appliances typically enter the main vertical stack of any drainage system via one of a number of swept branch connections. This results in the formation of a water 'curtain' at the active pipe junction, before the flow then forms an annular column that is maintained to the stack base, Figure 1.

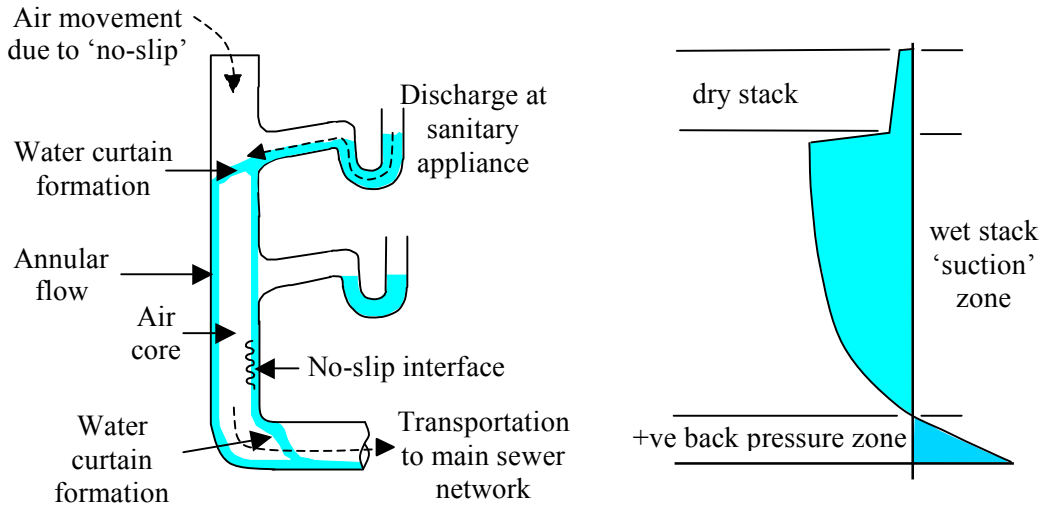

Figure 1 - Discharge leading to formation of annulus and idealised pressure profile

This annular flow results in the generation of predominantly negative pressures within the building drainage system, due to the condition of 'no-slip' present at the water-to-air interface that entrains air from the upper stack termination. This termination typically extends through the roof space thus allowing inflow to the pipe from atmosphere external to the building, or is located within the building space thereby relying upon negative pressure relief as provided by an appropriately positioned air admittance valve.

As entrained air enters the system, its route will govern the overall pressure response for the network, where friction losses in the dry stack will clearly result in a steady distributed increase in the absolute magnitude of negative pressure, and where localised pressure losses will be introduced by the presence of the water curtain at active branch connections. With peak negative pressures therefore occurring directly below active junctions, there must hence be a pressure regain, generated by water traction on the air core, in line with the atmospheric pressure present in the sewer connection pipework. This regain must be viewed in conjunction with the occurrence of positive pressure immediately upstream of the water curtain formed at the stack base. The resultant idealised pressure distribution diagram representing the steady state response of a system subject to one active discharge flow, as shown in Figure 1b, is well documented[1,2]. In order to facilitate such a representation, a range of simplifying assumptions have been made, however these are sufficiently robust to have underpinned many design recommendations presented in codes and guidelines internationally.

It will be appreciated from Figure 1 that, generally, the prevailing system pressure under normal operating conditions will be negative, thus providing a 'safe' route for any airborne contaminant that may be introduced, in droplet, particulate or aerosol form, via the sanitary appliance. However, any change in the magnitude of the positive pressure generated at the base of the stack clearly has the potential to vary the gradient of the pressure regain, and, dependent upon system design, introduce positive pressure in a region incorporating branch connections. Perhaps more importantly however, is the mapping of this steady state diagram on to the more representative transient system response that is governed by time-dependent discharge flows and the complex superposition of air pressure waves subject to transmission, attenuation, and reflection. It is known that negative transients are generated as a result of increases in appliance water flow, and the factors influencing the resultant pressure response of the system are reasonably well understood. Positive transients however, that arise when the entrained air drawn from the upper stack termination is sufficiently impeded, are much less well understood. Although the generation of a water curtain at a pipe offset will clearly introduce an impediment to entrained air, it is the (possibly accumulated) discharge flow that enters the sewer connection pipework via the pipe invert at the base of the stack that has provided the focus for recent research activity. These investigations become particularly pertinent when viewed within the context of the possible contribution of positive pressures to the mechanism of transmission of SARS facilitated by the drainage network of the Amoy Gardens buildings.

3. Community outbreak of SARS

The details relevant to the community outbreak of SARS referred to above have now been well documented and it is not the intention within this text to present again the findings made available by the Hong Kong Health Department and other involved organisations[3]. However, in order to undertake a preliminary risk assessment of contributory components, it is necessary to briefly reiterate relevant points, where these are that:

- those suffering from SARS were known to suffer from severe diarrhoea which, through the process of faecal virus shedding, resulted in the presence, within the drainage pipework, of a fine virus laden-mist.
- re-entry to residents' apartments was facilitated by dry U-traps where this route was aided by (oversized) shower cubicle extract fans that discharged to the outdoors lightwell.
- virus spread was then enhanced by the natural buoyancy effect in the lightwell and re-entry to apartments facilitated by open windows, Figure 2.

This relatively convoluted transmission route encompasses several co-incidental elements, some of which are common to most, if not all, drainage networks, and some that stand out as unusual. In order to be able to undertake an objective determination of future risk, it is important that contributory components are identified in terms of normalcy.

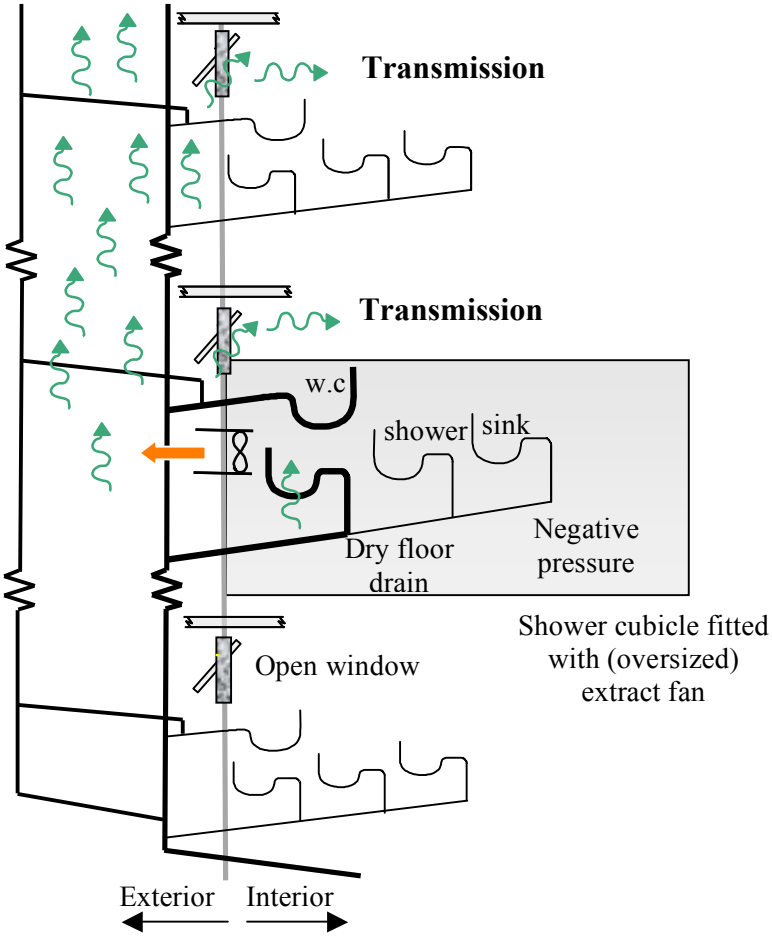

Figure 2 - Schematic diagram illustrating mode of transmission

With reference to Figure 2, contributory components may be identified as follows:

1. Physical interconnectivity of apartments through the link provided by the drainage pipework
   - *a universally common approach to the provision of drainage*

2. The presence of a fine virus-laden mist
   - *this factor is clearly dependent upon the function of the building served however, for facilities such as hospitals and high-rise apartment blocks, the presence of faecal-viral airborne particulates may be categorised as 'probable'.*

3. The incorporation (within any section of the building) of appliance traps that permit air movement
   - *this factor incorporates many aspects including; system design (to ensure suitably constrained pressure excursions); code compliance and installation approval (variable depending upon geographic location); maintenance (particularly where certain spaces within a building are subject to only infrequent use); unapproved system adaptation; trap evaporation (again dependent upon geographic location or other environmental factors).*

4. The generation of a prevailing sustained negative pressure within a residential space (caused in the Amoy Gardens case, by a shower extract fan)
   - *this factor will be relatively common for some specialised laboratories and some hospital wards and may also apply to some combined w.c./shower facilities.*

5. Discharge of domestic (fan-driven) exhaust air to building exterior
   - *a common (if not universally adopted) approach*

6. Buoyancy (or 'stack effect' movement) and re-entry to apartments via open windows
   - *a natural effect, but not one that introduces risk unless airborne pathogens are present.*

Assuming that all contributory factors identified may be allocated a representative risk factor based on both probability and consequence of occurrence, then the overall future risk of disease transmission by this mechanism may be determined. Clearly, however, an estimate of the probability of the presence of an appliance trap (or number of traps) that will permit air movement (point 3 above) encompasses a number of issues. Referring to the prevailing negative system pressures discussed in section 2, design specification aimed at avoiding 'slug' flow in both branch pipework and in the main stack has, historically, limited such pressure excursions, and has therefore generally protected the overall system integrity. However, associated operational issues such as inappropriate system adaptation, lack of maintenance or exceedance of performance limits can result in trap seal depletion, thereby introducing a vulnerability to the system. When viewed in conjunction with the occurrence of positive pressure generation (whether represented by a short duration transient or a longer duration surcharge typically generated downstream in the sewer connection pipework), it will be appreciated that the potential for cross contamination is introduced. This highlights the requirement for a clearer understanding of the factors that induce positive pressures, and reiterates the need for a better definition of their magnitude, duration and impact

characteristics. Since the transient nature of the system response will ultimately govern the overall response of the system and, in turn, will determine the degree of integrity offered by the connected water based appliance trap seal(s), it therefore becomes necessary to utilise numerical modelling techniques that are capable of analysing the time-dependent flow regime present throughout the network.

The ability of the AIRNET model to simulate the response of the building drainage and ventilation system is well established, and there exist a series of publications that document its development, from the fundamental use of the Method of Characteristics technique using simplified flow drivers and boundary conditions through to the more complex issues of detailed interactive flow modelling[4,5]. It is not the intention within this text to restate these developments, but rather to highlight the importance of the accurate empirical and theoretical definition of the boundary condition equations that form pairs with appropriate characteristic equations in order to allow the simulation calculation to proceed. In doing so, these algorithms ultimately define the behaviour of system components such as pipe terminations, appliance traps and pressure relief devices. Recent research activity has therefore focussed upon the definition of the characteristic parameters of water curtain behaviour and associated positive pressure generation that, once incorporated within AIRNET, will allow a better understanding, through analytical studies, of the risk of 'reverse' airflow and potential cross contamination.

4. Water curtain behaviour and boundary condition definition

At the pipe invert located at the base of the main stack, the downwards discharge flow carried by the water annulus will follow one of two routes, where each is dependent upon both the pipe configuration and the time-dependent rate of discharge. Clearly, the flow will follow the contour of the outer radius of the swept bend thus facilitating sustained contact between the water and the internal surface of the pipe before continuing downstream. However, the flow path that traces the inner radius is either forced, through gravity, to detach to form a water 'curtain', Figure 3a, or flows circumferentially without 'detachment', Figure 3b.

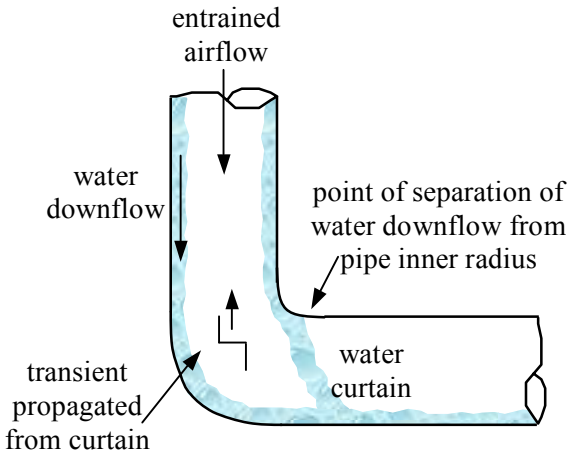

Figure 3a - Water curtain formed as flow

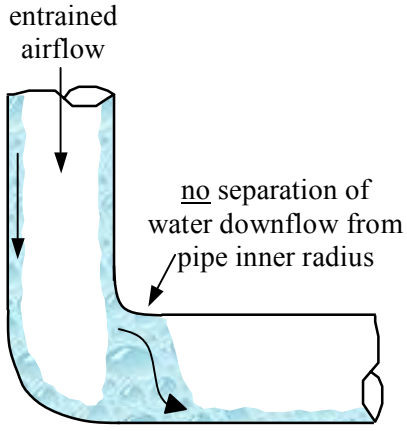

Figure 3b - Circumferential flow without 'detachment'

Clearly, when the discharge flow rate within the main stack is relatively low, the water reaching the upper surface of the pipe invert is more likely to run circumferentially providing little impediment to entrained air. However, as the flow rate increases, detachment becomes more likely, where the water curtain formed may demonstrate either partial or complete coverage of the pipe cross section[6]. It will be appreciated that whereas partial coverage may be represented by a change in the loss coefficient of what is effectively an orifice operating at the boundary between the main vertical stack and the sewer connection pipework, full coverage will result in the cessation of entrained air, and will generate a positive pressure transient that is propagated back through the vertical stack and connected pipework. From the fundamental concepts of surge theory based on the findings of Joukowsky[7], it is known that the resultant increase in pressure within the stack will be heavily dependent upon the rate of change of the influencing flow conditions as well as, to a lesser extent, the fluid density and the appropriate acoustic velocity of the pressure wave (the latter two of which may be assumed as constant for wave propagation in building drainage systems). Hence, an underpinning precept in analysing the pressure response of the system is a determination of the duration of 'closure' of the water curtain. This timescale must then be viewed comparatively with that representing pipe period ie the time taken for the wave generated by the water curtain to propagate to and from the closest system reflector.

The application of standard pressure transient theory dictates reflection coefficients for the system where (in summary):

- open ended pipe terminations exhibit a reflection coefficient of -1
- closed end pipe terminations exhibit a reflection coefficient of +1
- appliance trap seals exhibit a reflection coefficient of <1, and
- pipe junctions both reflect and transmit pressure waves where the magnitude of the transmitted wave will depend upon the relative diameters of connected pipework

Thus, the positive pressure wave generated by complete closure of the water curtain formed at the base of the stack will travel upwards through the system before encountering the lowest branch connection. At this point, an inactive branch will both reflect and transmit the wave. An active connection that introduces flow that only partially closes the pipe section will similarly reflect and transmit the wave, however that that results in the cessation of airflow will yield a +1 reflection coefficient only. This scheme is repeated for each branch connection, where reflections will also encompass those generated by installed appliances and pressure relief devices. Although the original waveform will be subject to attenuation and have superimposed upon it all other transmitted and reflected waves, it should be noted that for simple systems with few and/or long pipe connections, this positive pressure can easily propagate throughout the entire network before being reflected by the upper open vent. For more complex systems however, the number of junctions, the range of appliances connected and the pipe lengths under consideration often result in the greatest impact occurring in the lower region of the stack – a phenomenon well supported by anecdotal evidence.

Extensive site investigations undertaken by the authors[5] has established comprehensive pressure data relevant to those regions of the vertical stack in which positive pressures occur. Although this data yields useful information relating to the limits and mean value of positive pressure, the multiplicity of transmitted, attenuated and reflected waves at the measurement point means that, analytically, identification of each of the contributory pressure waves is impractical without the use of numerical modelling techniques. Thus, much of the research undertaken recently has focussed upon the simulation of water curtain behaviour such that time-dependent loss coefficients and characteristic descriptors of 'closure' may be defined.

Importantly, it should be noted that the water curtain formed at the active branch connection also demonstrates time dependent characteristics similar to those of the curtain generated at the stack base. Previous work aimed at simulating fluid flow through the definition of appropriate boundary condition equations for active junctions has focussed upon the determination of a loss coefficient applied to the entrained air flow, and dependent upon branch to stack configuration, pipe sizing and discharge flow rate. However, as with the stack base water curtain, the impediment to airflow at this junction will also demonstrate some form of oscillation between partial and full closure. It will therefore be seen that coincidental closure of both water curtains effectively introduces closed boundaries that may represented numerically by two +1 reflection coefficients, where equation 1 defines the time taken for the wave to travel from one boundary to the other and back.

$$\text{Pipe period} = \frac{2L}{c} \qquad (1)$$

where L = pipe length and c = wave propagation speed, ie acoustic velocity 320m/s)

This effect can be simulated using the AIRNET model, where a simple pipe network may be used to analyse the behaviour of the reflected pressure waves. Figure 4 shows an abbreviated schematic diagram representative of the single stack system installed in the laboratory at Heriot-Watt University, where the intentional absence of a number of complex branch and appliance connections limits the degree of superposition of transmitted, attenuated and reflected waves.

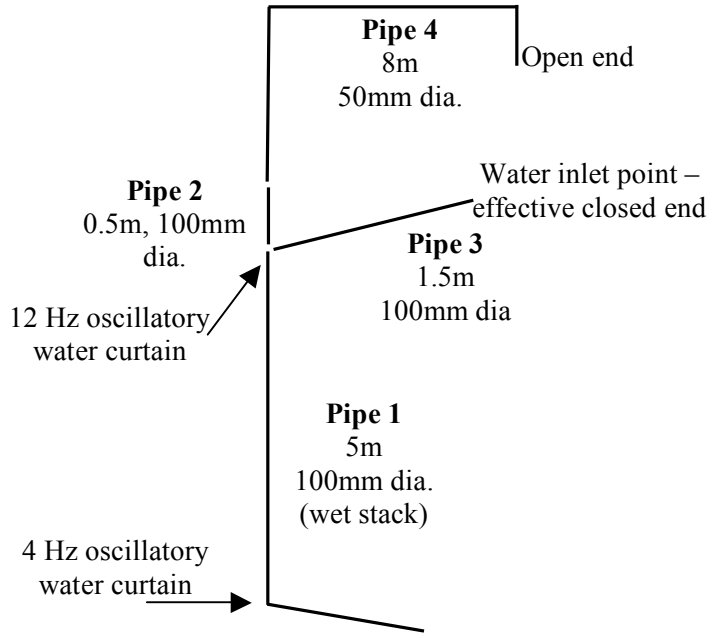

Figure 4 - Schematic diagram representative of single stack in laboratory

The important points to note from Figure 4 are therefore:

- the simplicity of the network (with only four pipe sections)
- the presence of the closed end on pipe 3 (representative of the water inlet pipe, through which flow is pumped at rates representative of those likely from domestic appliances) and an open end on pipe 4 (representative of the upper stack termination through which air is entrained)
- the simulation of a oscillating water curtain at the base of the stack
- the simulation of oscillating water curtain at the branch connection

The impact upon the transient response of the network of the intermittent closure of the water curtain at the base of the stack was assessed by imposing a linear waveform descriptor (shown as part of Figure 5). The frequency used was 4Hz ie that determined by previous examination of high resolution digital images allowing the generation of a time-dependent trace of water curtain coverage[8]. It will be appreciated that, although an amplitude multiplier of 0.5 has been used, at values above that required to yield a reflection coefficient of +1, any further imposition (in terms of magnitude) becomes meaningless. The water curtain generated at the branch connection point was similarly simulated using a linear waveform of frequency 12Hz and a 'capped' amplitude multiplier of 1.0 (also shown superimposed upon Figure 5). In order to allow an assessment of the individual impact of both oscillatory water curtains, each was initially set to operate separately during the simulation. Figure 5 shows that at the branch connection operating between 7 and 9 seconds, and that at the stack base applied between 15 and 17 seconds.

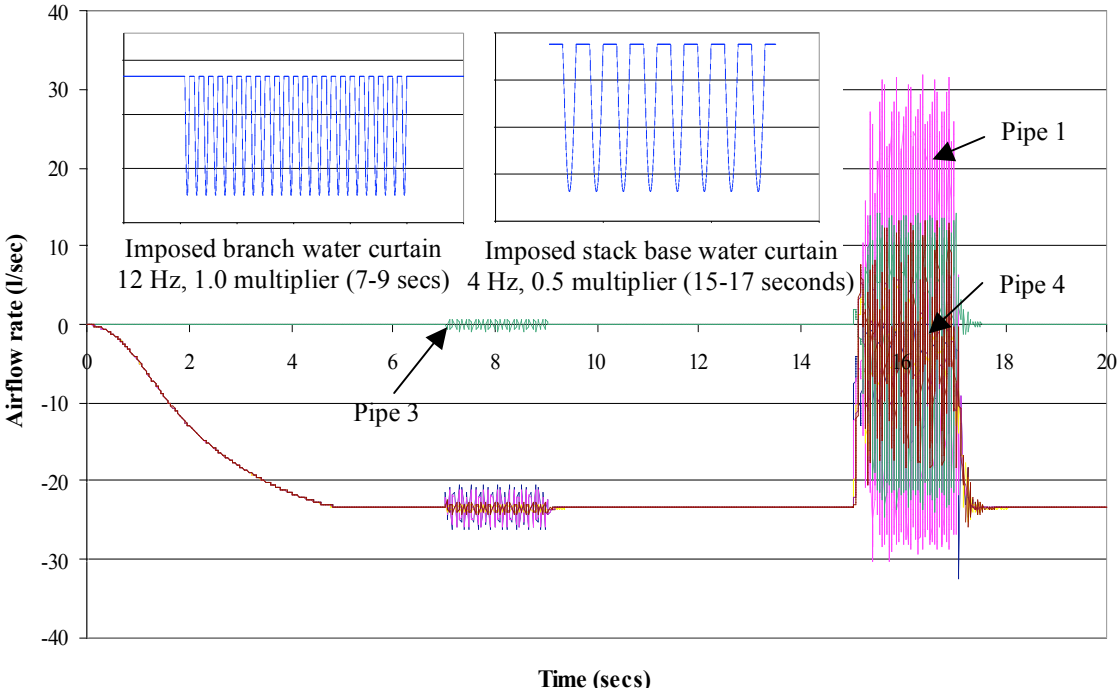

Figure 5 - Network response when stack base and branch water curtain applied separately (NB 'Downwards' airflow is represented by negative values)

It will be seen from Figure 5 that the oscillatory behaviour of the stack base water curtain (15-17 seconds) has a far greater impact upon air flow values within the network than that of the branch connection water curtain (imposed between 7 and 9 seconds). Since pressure relief for the branch connection generated positive transient is provided for by the open vent on pipe number 4, then the overall effect is relatively minor, although corresponding changes in airflow are induced in the wet stack (pipe number 1). Despite the absence of complete closure of the pipe cross section at the branch connection during the 15-17 second period, an interaction between the stack base positive transient nonetheless exits due to the operation of the appropriate loss coefficient applied to the airflow at the junction. Combined with the driving traction force provided by the water annulus in the wet stack, this accounts for the observed difference in magnitude.

Figure 6 demonstrates the output from the simulation model following the simultaneous application of the oscillation of both water curtains.

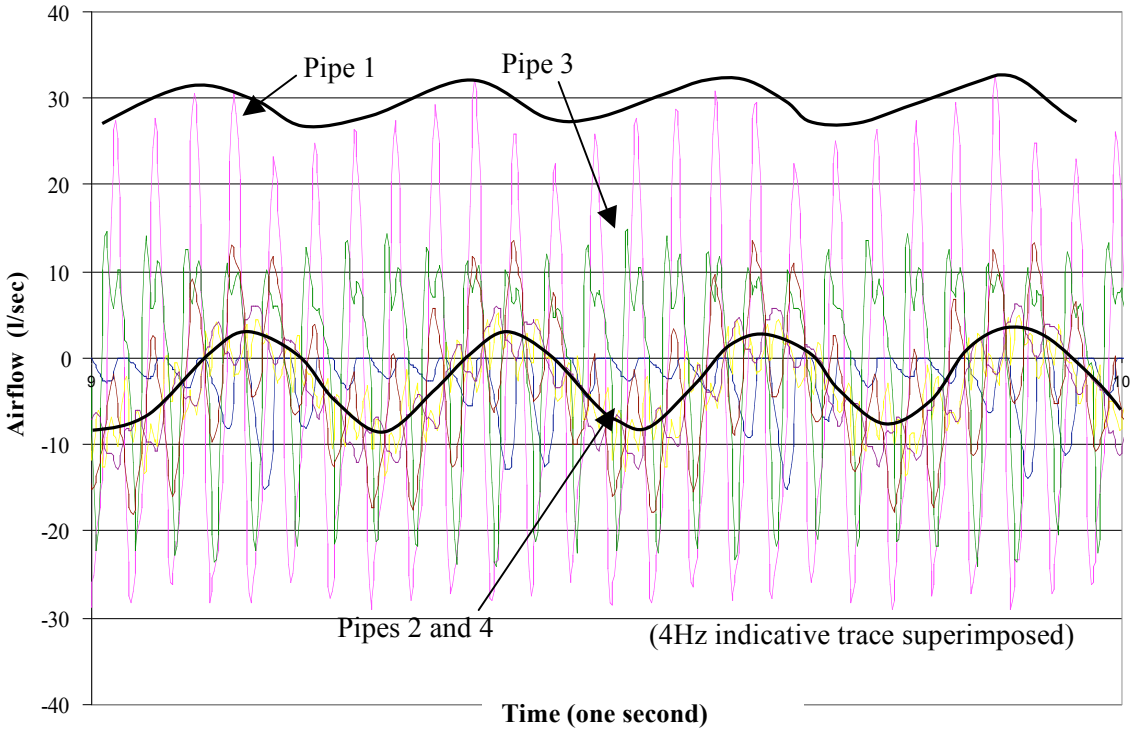

Figure 6 - Simulation output for simultaneous application of stack base and branch water

Much as would be expected, the combination of water curtain closures dominates the airflow response in pipe one. Figure 6 (with an x-axis spanning one second), also demonstrates how the resultant frequency of airflow oscillation generated in the wet stack region between the two water curtain locations is approximately 26Hz. This frequency is clearly in line with the value of pipe period determined for a section of length 5 metres, using equation 1 where:

$$\text{Pipe period} = \frac{2L}{c} = \frac{2 \times 5}{320} = 0.03125$$

With a frequency of oscillation of 26Hz corresponding to a pipe period of 0.03846, it can be seen that the simple calculation afforded by equation 1 yields an approximate figure that demonstrates close agreement with simulation predictions. Further, it can be seen from Figure 6 that there also exists a superimposed frequency of 4 Hz as driven by that representative of the closure of the water curtain at the base of the stack – an observation in line with the output shown in Figure 5.

Importantly, both these results have been corroborated by laboratory measurements, thus highlighting two important factors:

1. although the water curtain at the base of the stack demonstrates a varying loss coefficient, complete closure has a notable effect on the overall system response through the generation of air pressure transients that interact with flow introduced via active branch connections.

2. when the (previously established) frequency of closure of the stack base water curtain of 4 Hz is viewed in conjunction with an imposed frequency of oscillation of the water curtain formed at the active branch connection, the resultant airflow throughout the network, demonstrates a frequency that is dominated (in a simple pipe network) by the effective 'closure' of the air path at the two water curtain locations (represented, in the above example, by the limits of the wet stack).

7. Conclusions

This paper uses the example of the 'community' outbreak of SARS in Amoy Gardens in Hong Kong in March 2003 as an example of the importance of designing and operating building drainage and ventilation networks such that system integrity is maintained via trap seal retention. Based on the route of transmission of the SARS virus as identified by the Hong Kong Health Department and affiliated organisations, the paper identifies the individual contributory components, and assesses the degree of normalcy of each, thus highlighting the associated probability of occurrence in order to facilitate a determination of future risk. In doing so, the paper identifies the difficulties associated with predicting the 'reverse' flow of air following the generation of positive air pressure transients at the base of the vertical stack - a proposed vector in the SARS transmission, and highlights the suitability and role of numerical modelling techniques (based upon the application of the St. Venant equations of unsteady flow) in determining system operating parameters. The importance of the ability to simulate the transient response of the entire network of connected pipes has been well recognised within the academic community for some time however, it was not until the Amoy Gardens outbreak of SARS that this issue received wider acknowledgement.

Inherent within any approach to predicting network response to both normal and extreme operating conditions, is a representation of the behaviour of air pressure transients and, within the context of predicting 'reverse' airflow and the potential ingress of foul odour, the generation of positive pressure. This paper has highlighted recent developments in the understanding of the behaviour of water curtain formation, and importantly, water curtain interaction, and has demonstrated how numerical modelling techniques may be used to assess this interaction and its effect upon resultant system airflow, pressure and trap seal integrity.

8. References

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Presentation of Authors

Dr Lynne Jack is a Senior Lecturer in the School of the Built Environment and has been a member of the Drainage Research Group at Heriot-Watt University since 1993. Her research interests include air pressure transients in building drainage ventilation systems and the effect of climate change upon the performance of roof drainage systems.

Professor John Swaffield is Head of the School of the Built Environment and leads the Drainage Research Group at Heriot-Watt University. His research interests include water conservation and the development of mathematical simulations for drainage and vent system flows. He has been involved in drainage and water conservation research for 30 years and has contributed regularly to CIBW62 meetings since 1975.

Mr Steven Filsell is a full time research student based in the School of the Built Environment at Heriot-Watt University working on a project entitled 'Investigations of Positive Air Pressure Transients in Building Drainage Vent Systems'. Steven's research is funded by the UK EPSRC (Engineering and Physical Sciences Research Council).

Decision-making and assessment tool for current design of high-rise building drainage system in Taiwan

(1) C.L. Cheng, Dr. (2) K.C. Ho, Mr. (3) C.J. Yen, Ms.

(1) CCL@mail.ntust.edu.tw

(2) quenchhu@hotmail.com

(3) D9313006@mail.ntust.edu.tw

National Taiwan University of Science and Technology, Department of Architecture, 43 Keelung Road Sec.4, Taipei, Taiwan, R.O.C.

Abstract

The main purpose of this research is to clarify the decision-making framework and to evaluate the performance of drainage system in high-rise building through the empirical observation and basic understanding of stack fluid mechanism. This paper concluded a schematic structure of drainage system in high-rise building, meanwhile, deliberated intention to search the supporting factors and flow path for decision-making and assessment tool for performance evaluation of high-rise building drainage system. The evaluation method had been verified and proved to be practicable. These results can support the decision-making and be assessment tool for current design of high-rise building drainage system.

Keywords

high-rise building, drainage system, performance evaluation, trap

1. Introduction

The design of high-rise building is complex and high integration work including various professional cooperation. The successful accomplish of such landmark is also seen as technical achievement of a country. Nonetheless, the importance of building drainage, which is a humble but very substantial issue, might not be ignored. Owing to the increasing of potential energy of height, inappropriate design of drainage system is facile to cause the sanitary problems in high-rise building and inconvenient utility. Particularly, people recognize the importance of healthy environment through the impact of SARS disease. The main purpose of this research is to clarify the decision-making framework and to evaluate the performance of drainage system in high-rise building through the empirical observation and basic understanding of stack fluid mechanism. Firstly, we investigated the existing high-rise buildings with 52 cases and summarize the design methodology from interviews of designer and plumbing engineers. Through the observations and interviews, we deconstructed the existing drainage system and found the crucial components of drainage construction. According to the deconstruction analysis, we concluded a schematic structure of drainage system in high-rise building. Finally, this study deliberated intention to search the supporting factors and flow path for decision-making and assessment tool for performance evaluation of high-rise building drainage system. The results of this research would contribute to the domestic building technology and improve the design of drainage system in high-rise building.

2. Reviews and schematic structure of drainage system

Since 1985, Tai-power office building that is the first domestic building above 100 meters was constructed, high-rise building evidently appeared to the metropolis area of Taiwan from north to south. Moreover, Taipei 101 is seen as the milestone of high-rise building currently. Taiwan building code conducted a chapter of high-rise building in 1994; meanwhile it defined the condition of high-rise building to be total construction height over 100 meters or 16 floors. According to the official documents, 7242 high-rise buildings were constructed from 1992 to 2004. Although there is a decreasing tendency for high-rise construction, which are revealed from official documents, the substantial issues of such mass existing buildings should not be ignored for its significant influence.

The gravity drainage system without any energy supply is commonly used in building

all over the world, and the trap with simple structure is also preferred to set as a critical part for most of sanitary facilities because of its easy elimination of stench and vermin. Owing to the increasing of potential energy of height, inappropriate design of drainage system is facile to cause the sanitary problems in high-rise building and inconvenient utility. Particularly, people recognize the importance of healthy environment through the impact of SARS disease. The community infections of Hong Kong give us a great lesson that the problems of drainage system including the infectious disease caused from loss of seal water in trap, and we should not ignore the hidden troubles of building drainage.

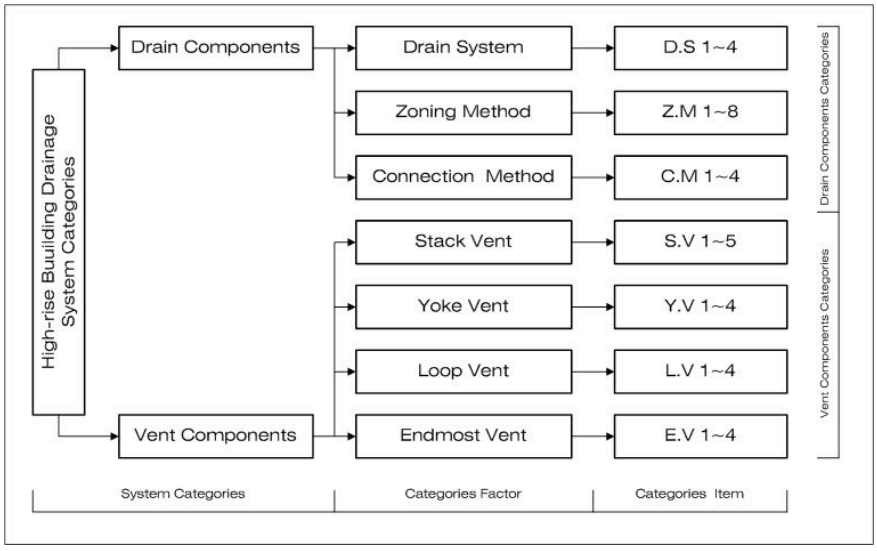

Figure 1 - Schematic structure of high-rise building drainage system

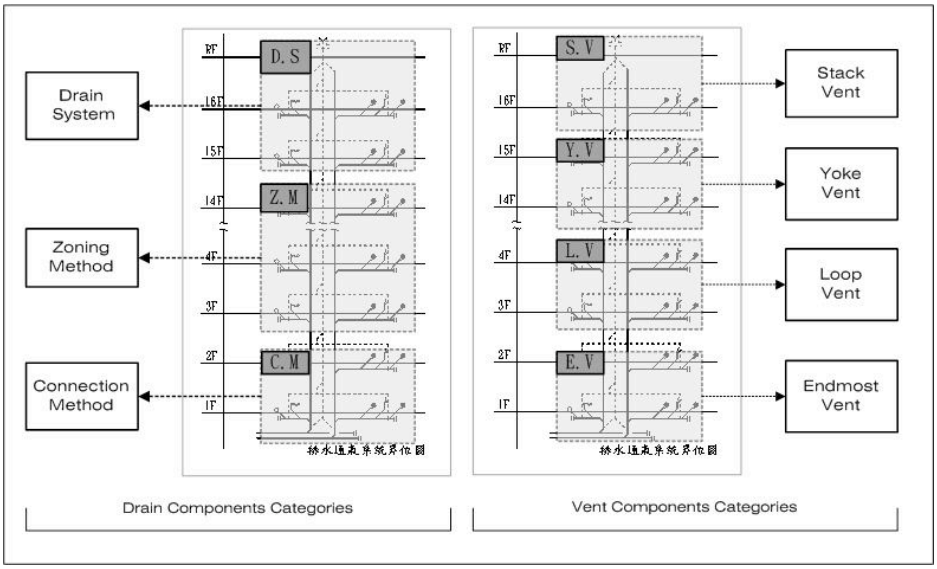

Figure 2 - Crucial components of drainage system

In order to improve the drainage performance of existing high-rise building, investigation is necessary for the fundamental understanding of current technical issues. Accordingly, the appropriate design technology of domestic application must be conducted to confirm the proper performance. Through the observations and interviews, this paper summarized the schematic structure of high-rise building drainage system as shown as Figure-1. It contains system categories and design items, hence design items would connect to be system components as object of design decision-making or performance assessment. As a result, there are 7 items and 33 design options concluded as elementary components for high-rise building drainage system design. Figure-2 shows the schematic structure of these crucial components.

3. Analysis of crucial components

The drainage system is an output product as whole from design process and series decision-making operation. As we deconstruct the system, it would be clear for understanding the framework and components of system construction. Through the initial deconstruction and analysis, two categories with function of drain and vent are concluded, and each character and identity of component is expounded as the following content.

3.1 Drain components

(1) Drain System (D.S 1-4)

The results of investigation reveal that dual-pipe drainage & vent system is the majority of existing high-rise buildings in Taiwan. The first of drain component D.S (Drain System) mainly focuses on the type of drain connection to vertical stack. As the technical review of drain performance, it could be divided to 4 levels of decision-making objects. Figure-3 shows the schematic structure and its position of D.S component including the details of each connection levels and 3D vision.

(2) Zoning Method (Z.M 1-8)

Owing to the increasing of potential energy of height, inappropriate design of drainage system is facile to cause the sanitary problems in high-rise building and inconvenient utility. In order to reduce the stack air pressure fluctuation, zoning method is commonly adopted in high-rise building drainage system design. The second of drain component Z.M (Zoning Method) mainly focuses on the type of drainage system zoning. As the

technical review of drain performance, it could be divided to 8 levels of decision-making objects. Figure-4 shows the schematic structure and its position of Z.M component including the details of the connection levels and 3D vision.

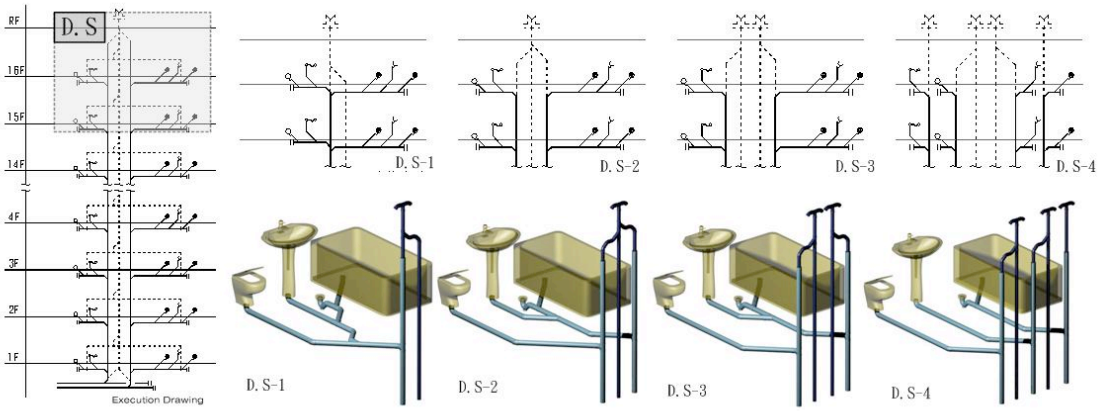

Figure 3 - Schematic structure and its position of D.S component

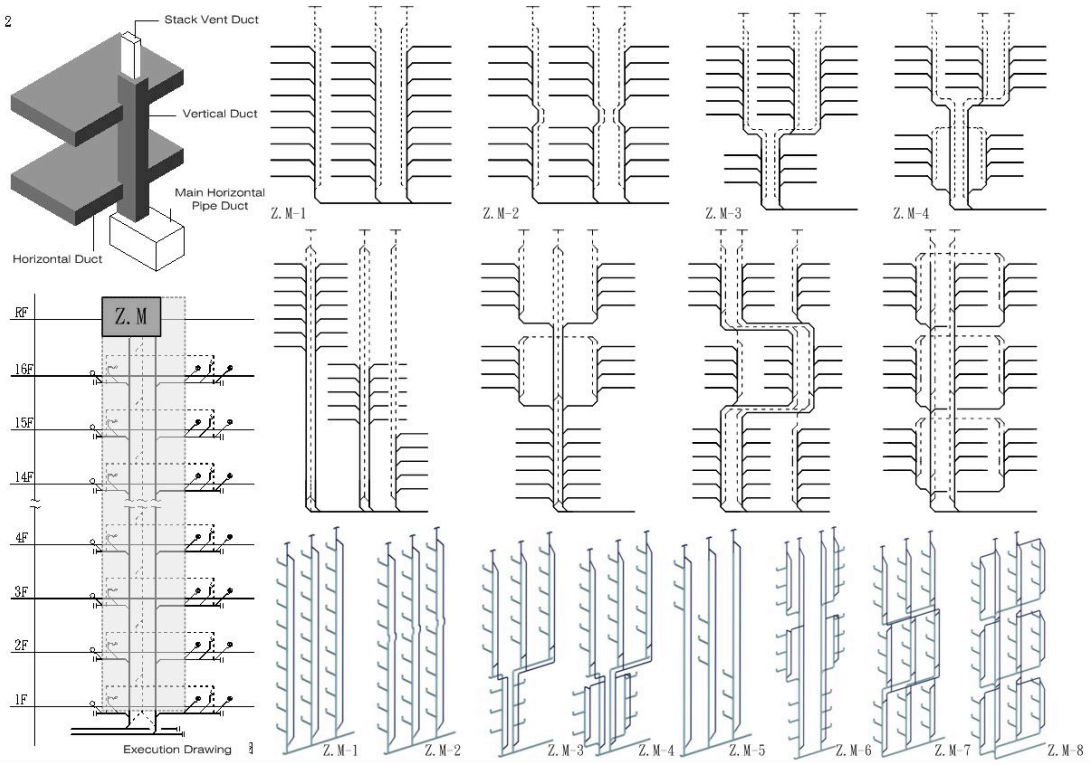

Figure 4 - Schematic structure and its position of Z.M component

(3) Connection Method (C.M 1-4)

From vertical stack to horizontal drain, the hydraulic jump would cause the positive pressure and destroy the trap seal of upper floor. Therefore, the connection method of this component is important for performance evaluation in high-rise building drainage system design. The third of drain component C.M (Connection Method) mainly focuses on the position from vertical stack to horizontal drain. As the technical review of drain performance, it could be divided to 4 levels of decision-making objects. Figure-5 shows the schematic structure and its position of Z.M component including the details of the connection levels and 3D vision.

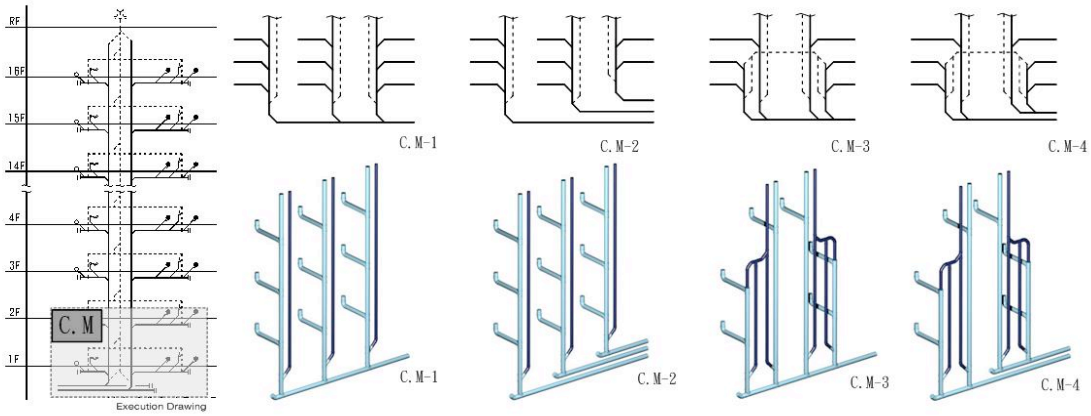

Figure 5 - Schematic structure and its position of Z.M component

3.2 Vent components

(1) Stack Vent (S.V 1-5)

The vent component in drainage system is set for mitigating the air pressure fluctuation and to protect the trap seal in buildings. The first of vent component S.V (Stack Vent) mainly focuses on the top area of high-rise building open the outdoors. As the technical review of drain performance, it could be divided to 5 levels of decision-making objects. Figure-6 shows the schematic structure and its position of S.V component including the details of the connection levels and 3D vision.

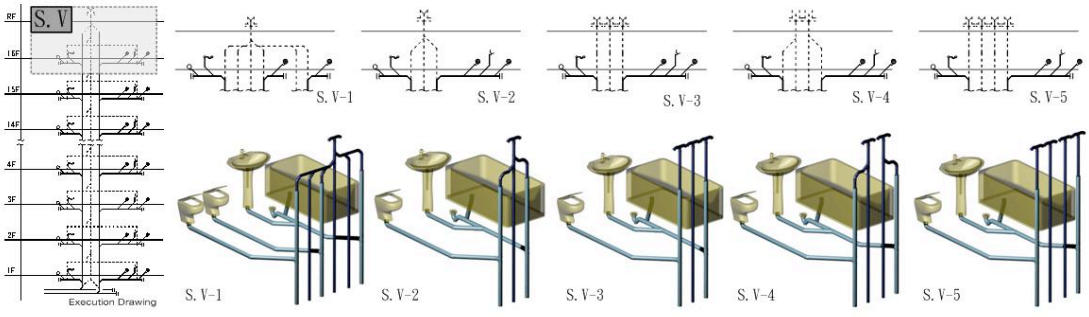

Figure 6 - Schematic structure and its position of S.V component

(2) Yoke Vent (Y.V 1-4)

The second of vent component Y.V (Yoke Vent) mainly focuses on the connection type between stacks of high-rise building. As the technical review of drain performance, it could be divided to 4 levels of decision-making objects. Figure-7 shows the schematic structure and its position of Y.V component including the details of the connection levels and 3D vision.

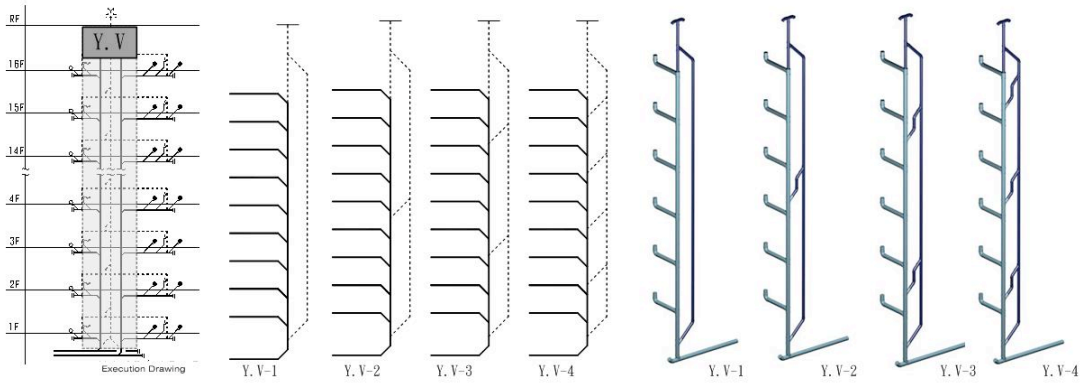

Figure 7- Schematic structure and its position of Y.V component

(3) Loop Vent (L.V 1-4)

The third of vent component L.V (Loop Vent) is sub-system of drainage and close to the terminal facilities. As the technical review of drain performance, it could be divided to 4 levels of decision-making objects. Figure-8 shows the schematic structure and its position of L.V component including the details of the connection levels and 3D vision.

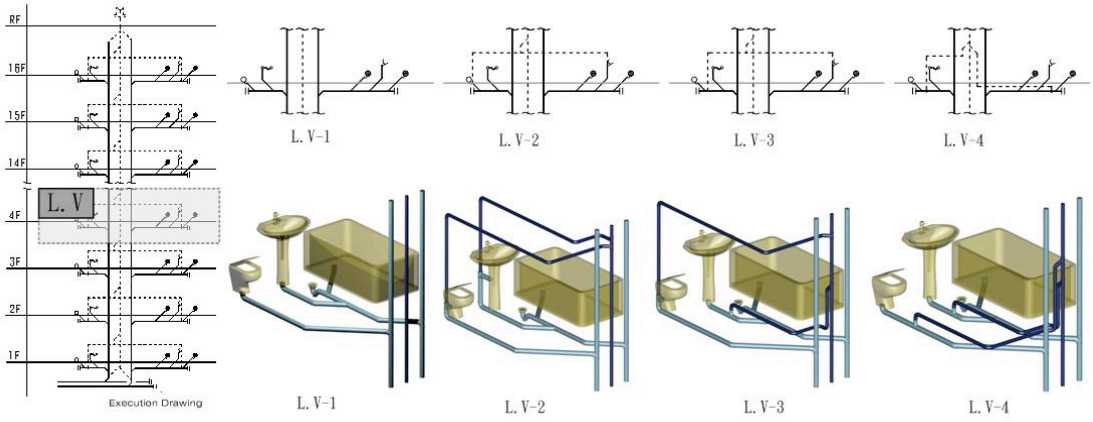

Figure 8- Schematic structure and its position of L.V component

(4) Endmost Vent (E.V 1-4)

The last of vent component E.V (Endmost Vent) mainly focuses on the position near vertical stack turn to horizontal drain. It usually set for mitigating the problems caused by positive pressure. As the technical review of drain performance, it could be divided to 4 levels of decision-making objects. Figure-9 shows the schematic structure and its position of L.V component including the details of the connection levels and 3D vision.

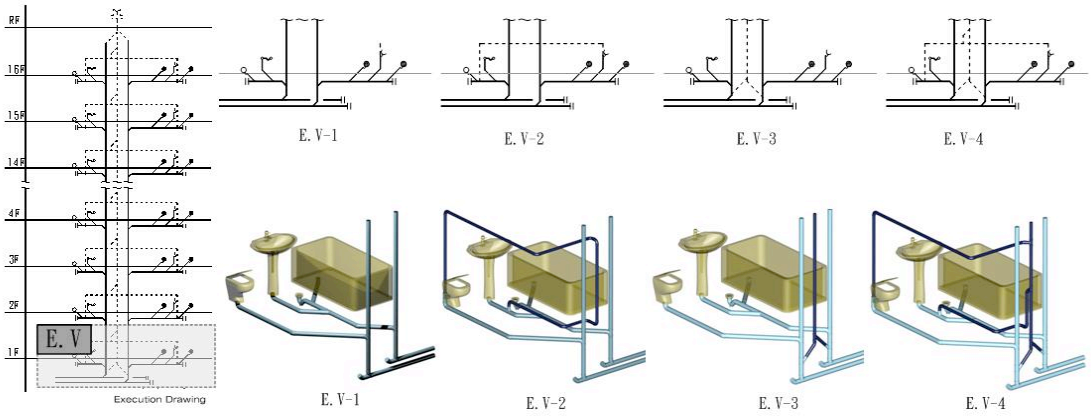

Figure 9- Schematic structure and its position of L.V component

4. Process of decision-making

Fundamentally, the regulation would guideline the basic performance demand of drainage system. As practical application, engineers generally follow the regulation and their experiences. The final design results present the performance of individual components function. Consequently, the design of high-rise building drainage system can be seen as a serious decision-making of individual components and integrating process as shown in Figure-10.

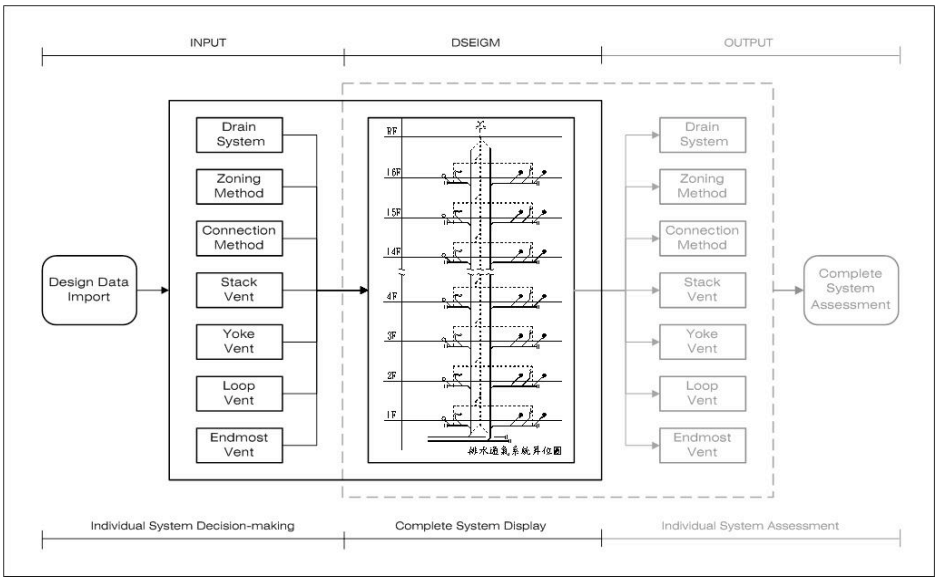

Figure 10- Individual components and integrating process

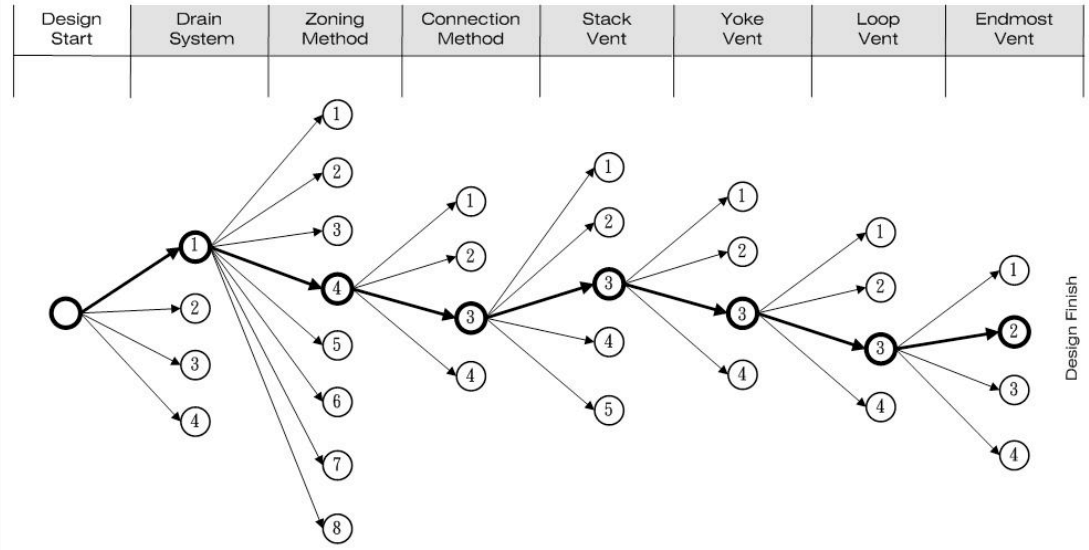

Figure 11- The flow path of decision-supporting

As we know, the design progress is a black box with complex integrating operation before final result is produced. In order to clarify the empirical design process, we arrange a decision-supporting flow path due to the crucial components categories mentioned above. Figure-11 shows the flow path of decision-supporting from the start to the accomplishment of design for the high-rise building drainage system.

According to the arranged schematic structure, it can be mainly divided by two categories with drain and vent, then to be followed by concluding seven items and 33 optional components. These optional components can be seen as feedback factors and

decision-supporting of design process. Figure-12 shows the whole process of empirical design flow path.

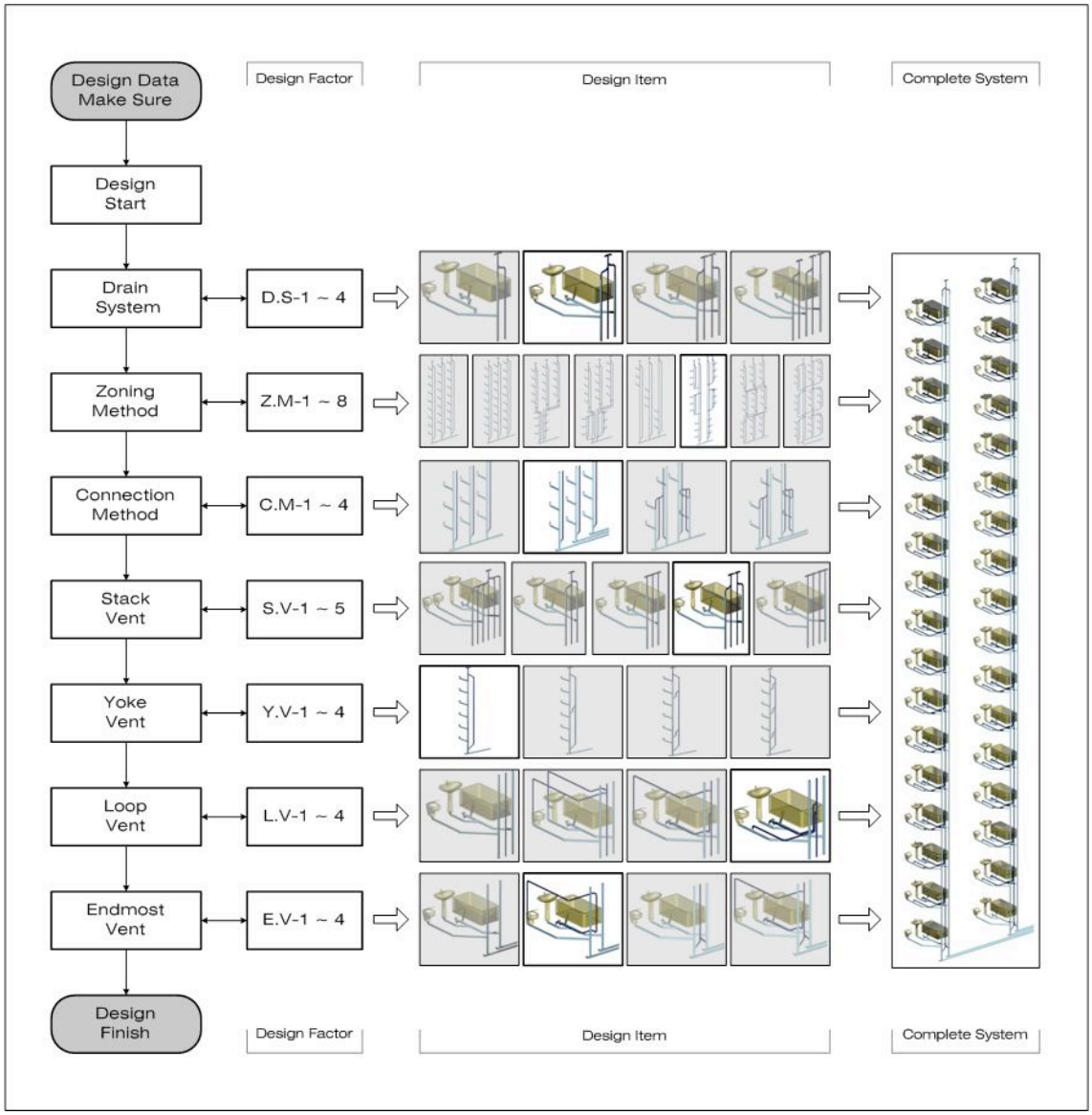

Figure 12- Whole process of empirical design flow path

5. Assessment and verification

The empirical design process for high-rise building drainage system is now clarified by schematic analysis. However, as practical application for designer, assessment tool would be important for evaluating the final system result and its performance. This paper referred the theory of FMEA (Failure Mode Effect Analysis) to build an evaluation system due to the understanding of design components and decision-making flow path. Therefore, the procedure of assessment treats the design result as object, and

the crucial components would be deconstructed as evaluating items. Figure-13 shows the framework of evaluation mechanism.

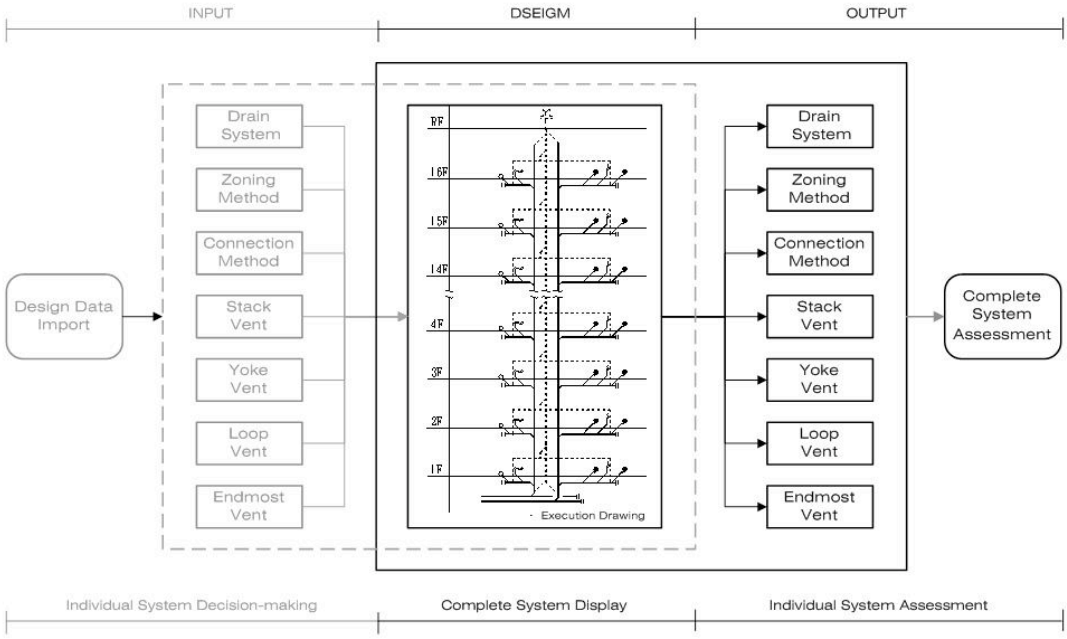

Figure 13- The framework of evaluation mechanism

According to an normal distribution assumption for practical design performance, we can easily identify the performance with four levels of 'basic', 'fine', 'good' and 'excellent'. Thus, the quantitative performance categories for evaluation of each item are set up from 0.8 to 1.4 which bases on a condition of "fine level" with value of 1.0. Table 1 shows the approximate four levels of each item's evaluation and weighting value. Consequently, the evaluation result can be revealed by the product of each item's weighting value as the following equation (1).

$$P_F = P_{DS} \times P_{ZM} \times P_{CM} \times P_{SV} \times P_{YV} \times P_{LV} \times P_{EV} \quad \text{.....(1)}$$

Herein, we defined the range of weighting value for each level with 'basic', 'fine', 'good' and 'excellent'. As mentioned above, deconstructing the design flow path would offer an evaluation framework for application of assessment tool.

Table 1- Approximate four levels of each item's weighting value

Performance categories	Basic		Fine		Good		Excellent	
D.S (1-4)	0.8		1.0		1.2		1.4	
Z.M (1-8)	0.80	1.00	1.05	1.10	1.15	1.20	1.25	1.30
C.M (1-4)	0.8		1.0		1.2		1.4	
S.V (1-5)	0.8		1.0		1.2		1.25	1.30
Y.V (1-4)	0.8		1.0		1.2		1.4	
L.V (1-4)	0.8		1.0		1.2		1.4	
E.V (1-4)	0.8		1.0		1.2		1.4	

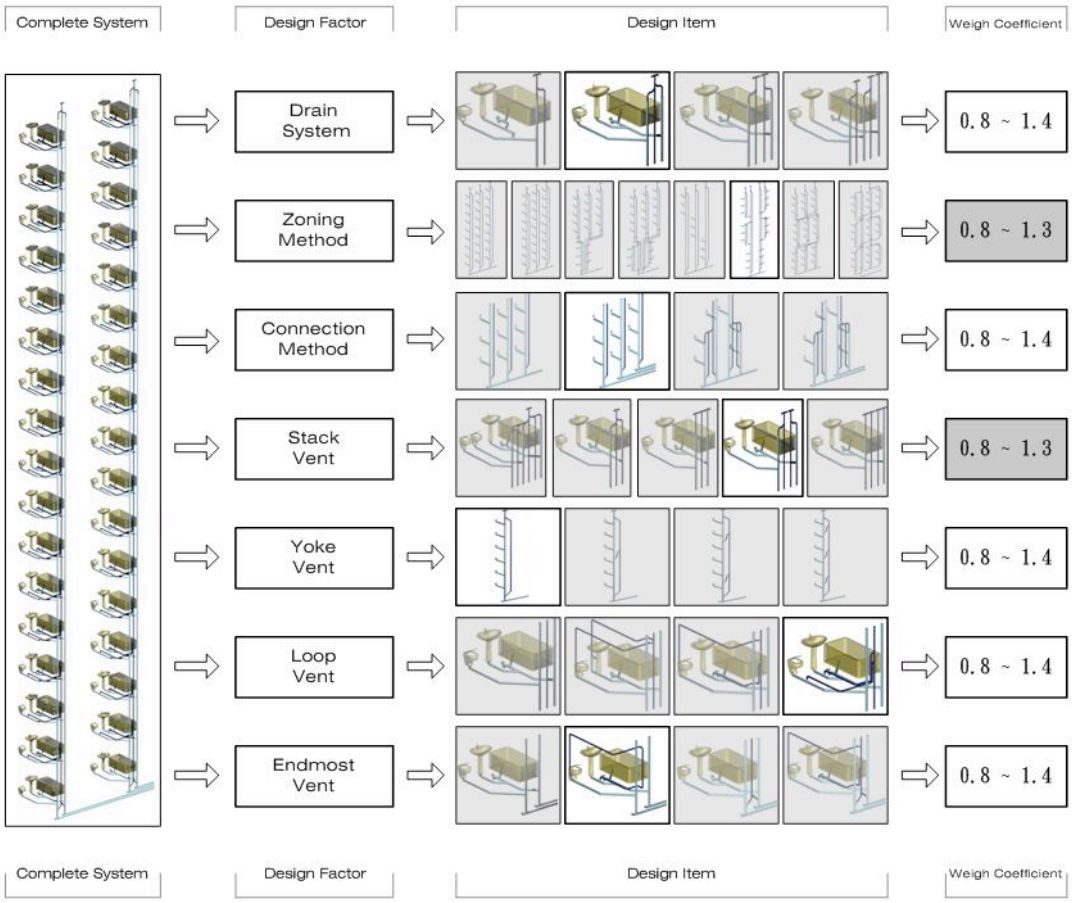

Figure 14- Flow path for evaluation process of system performance

Figure-14 shows the opposite flow path for evaluation process of system performance. In order to verify this assessment tool to be practicable, 52 high-rise building cases were evaluated by the proposed flow path and calculated its product of each item's weighting value due to the equation (1). Figure-15 shows the verification results of these cases and reveals that the drainage system performance could be identified by this assessment method.

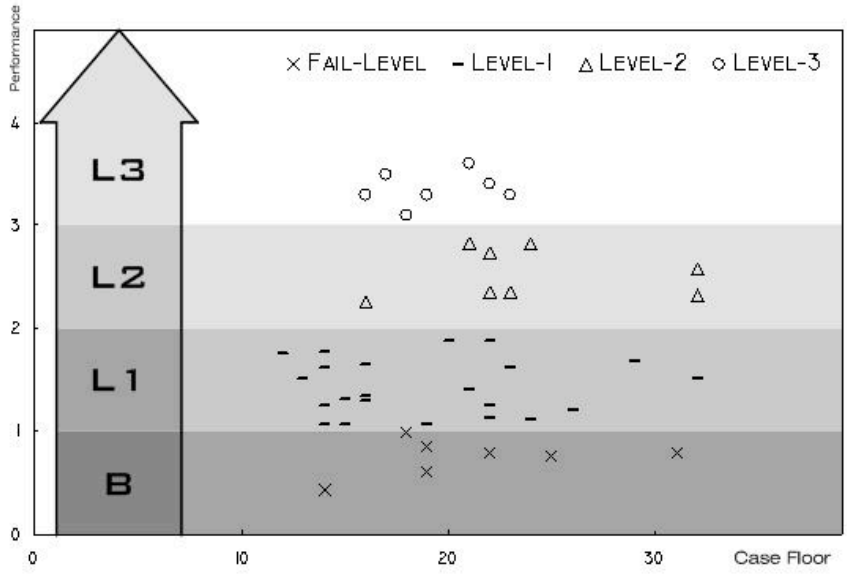

Figure 15- The verification results of practical cases

6. Conclusion

Pressure fluctuation control in vertical drainage stacks has been identified as important to insure sanitary drainage performance in early empirical studies. Chaotic plumbing and over-design are common in utility services within building envelopes from domestic investigations in Taiwan. The main purpose of the research is to explore the design procedure of drainage system in high-rise building through the analysis of its crucial components. As the results, we concluded seven items and 33 optional components and schematic framework from practical investigation and interview. Furthermore, the reversing flow path of design process and deconstructing operation offer a mechanism of assessment tool for system evaluation. The evaluation method had been verified and proved to be practicable. These results can support the decision-making and be assessment tool for current design of high-rise building drainage system in Taiwan.

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Main author presentation

Cheng-Li Cheng is the Professor at National Taiwan University of Science and Technology, Department of Architecture. He is a researcher and published widely on a range of water supply and drainage in building. He has published extensively on a range of sustainable issues, including the water and energy conservation for green building. Currently he also acts as referee of Taiwan Green Building Evaluation Committee and Nation Building Code Review Committee.

Research on the experiments and performance evaluation of building floor drains

W.H. Lu (1), C.L. Cheng (2), C. P. Hsiao (3), Y. C. Ding (4)
sammy@abri.gov.tw
CCL@mail.ntust.edu.tw
wip@abri.gov.tw
y.c.ding@abri.gov.tw
(1)(3)(4) Architecture and Building Research Institute, Ministry of the Interior
13F 333 Dun-Hua S. Road Sec.2, Taipei, Taiwan, R.O.C.
(2)National Taiwan University of Science and Technology, Department of Architecture,
43 Keelung Road Sec.4, Taipei, Taiwan, R.O.C.

Abstract
The drainage system within a building affects the healthiness and comfort of our living environment greatly. Improper sanitary equipments and vertical drainage stack design can easily affect the performance of the drainage pipes. In effect, the sanitary equipments can no longer contain the trap and therefore diseases, such as SARS that just took place not so long ago, can transmit along the pipes to different parts of the building. Taiwan and Hong Kong are the living examples in this case, especially in the case of TaoDa community in Hong Kong. Researchers realized that the SARS virus was passed to the whole community through the sanitary drainage system.
The major focus of this research is the experiment about the floor drains used in Taiwan. To determine the performance of each floor drain, we study the vaporizing rate of the trap seal water and the seal water strength by the experimental tower established in Taiwan by ABRI. There developed some kinds floor drain for variation control in this research. Meanwhile, the tendency of seal water vaporizing rate and the relation between seal water depth and strength had been confirmed in this paper. At the same time, part of the performance testing methods and processes for the sanitary, such as floor drain, had been confirmed. With the results of the experiments and investigation, we are going to deliberate proper methods and standards that suit our technical developments and sanitary testing for architectural drainage systems.

Keywords:
floor drain, building drainage system, testing method

1. INTRODUCTION

The drainage system within a building affects the healthiness and comfort of our living environment greatly. Improper sanitary equipments and vertical drainage stack design can easily affect the performance of the drainage pipes. In effect, the sanitary equipments can no longer contain the trap and therefore diseases, such as SARS that just took place not so long ago, can transmit along the pipes to different parts of the building. Taiwan and Hong Kong are the living examples in this case, especially in the case of TaoDa community in Hong Kong. Researchers realized that the SARS virus was passed to the whole community through the sanitary drainage system. From these, we can see that we can no longer ignore the hidden problems related to the performance of architectural drainage system.

The drain consisted with a trap widely used in Taiwan and the part of the world as shown in Figure 1 and Figure 2. But the performance of the drains seems not be confirmed yet, and the maintenance has also not be required. A bad discharge performance case of floor drain within public toilet had been found in central Taiwan. In the case of clearance and occupant's safety, the cleaner open the trap structure of floor drains to keep the discharge smoothly, shown as Figure 3. As the previous research shown in the International SARS Symposium, the function of trap seal water should be confirmed in each drain built in a building, especially included the natural vaporizing and air pressure influence from the discharge in a drainage stack. (Julius, 2004)

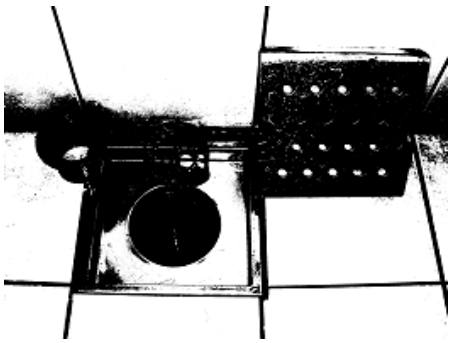

Figure 1 The constitution of floor drain at a shower room (MiaoLi, Taiwan)

Figure 2 The outside floor drain (suburban, Paris)

This research focused on the performance testing and evaluation of drain in a building. By the experimental tower of ABRI (Architecture and Building Research Institute) established in Tainan, Taiwan, we executed the trap seal water strength and vaporizing rate experiment. In the next, we try to develop a prediction method of them that can be calculated by the basic parameter of drains.

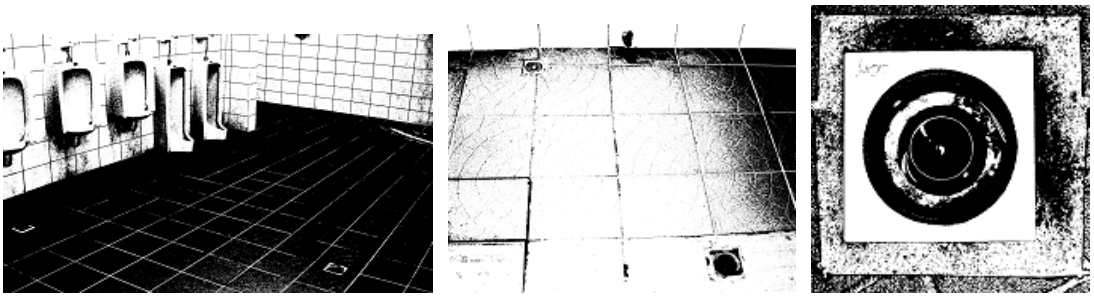

Figure3 The current usage of floor drains at a public toilet (MiaoLi, Taiwan)

2. MECHANISM OF VERTICAL DRAINAGE FLOW

Appliance discharges to a vertical drain stack may be described as an unsteady or time dependent flow. The appliance discharge flow form contributes to this flow condition (Swaffield and Cambell, 1995). An actual vertical drainage stack discharge has a complex phenomenon and may consist of triple phase flow features incorporating solids, liquids and air. Airflow in the drainage stack is promoted by through-flow mixing and the friction interaction between falling water and air. This mechanism causes negative pressure in the upper floors and positive pressure in the lower floors in the building vertical drainage system.

According to previous researches, the airflow rate (Q_a) was identified as a critical parameter for a prediction model that can express the vertical drainage flow mechanism. The airflow performance in a vertical drainage stack is the dominating issue that must be solved. While the airflow rate is dominant in the vertical drainage stack, it plays a critical role in the subsequent vertical drainage stack operation where the mechanism may be assumed to be a quasi-fan machine. The fan laws can thus be introduced into the vertical drainage flow (Kiya et al., 1995). The fan laws can be expressed using hydraulic parameters such as the air density, pressure, velocity, gravity, resistance coefficient, and lift. Practically, the operation energy for airflow within the fan occurs mainly from electric power, thus the potential energy from height is the dominating power for conducting airflow within a vertical drainage stack. This mechanism can be expressed as quasi-fan theory; namely, the initial vertical drainage flow model was conducted using the machine laws.

Air pressure in a vertical drainage stack is caused by a series of interactions between downstream water and through-flow air in vertical pipe. Figure 4 illustrates the flow state and modified interaction. The main parameters, air pressure, airflow rate and the resistance coefficients, are the essential factors for the air pressure distribution model in a vertical drainage stack.

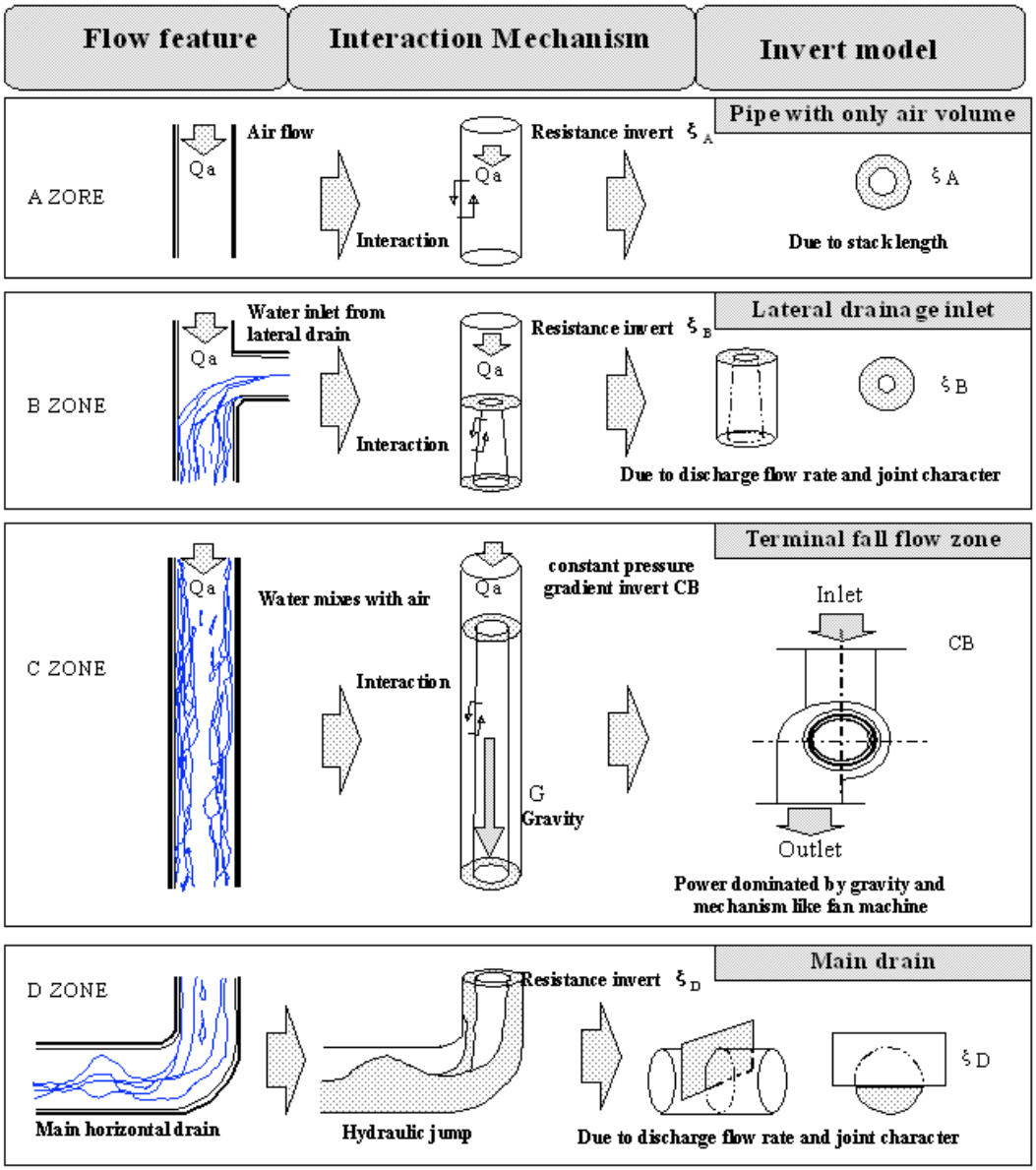

Figure. 4 Vertical drainage features and inverted model mechanism

3. THEORETICAL REVIEWS

The National Plumbing Code (NPC) guidelines from the US were used to set the permitted flow rate for drainage system regulations (Wyly and Eaton, 1961). Following initial HASS 203 work from Japan in the 1970s, the steady flow condition method was merged as the reference provision and evaluation technique. Hence, a series of researches on the steady flow method with reference to building drainage networks were conducted. An air pressure distribution prediction model for drainage stacks in high-rise (108m), (Cheng et al., 1996) and medium-height (30m) experiment towers (Ohtsuka,

1988a; Ohtsuka, 1988b) was developed in Japan in 1985. Considerable progress has been made in predicting the air pressure distribution within a vertical drainage stack.

According to the vertical drainage flow stack feature from the theoretical reviews, the drainage stack profile was divided into four zones, shown in the following diagram, Figure 5. Each zone is individually modeled due to the corresponding characteristics. The air pressure distribution, which reveals the time average air pressure data with steady flow condition, does not involve instantaneous air pressure fluctuations in vertical drainage flow. The features of each zone are described in the following.

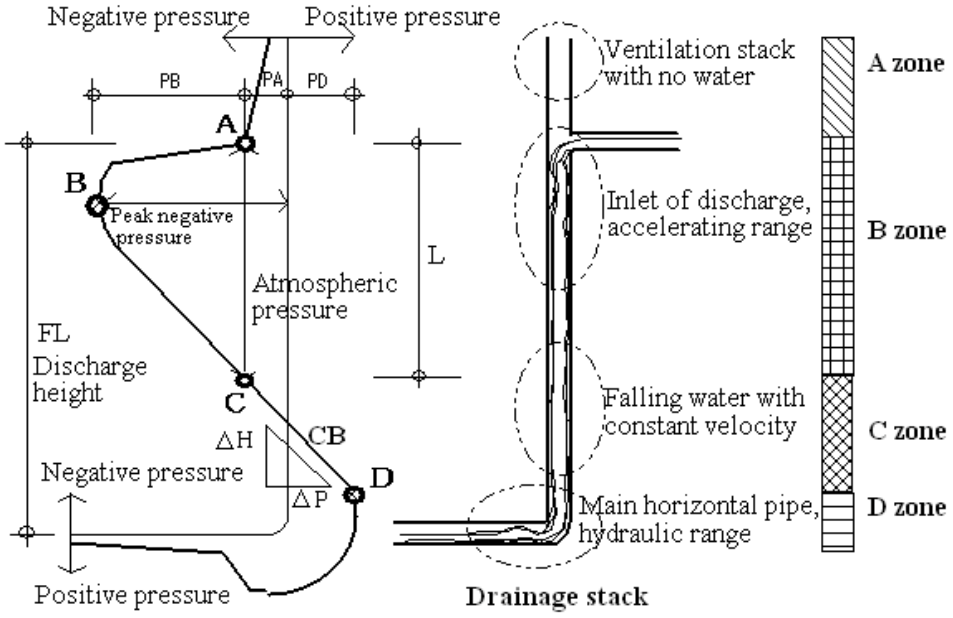

Figure 5 Air pressure distribution zone profile in a drainage stack

(1) A zone

This zone is located at the upstream part of the stack vent from the discharge entry, thus consists only of airflow. This allows us to employ the following air duct model with a constant drag coefficient ξ_A to calculate the air pressure P_A of A zone as shown in Eq. (1).

$$P_A = \xi_A \times (\gamma \div (2g)) \times V_a^2 \quad \cdots\cdots (1)$$

(2) B zone

B zone is from the discharge entry to the downstream point where the air pressure recovers after reaching its negative peak. According to the quasi-fan machine mechanism, the air duct model can be employed with a constant drag coefficient ξ_B to

calculate the air pressure P_B of B zone. The function can be expressed as follows in Eq. (2).

$$P_B = \xi_B \times (\gamma \div (2g)) \times V_a^2 \ldots \quad (2)$$

The previous researches indicated that the drag coefficient ξ_B of the air duct model in Eq. (2) is not likely to be constant because the air flow rate exhibits an extreme range. From the hydraulics observation, the complicated interaction of the incorporated water and air accelerate and decelerate in the same phase. The drag coefficient ξ_B may be calculated as an independent parameter with a direct ratio to the water flow rate under general discharge conditions. The calculation deviation is still acceptable excluding the extremely large range.

A new parameter L, i.e. the length scale of the B zone, was also conducted to modify the B zone prediction model. It was identified that ξ_B and L are both dependent on the stack air flow Q_a or V_a (Cheng et al., 1996). Therefore, the function of the pressure P_B may also be expressed in the following Eq. (3). Parameter L can be determined from Eq. (3) due to the calculation value of P_B using Eq. (2).

$$P_B = C \times L^{0.7} \ldots \quad (3)$$

(3) C zone

Similar to the quasi-fan machine law, the variation in air pressure in a stack is produced by the kinetic to potential energy height transformation. The downstream water flow drags the airflow and produces the air pressure fluctuation in the vertical drainage stack. The modification feature for this interaction is shown in Figure 1. The airflow in zone C gains energy as a form of static pressure increment through the deceleration against the falling water. A constant positive pressure gradient (CB) in the downstream direction produces constant transfer momentum from the falling water into the airflow.

According to the early empirical work, it was assumed that the frictional force acting on the water surface was proportional to the square of the bulk velocity difference between the water and air, equal to the square root of the constant pressure gradient CB in this zone. As a result, this can be expressed using the airflow rate in Eq. (4) with two empirical constants, α and β. This is called the two parameters method used in earlier research (Cheng et al, 1996).

$$CB = \Delta P \div \Delta H \quad = \alpha^2 \times (\beta - Q_a)^2 \ldots \quad (4)$$

(4) D zone

Owing to the hydraulic jump at the vertical stack pipe and horizontal drain pipe connection, the D zone provides air resistance, similar to that from zone A. Hence, the following equation with a constant drag coefficient ξ_D is appropriate for calculating the air pressure $P_{D,}$ and the air pressure distribution in zone D, as shown in Eq. (5).

$$P_D = \xi_D \times (\gamma \div (2g)) \times V_a^2 \ \ldots \qquad (5)$$

Therefore, the stack airflow rate Q_a or V_a is an important factor in the air pressure distribution prediction model for a building vertical drainage stack. A method to calculate the air pressure profile of each zone is shown in Figure 5 as a function of Q_a or V_a. These profiles are assembled to introduce the entire air pressure distribution in a building vertical drainage stack. As a prediction model, however, this calculation method is not a complete theoretical solution but semi-empirical approach with experimental parameters.

4. EXPERIMENT AND INITIAL RESULTS

4.1 experimental tower and its devices

Experiments were performed on an experimental tower 16.5 m in height. There are 5 floors, 3 kinds of drainage system, 4 sets of moving unit bath(UB), and the water supply system in this experimental tower. Figure 6 showed the layout and views of this experimental tower. The experimental device details and drainage system were shown in Figure 7 and Figure 8. The diameter of the stack pipe was φ100mm, the building drain pipe was φ125mm, the horizontal fixture drain branch (branch pipe) wasφ75mm, the vent stack pipe of 2-Pipes system was φ100mm, and the relief vent pipe was φ50mm. The air pressure was measured using a small diffuse semiconductor air pressure transducer. Four points were measured on floors 2-5 of each individual system, respectively. The stack pipe was connected to the drainage pipe using a typical joint to view the hydraulic jump effect. The drainage pipe was set straight and opened to the air. Concerning the recording data format, the mean air pressure value was surveyed for 40 seconds in each measurement with 10ms sampling time. The central 20-second samples with 2000 data were adopted for the mean air pressure performance value.

The air tightness condition of these systems has been confirmed as shown in Figure 9.

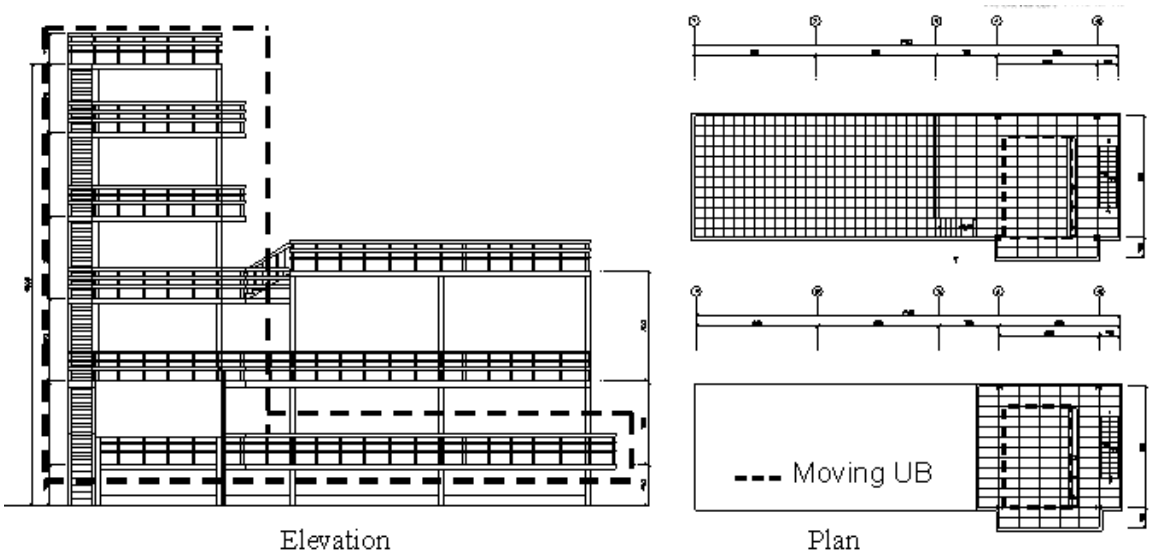

Figure 6 The layout of the lower experimental tower of ABRI in Tainan [7]

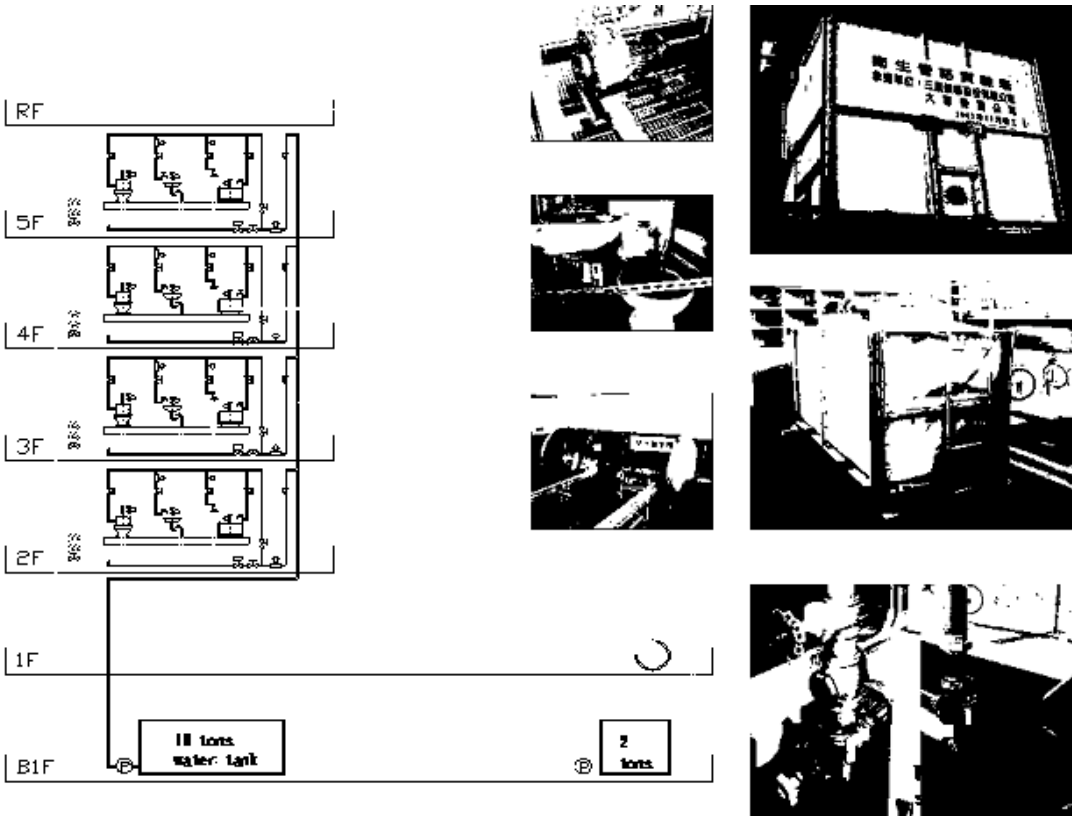

Figure 7 The lower experimental tower and its devices.[4] [7]

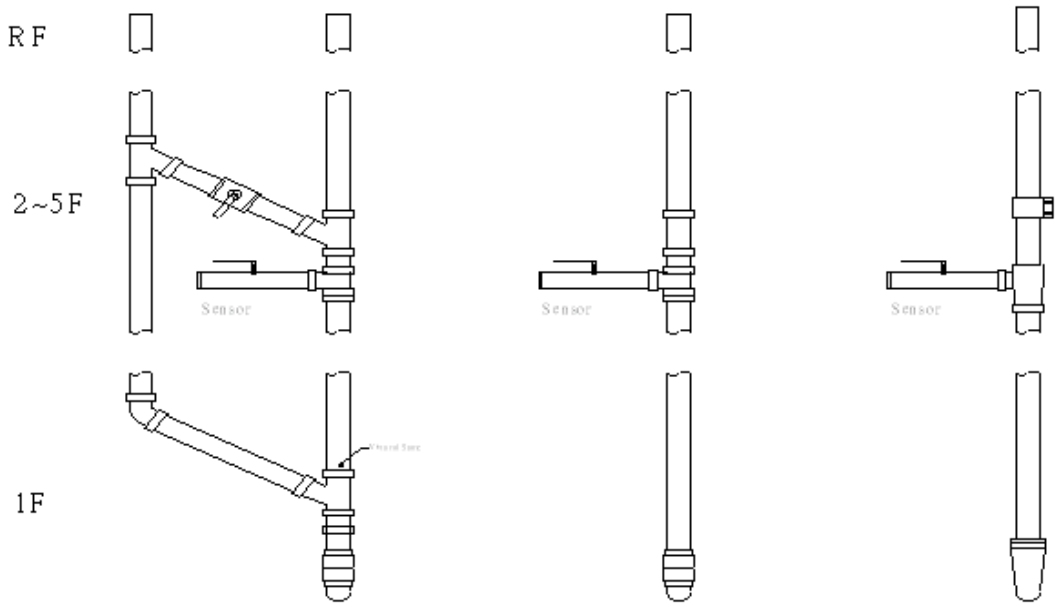

Figure 8 The drainage system of lower experimental tower of ABRI.[4] [7] [8] [9]

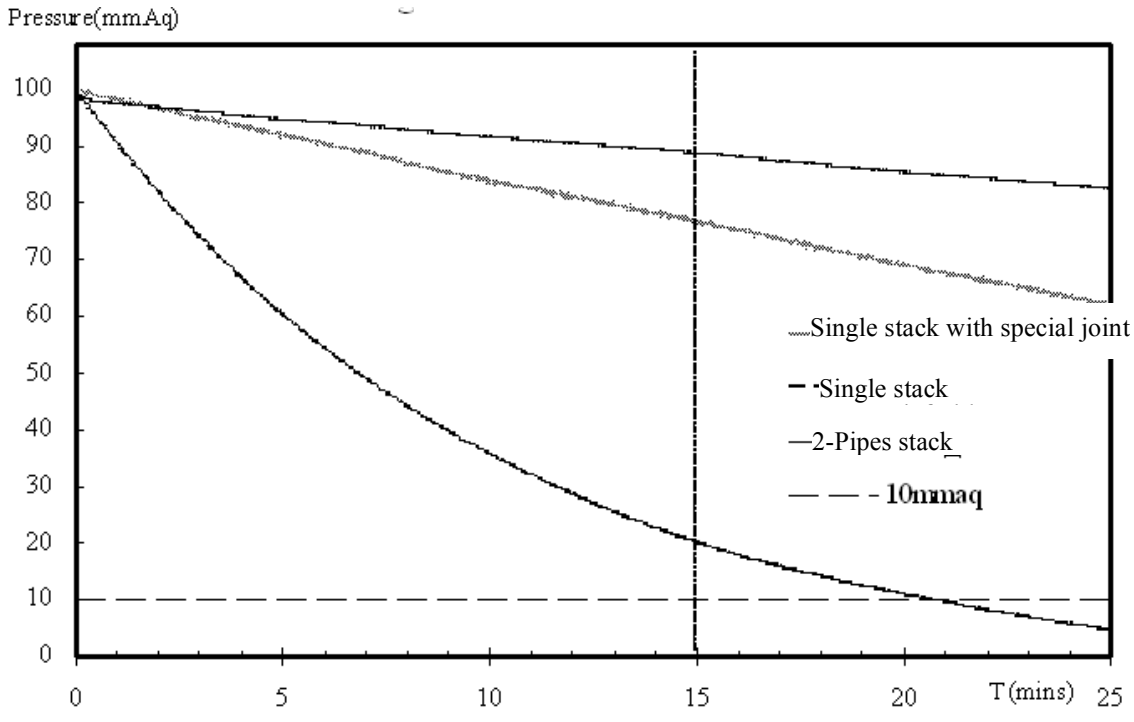

Figure 9 Results of air tightness of experimental drainage systems [7]

As the initial results of 3 kinds of experimental drainage system shown, the air pressure distribution of single stack system is following the previous theory. Therefore, the experiment of seal water strength was processed under single stack system. The discharge floor is 5F, the testing sample insert position of negative pressure zone is 4F, and the testing sample insert position of positive pressure zone is 2F.(shown as Figure 10)

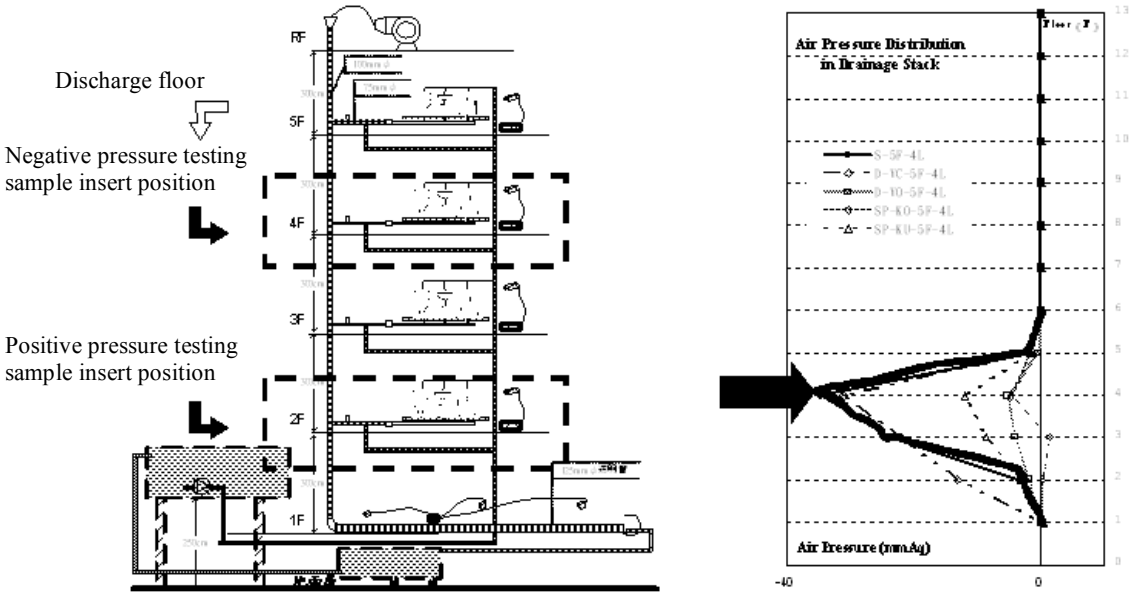

Figure 10 The position of discharge and testing sample insert of seal water strength [4] [7] [8] [9]

4.2 experiment on vaporizing rate and strength of trap seal water

There are 9 samples of floor drain and basin drain evaluated in this research shown as Figure 12. The specifications are shown as Tab. 1. At the first, we experimented on the natural vaporizing rate of trap seal water of these samples. By the measurement of trap seal water weight, we evaluated the vaporizing rate of the samples that consist of trap structure, shown in Figure 13. At the same time, the environment condition had been monitored, including interior wind speed, humidity, and temperature. The interior wind speed was controlled under 0.5 m/s. And the humidity was controlled between RH 60% with RH 80%, the temperature was also controlled between 25±2℃. The background environment condition had been measured by instrument (T＆D TR-72S)。

By the experiment finished over 160 hours, the vaporizing rate of trap seal water (sample No. 1)can be summarized as the regression equation shown as Figure 13. It can preserve from the loss of trap seal water for upon 160 hours (almost a week) with the natural evaporation. Meanwhile, we discussed the relation between vaporizing rate and

the vaporizing area on the top of drains to clear one of the factors within trap seal water loss.

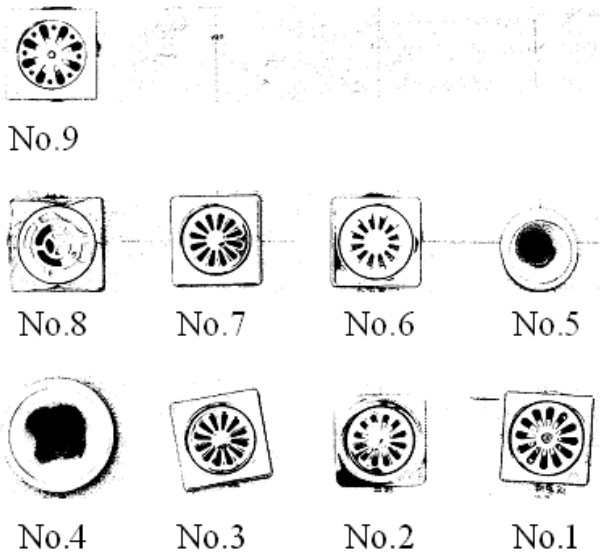

Figure 11 The drain samples of this research

Tab.1 Dimension of the experimental drains.[8] [9]

Type of floor drain	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9
Net weight (g)	214.7	110	96.3	82.2	47	77.7	83.5	91.3	203.2
Internal dimension (mm)	75.6	68.49	-	55.39	55.39	55.39	68.5	72.63	67.7
Net weight (mm)	12.6	7.15	-	40.25	40.25	12.87	17.9	32.6	15.15
Total weight (g) (fully filled with seal water)	272	129.2	-	244.6	113.3	103.6	114.8	133	252.3
Net weight of total seal water (g)	57.3	19.2	-	162.4	66.3	25.9	31.3	41.7	49.1
Weight of effective seal water (g)	18	3.3	-	86.9	34.1	-	-	20.5	43.2
Depth of effective seal water (mm)	0.49	-	-	-	-	-	-	-	8.75
Opening area vaporizing possible (mm^2)	3795.0	3092.6	-	4223.5	1789.1	928.9	1519.8	1829.7	3018.0

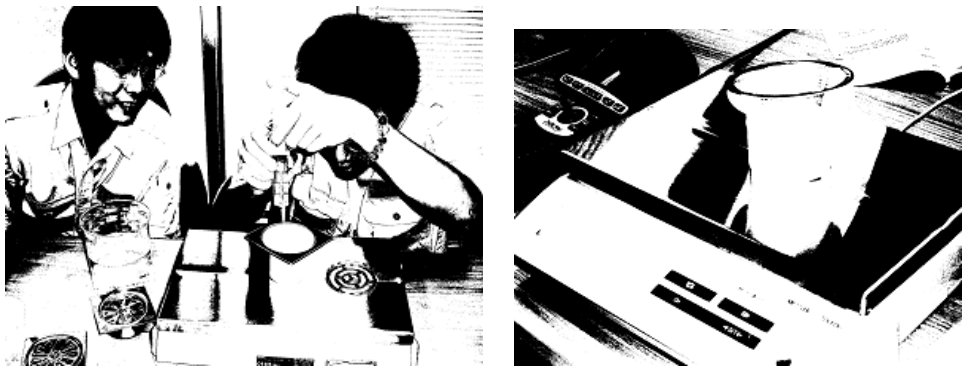

Figure 12 Measurement process of trap seal water weight[8] [9]

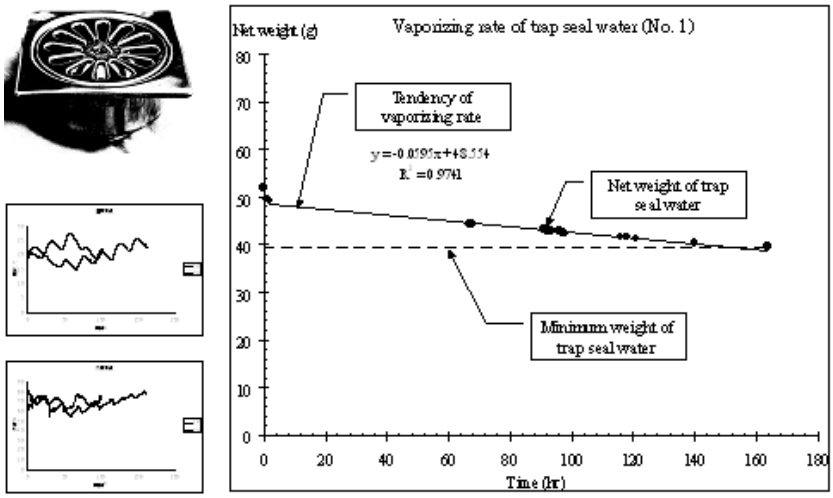

Figure 13 Tendency of vaporizing rate of trap seal water (sample No.1)

This research developed a process of trap seal water strength experiments with single stack system to confirm the process of trap seal water strength test, as Figure 14 shown. The testing sample had been inserted at the branch pipe of 2F (positive pressure zone) and 4F (negative pressure zone). The water was discharged from 5F and continuous, and the flow rate increased per 0.1 l/s step by step until the trap seal water losing its function. There are 5 points of air pressure measured in this testing system, including stack side and sample side. Figure 15 showed the results of trap seal water strength of floor drain (T Sample). When the discharge flow rate increasing to 2.9 l/s, the air pressure with in the piping system existed a dropped point. As an observation in phase, the trap seal water blew off or siphoned off under the discharge flow rate. The air pressure of sample side was about –14 mmAq.

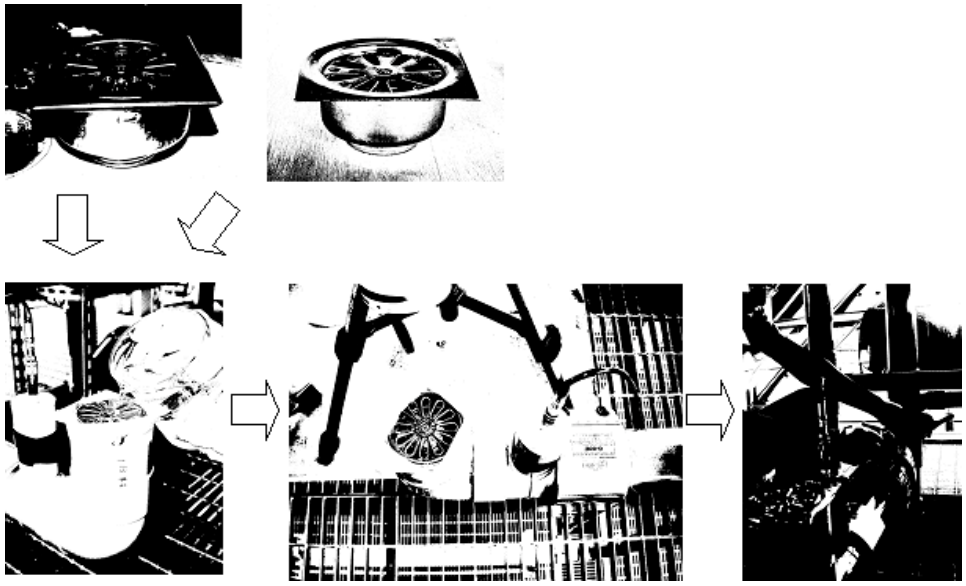

Figure 14 Process of trap seal water strength experiments [8] [9]

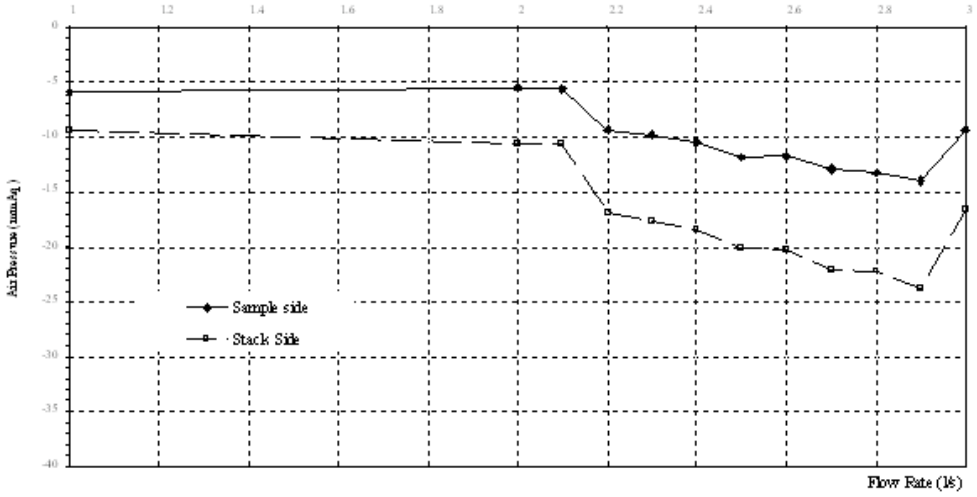

Figure 15 Results of trap seal water strength of floor drain (T Sample)

By the structure of previous drain samples, this research also developed 8 drain models designed for trap seal water strength experiments, as shown in Figure 16. The designed trap seal water depth was between 15 mm with 80 mm. Therefore, the effective depth of trap seal water was between 10 mm with 60 mm, shown in Tab. 2.

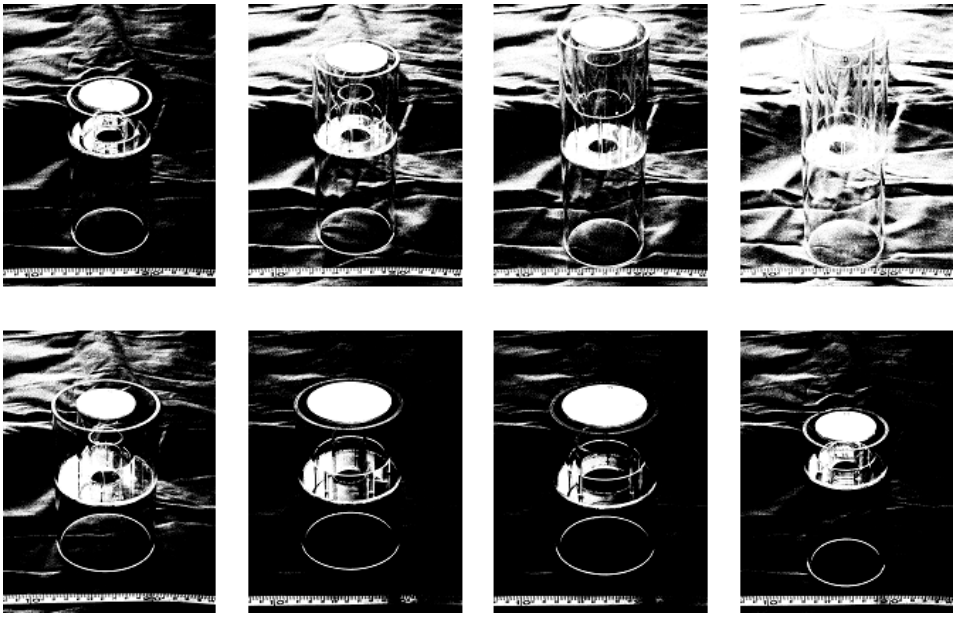

Figure 16 Experimental models of designed floor drain [8] [9]

Tab. 2 Dimension of the experimental models of designed floor drain [8] [9]

Type of floor drain	A	B	C	D	E	F	G	H
Net weight (g)	139	181.1	221.5	236	200.9	77.7	227.5	132.8
Total weight (fully filled with seal water) (g)	175.3	270.3	397.6	402.5	387.4	397.7	359.2	168.6
Net weight of total seal water (g)	36.3	89.2	176.1	166.5	186.5	320	131.7	35.8
Weight of effective seal water (g)	24.1	42.2	80.9	118.5	92.7	88.8	60.3	12.6
Depth of seal water (mm)	20	40	80	80	40	40	40	15
Depth of effective seal water (mm)	10	20	40	60	20	20	20	10
Opening area vaporizing possible (mm^2)	1253.5	1253.5	1253.5	1253.5	3578.3	1693.4	1693.4	1253.5

Following the previous process of trap seal water strength, each designed drain model had been tested in single stack system of the lower experimental tower individually. Figure 17 showed the results of trap seal water strength of model B (effective depth of trap seal water was 20 mm). The effective trap seal water losing in negative pressure zone was under the discharge flow rate 2.7 l/s, and the sample side air pressure was about –10.1 mmAq. In positive pressure zone, trap seal water was losing under the discharge flow rate 2.6 l/s, and the sample side air pressure was about –1.8 mmAq due to the resonance effect of trap seal water vibration.

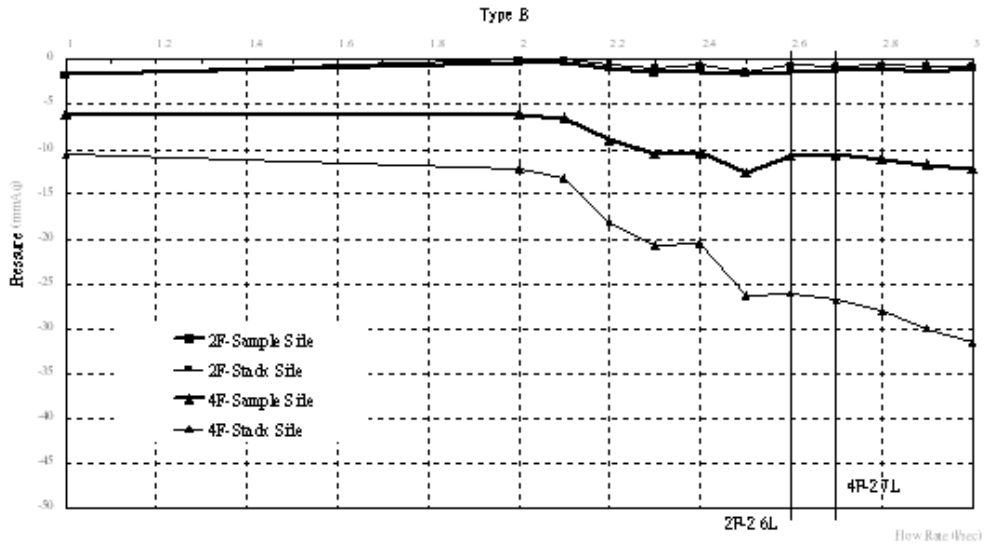

Figure 17 Results of trap seal water strength of designed floor drain model (Type B)

5. DISCUSSION

By the initial results of trap seal water vaporizing rate, this research had analyzed relation between vaporizing rates with opening area of drain samples as Figure 18 and Equation (6) shown. The vaporizing rate (VpR) depended on the opening area of drain. When the weight of effective trap seal water and the vaporizing rate had been measured, the time of seal water natural vaporizing until trap function losing could be calculated by Equation (7).

$$VpR = 0.0029 \times A \quad (6)$$

$$T(Vp) = Wi / VpR \quad (7)$$

VpR rate of seal water natural vaporizing (g/Hr)

A opening area of floor drains for vaporizing possible (mm^2)

Wi weight of effective seal water ensuring the trap seal function (g)

T(Vp) time of seal water natural vaporizing until trap function losing (Hr)

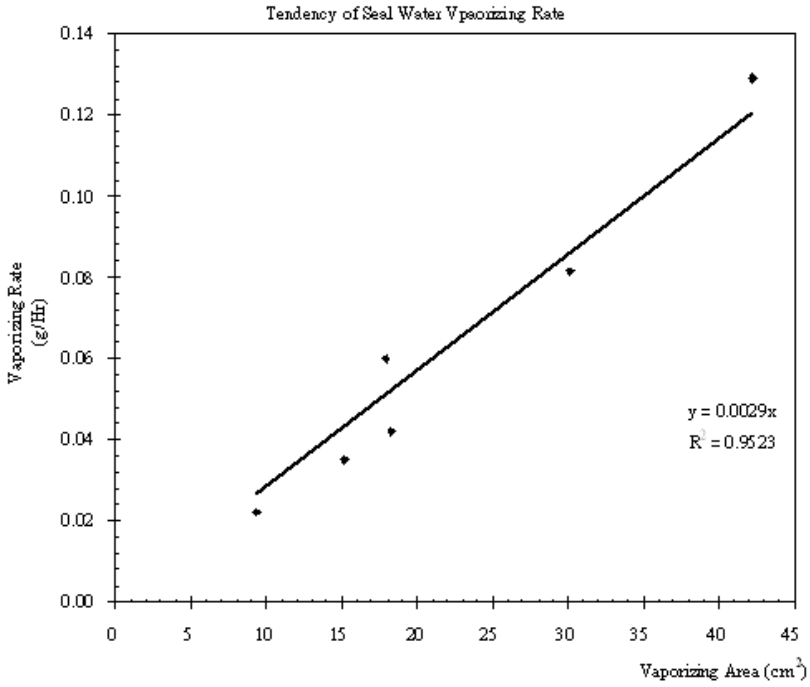

Figure 18 Relation between vaporizing rate with opening area of drain samples [8] [9]

By the initial results of trap seal water strength of drain models, this research had also analyzed relation between strength with their effective trap seal water depths as Figure 19 to Figure 20, and Equation (8) to Equation (9) shown. The trap seal water strength (Ssw) depended on the effective seal water depth of drain. Because of the resonance effect, the trap seal water strength of positive pressure zone was different from that of negative pressure zone. Following the regression equation, the strength of trap seal water until trap function losing could be calculated by their effective seal water depth.
The regression function of trap seal water strength from seal water depth were shown as the equations following.

$$Ssw\ (N) = -0.6058 \times Dsw \quad (8)$$

$$Ssw\ (P) = -0.1114 \times Dsw \quad (9)$$

Ssw (N) strength of seal water (negative pressure zone) (mmAq)
Ssw (P) strength of seal water (positive pressure zone) (mmAq)
Dsw depth of effective seal water (mm)

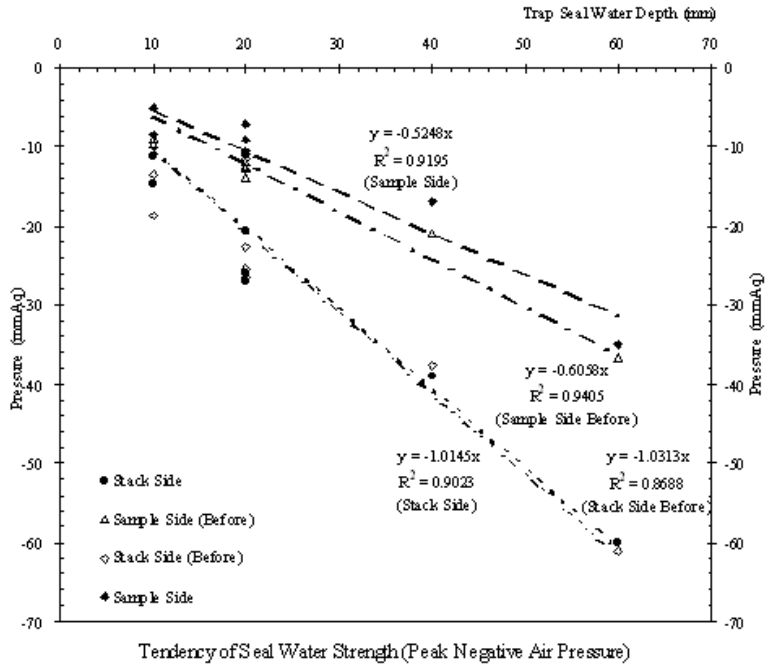

Figure 19 Relation within trap seal water depth and pressure strength (negative pressure zone)[8] [9]

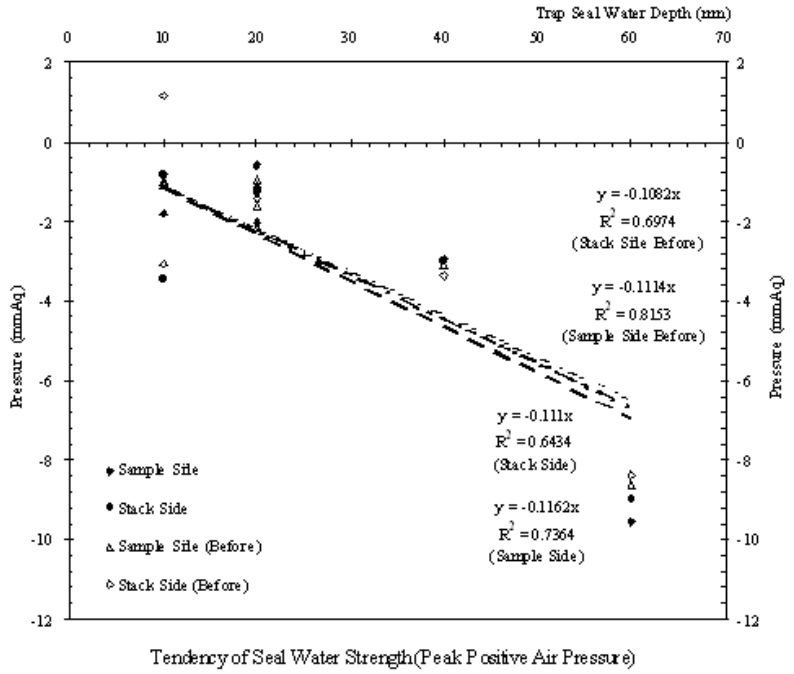

Figure 20 Relation within trap seal water depth and pressure strength (positive pressure zone) [8] [9]

6. CONCLUSIONS

To determine the performance of each floor drain, we study the vaporizing rate of the trap seal water and the seal water strength by the experimental tower established in Taiwan by ABRI. There developed some kinds floor drain for variation control in this research. Meanwhile, the tendency of seal water vaporizing rate and the relation between seal water depth and strength had been confirmed in this research.

At the same time, part of the performance testing methods and processes for the sanitary, such as floor drain, had been confirmed. With the results of the experiments and investigation, we are going to deliberate proper methods and standards that suit our technical developments and sanitary testing for architectural drainage systems.

Nomenclature

Ah length from the top of stack vent pipe to the discharge height (m)

P_A pressure of A zone

P_B pressure of B zone

P_D pressure of D zone

γ specific weight of air(kgf/m3)

V_a velocity of air flow at stack vent (m/s)

Q_a air flow rate in stack vent (m^3/s)

Ssw (N) strength of seal water (negative pressure zone) (mmAq)

Ssw (P) strength of seal water (positive pressure zone) (mmAq)

Dsw depth of effective seal water (mm)

Wi maximum weight of seal water ensuring the trap seal function (g)

T(Vp) time of seal water natural vaporizing until trap function losing (Hr)

Q_w water flow rate (V/s)

ξ_A drag coefficient of A zone

ξ_B drag coefficient of B zone

ξ_D drag coefficient of D Zone

CB constant pressure gradient (mmAq/m)

$\alpha\beta$ empirical constant of constant pressure gradient in C zone

g acceleration of gravity (m/s^2)

FL Discharge floor height (m)

L Length scale of the B zone (m)

C_L Constant of L

VpR rate of seal water natural vaporizing (g/Hr)

A opening area of floor drains for vaporizing possible (mm^2)

ACKNOWLEDGEMENTS

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Main author presentation

Dr. Lu Wen-Hung is an associate researcher of the Architecture & Building Research Institute, Ministry of the Interior, Taiwan. His main research focuses on the building drainage system performance testing and green building.

Transient identification of defective trap seals.

D.P.Campbell
d.p.campbell@hw.ac.uk
Drainage Research Group, School of the Built Environment, Heriot Watt University, Edinburgh, EH14 4AS

Abstract.

The prevention of the ingress of contaminated air into habitable space has been a central concern in the design of building drainage and vent systems since the 1850s. Failure to provide the necessary protection, primarily through appliance water trap seals, was shown to have been a significant contributor to the SARS epidemic spread in Hong Kong in 2003. Good practice has evolved to include wherever practical long radius bends to minimize the local air pressure changes. Similarly modern usage of drainage networks includes the random discharge of disposable sanitary and hygiene products that may interact with undesirable rapid changes in flow direction and thereby contribute to local surcharge conditions. However a maintenance regime within a large complex building network also requires a degree of prior knowledge of possible defective appliance trap seal locations. This paper proposes the use of air pressure transients to excite the appliance seals of a building drainage system, then use transient response measurement to identify, during periods of system non-use, the location of depleted trap seals through computer analysis. Validation of system transient response simulation is presented together with indications of the impact of a defective appliance trap seal on the system response to an applied low amplitude, short duration, pressure surge. Comparison of the defect free and defective system response is shown to be sufficiently discriminatory to allow the identification of appliance trap seal in need of replenishment.

Keywords

Building drainage, transient, fault identification, remote sensing

1. Introduction

Recent evidence has confirmed the necessity to prevent the ingress of possibly contaminated air from a building drainage and vent system into habitable space. The identification of dry floor traps as a significant cause of the SARS epidemic spread within the Amoy Gardens housing complex in Hong Kong in 2003,[1] was a timely reminder that the Victorian engineers' obsession with odour exclusion was well

founded, if possibly not fully understood at the time [2]. The ingress of contaminated air was from the drainage network into habitable space via the shower cubicles held at sub-atmospheric pressures by the operation of shower cubicle fans; the drainage network was a standard one pipe system where the w.c. waste is vented to a separate vent stack. The drying out of the 50 mm floor trap for any reason allowed an air path from both the vent and wet stacks into habitable space, exacerbated by shower cubicle fan operation. Subsequent air discharge to atmosphere via the shower cubicle fan exhaust precipitated the spread of infection to both upper apartments in the affected tower and transmission to adjacent towers in the complex. The remedial action considered included the introduction of automatic floor trap seal replenishment or the provision of mechanical floor trap seals. The operation of a shower fan undoubtedly increased the likelihood of trap seal evaporation. It is stressed that the operation of such fans may be included in the analysis techniques discussed in this paper by the simple expedient of introducing a variable and time dependent compartment pressure as an integral part of the trap seal boundary condition[3].

Trap depletion may occur as a result of excessive positive or negative pressure within the network generated by system operation or from outside sources. The pressure regime within the network may also result in trap failure due to bubbling through of gas, a failure condition almost unidentifiable later as the trap may appear to be fully charged when the pressure fluctuations in the network subside[(3)]. Current depleted trap seal identification relies upon visual inspection, detection of an unpleasant aroma, or possibly the identification of the characteristic sound of a drawn trap. In a complex building this approach cannot be expected to identify all failure conditions. This paper will introduce the concept of transient identification of depleted trap seals. In doing so, the paper will draw upon accepted pressure surge theory already being considered as a basis for defect identification in large scale water distribution networks[(4)].

Pressure transients propagated into a pipe network will be reflected and transmitted by all the network junctions and reflected by all the branch terminations. The form of the termination will determine the reflection coefficient. Hence any particular exit termination will have a characteristic signature, that will affect the pressure regime recorded within the network over a period of time. This signature will include the time taken for the altered reflection, travelling at the acoustic velocity in air, to arrive at a monitoring station, thus locating the defect. Thus, for any network it is possible to postulate that a comparison of a defect free network response with that generated with one or more defective components, will identify the location of the defects.

This approach depends upon the ability to simulate mathematically the transient propagation within any network. Normally the modeling of low amplitude air pressure transients in building drainage and vent systems requires a representation of the shear between the applied appliance water discharge flows and the entrained air within the system vertical stacks[(5)]. Simulation development has shown that this is wholly practical with the model being able to replicate system response to water driven air pressure transient propagation[(3)]. However, in this application, modelling the appliance discharge water flows and the consequent shear that generates both the entrained airflow and its accompanying transients is not necessary. It is envisaged that the system response to an applied pressure transient would take place when there was no water

flow in the network – for example an automated nighttime procedure. This allows a considerable simplification to the model that effectively becomes an air pressure transient simulation that can be based on traditional surge prediction techniques.

2. Low amplitude air pressure transient representation

The application of the method of characteristics (MoC) to the modelling of pressure surge, initially in large civil engineering applications, was introduced in the 1960s[6]. Since that time the MoC solution of the equations of continuity and momentum has been applied to such diverse areas as aircraft refueling and free surface drainage flows as well as traditional waterhammer[7,8], and the simulation of network air pressure transient propagation as a result of an imposed pressure vs. time regime. The equations of continuity and momentum for the case of low amplitude air pressure transient propagation may be shown[9] to be linked via the wave speed, $c = (\gamma p/\rho)^{0.5}$. In this case, expressing the equations in terms of wave speed and fluid velocity leads to:

$$c^2 \, \partial u / \partial x + [2/(\gamma-1) \, c \, [\partial c / \partial t + u \, \partial c / \partial x] = 0 \qquad (1)$$

$$2/(\gamma-1) \, c \, \partial c / \partial x + [\partial u / \partial t + u \, \partial u / \partial x] + 4 f u | u | / 2D = 0 \qquad (2)$$

These relationships are a pair of quasi-linear hyperbolic partial differential equations that are amenable to finite difference solution[6] when transformed via the MoC into the finite difference relationships that link conditions at a node one time step in the future to current conditions at adjacent upstream and downstream nodes in the simulation network. Swaffield and Campbell[10] illustrated the use of this technique to simulate system conditions, noting that only one characteristic equation exists at a boundary, thereby requiring a boundary equation that links airflow or pressure at the boundary to other system parameters. These conditions may depend on the local pressure regime within the network, for example the opening pressure for an Air Admittance Valve or the displacement of a trap seal. Boundary conditions fall into two broad categories, passive and active. Passive boundary conditions typically define system pipe terminations, for example junctions of two or more pipes or open or closed ends. These boundaries remain constant whatever the local pressure – flow condition within the system. In the case of a junction of N pipes, some terminating and some originating at the junction, there is a need for 2N equations to solve for airflow and pressure at the first and last nodes of these pipes, note that pressure is taken as defined by wave speed. Each terminating pipe has a C^+ characteristic, while each originating pipe has an available C^- entry characteristic. In addition continuity of flow and either the equivalence of pressure at the junction or a representation of the junction local loss provide the correct number of equations required.

Active boundary conditions depend upon the prevailing condition at the boundary. An AAV boundary depends upon the local air pressure at the branch to AAV interface[3]. The boundary can therefore have zero velocity if the pressure is above the AAV opening pressure level. If the suction in the pipe is sufficient to open the AAV then the boundary equation is provided by the variable valve loss coefficient, in turn dependant on local line pressure. Note that some modern AAVs, or waterless trap sheath devices, may have complex opening cycles that generate high frequency low amplitude

transients which are not considered here. The AAV boundary condition may thus be written as: $p_{local} = p_{atm} - K_{local\ p} Q_{local} | Q_{local} |$, where $K_{local\ p}$ decreases as the local pressure falls and the absolute value of flow is used to ensure the correct sign for the valve loss, conventionally inflow taken as negative. If p_{local} rises above the AAV opening pressure then the zero flow boundary condition applies. Solution of the equations with the locally available characteristic equation at a pipe exit (C^+ equation) – is sufficient to yield pressure and velocity predictions at the boundary. The boundary condition applicable for a trap seal is based on the application of the equation of motion to the seal water column

$$p_{local,t+\Delta t} - (p_{atm} + p_{room} + pg((H_{system}-H_{appliance}) - 0.5(u_{t+\Delta t}+u_t)\Delta t) - L_{trap}\, 32.0\mu\, u_t / D^2_{trap} - \rho L_{trap}\, A_{pt} (u_{t+\Delta t}-u_t)/\Delta t = 0 \quad (3)$$

solved with the available C^+ equation. This is inevitably an iterative solution as both $p_{local,t+\Delta t}$ and $u_{t+\Delta t}$ are unknown, the velocity term being defined by the C^+ characteristic, coupled with the wave speed pressure relationship. The mass of the trap seal water, represented in equation (3) by the length of the water column L_{trap}, is monitored at each time step. Obviously suction in the system will result in water loss as the system side height H_{system} cannot exceed zero**.** Either suction or positive pressure can displace the water column so that an air path is formed through the trap as soon as the water level on either side falls to the lowest point of curvature of the trap. This failure condition is identified by monitoring the value of trap seal length at each time step. Comparison with the geometry of the trap allows the trap seal boundary condition to be modified to represent a concentrated loss in either of these cases. These cases are referred to as 'bubble through' trap seal failures and are difficult to identify post event as the water column will revert to an equilibrium position as the transient event abates[3]. Self-selection of the appropriate boundary condition is achieved through the software.

For this application it is also be necessary to model a transient propagation device similar to that employed by Campbell[10]. This is easily accomplished within the MoC solution as the applied pressure – time profile may be introduced as a boundary condition, reverting to either an open end (pressure equal to atmospheric) or closed end (local velocity zero) at the end of the pre-set time interval. The technique discussed in this paper is at the proof of concept stage. In developing the proposed methodology consideration was given to employing a purely acoustic technique as opposed to the introduction of a pressure pulse, but this concept was rejected on the basis of having a low signal-to-noise ratio.In the majority of method of characteristics applications the frictional terms are defined by the Darcy and Colebrook White equations, and remain roughly constant, despite a dependence on Reynolds Number. In the application considered here where the drainage system is considered to be dry this frictional representation is adequate.

3. Validation of the proposed application of a MoC simulation.

The proposed monitoring of the dry system response to an applied pressure regime has been previously investigated[10, 11]. The propagation of air pressure transients through a drainage network was investigated by means of a pressure transient generator that was capable of imposing a pre-set pressure boundary condition onto the network. The response of both water seal traps and Aavs was considered, along with other interactions such as water curtains and branch to stack junctions.

In the case of both the trap seal displacement, and AAV operation, close agreement was achieved between the measured and predicted air pressure transient response of the system under laboratory conditions, providing confidence in the application of the methodology proposed. A wider validation of the simulation, including the water flow initiated entrained air, is presented elsewhere[3]. The method can be used as a forensic tool to determine the point of likely system failure and also post-event water levels in traps.

4. Defective appliance identification matrix.

The transient response of the system to an applied pressure surge may be simulated, assuming all the appliance trap seals are intact, at one location chosen to be representative of the network. This might be considered 'Case zero data', ${}_{m}Sp_{0}$, where m indicates the location of the monitor station. For a network with N(T) exit appliances of any one type T, it follows that simulating the response of the network to the same applied pressure surge while introducing sequential failures in the exit appliances will generate a series of 'Failure case data', ${}_{m}Sp_{1\text{-}N(T)}$. This effectively builds a database for the network that enumerates its response to each appliance defect. The defect condition for one type of appliance, T, may be represented by a binary string. Here '1' might represent a functioning appliance and '0' a defective unit. If appliance J of N was defective then the string would have the form: $S(1_{1\rightarrow J-1},\ 0,\ 1_{J+1\rightarrow N})_{T.}$ Similarly if two appliances K and I of one type were defective then the string takes the form: $S(1_{1\rightarrow k-1},\ 0,\ 1_{K+1\rightarrow I-1,}\ 0,\ 1_{I+1\rightarrow N}\ )_{T}$ Subsequent operation of the network, monitored at location m, yields an actual response pressure – time profile, ${}_{m}Sp_{actual}$ that may be compared to the simulated database, ${}_{m}Sp_{1\text{-}N(T)}$. The degree of fit may be estimated by a 'least squares' Compliance Function

$$C_{(actual\text{-}J)} = \sum_{i=1}^{npoint} \left({}_{m}Sp_{actual} - {}_{m}Sp_{J=1\text{-}N(T)}\right)^{2} \qquad (4)$$

that generates a series of $C_{(actual\ -\ defect\ appliance\ number)}$ values. Clearly the value of C = 0 when the database profiles match the monitored system response. A matrix may therefore be constructed where the coefficient values $C_{(actual\ -\ defect\ appliance\ number)}$ may be listed against the 'no failure' case, labeled 0, and the likely failure appliance, labeled 1 – 11 for the 11 traps used in this simulation. The values of the compliance function in each case indicates the relative divergence of the measured system response from that predicted for any particular trap seal failure condition, yielding a matrix of form:

Fault condition (Actual)	$C_{(Actual-1)}$	$C_{(Actual-2)}$	$C_{(Actual-N)}$
0	Value	Value	Value
1	0	Value	Value
2	Value	0	Value
N	Value	Value	0

Comparison of the compliance function values will therefore identify the location of the failure condition. Multiple simultaneous appliance failures of one type may also be handled in this way, however the number of trial fits will increase considerably. If the system includes N water seal traps of which M may be defective simultaneously, then the number of combinations to be checked becomes N ! / ((N-M) ! M !). However, the operation of a drainage and vent system limits the number of potential failure conditions. Once a trap has been lost it acts as a relief vent to the system thereby preventing further seal depletion.

5. Potential of transient defect identification within building drainage and vent systems

Figure 1 illustrates the divergence between the system response, predicted at the simulated pressure transducer connection**,** for one trap seal failure condition on the top branch. **Table 1** presents the Compliance Function matrix, while **Figure 2** illustrate the matrix values graphically, making explicit the reduction in compliance function value to zero, when the depleted trap is identified. Note that **Figure 2** details the Compliance Function values for some traps only.

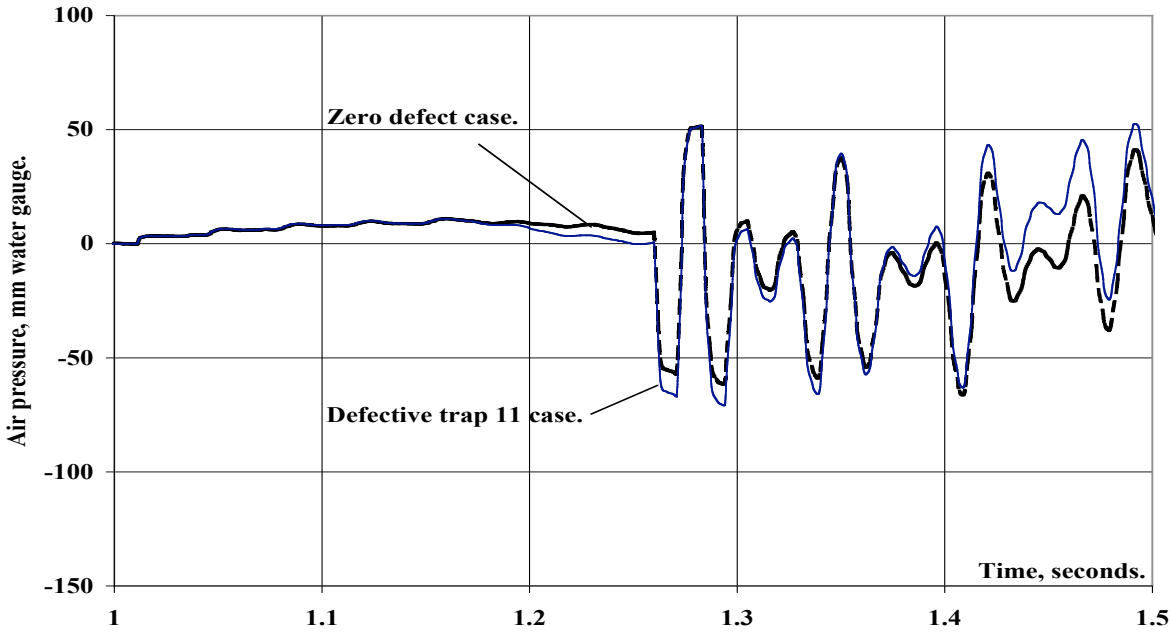

Figure 1 - Comparison of the simulated transducer station response for the zero defective trap case and a dry trap on branch 11.

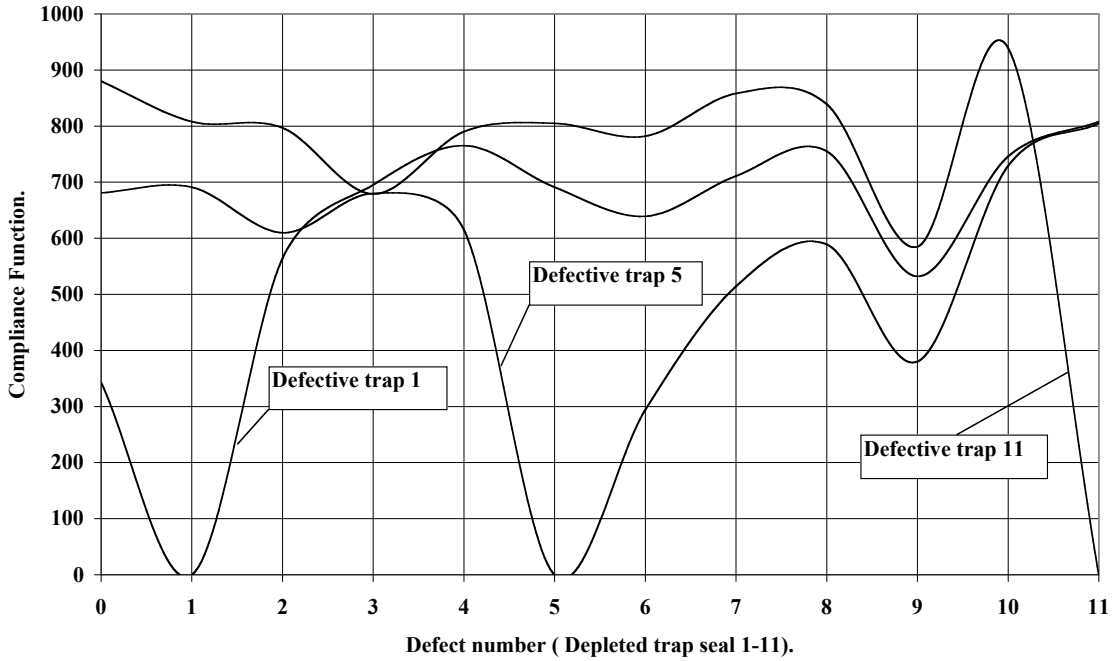

Figure 2 - Compliance Function values for traps 1, 5 and 11.

Table 1 - Compliance Function values for the 11 storey system including the zero defect case. Note symmetrical matrix with zero value diagonal.

Compliance function values.

Trap Defect	1	2	3	4	5	6	7	8	9	10	11
0	343.	734.	765.	791.	681.	627.	734.	739.	528.	803.	880.
1	0.	564.	695.	765.	691.	639.	711.	755.	532.	746.	808.
2	564.	0.	705.	756.	610.	630.	706.	722.	509.	779.	797.
3	695.	705.	0.	775.	680.	638.	716.	807.	580.	796.	679.
4	765.	756.	775.	0.	615.	564.	503.	741.	548.	822.	790.
5	691.	610.	680.	615.	0.	294.	514.	589.	380.	729.	805.
6	639.	630.	638.	564.	294.	0.	475.	628.	443.	706.	782.
7	711.	706.	716.	503.	514.	475.	0.	624.	503.	806.	858.
8	755.	722.	807.	741.	589.	628.	624.	0.	484.	779.	839.
9	532.	509.	580.	548.	380.	443.	503.	484.	0.	360.	585.
10	746.	779.	796.	822.	729.	706.	806.	779.	360.	0.	939.
11	808.	797.	679.	790.	805.	782.	858.	839.	585.	939.	0.

It will be seen that the Compliance Matrix is symmetrical, if the zero failure case is ignored, with a zero diagonal as expected. The simulated output indicates that the technique would be applicable to the special case of identification of depleted trap seals in a complex building drainage and vent system. It is apparent from the output that short periods of transient excitation would be sufficient to generate the pressure transient response necessary to identify the failure location. However, there are obvious issues that would need to be explored further prior to confirming the applicability of the process, such as the effect of signal noise on the comparison between the defect free and defective trap transient response. While this can only be resolved by an experimental programme, **Figure 3** illustrates the likely effect of noise on the comparison between predicted and measured signals for a defective trap on branch 5.

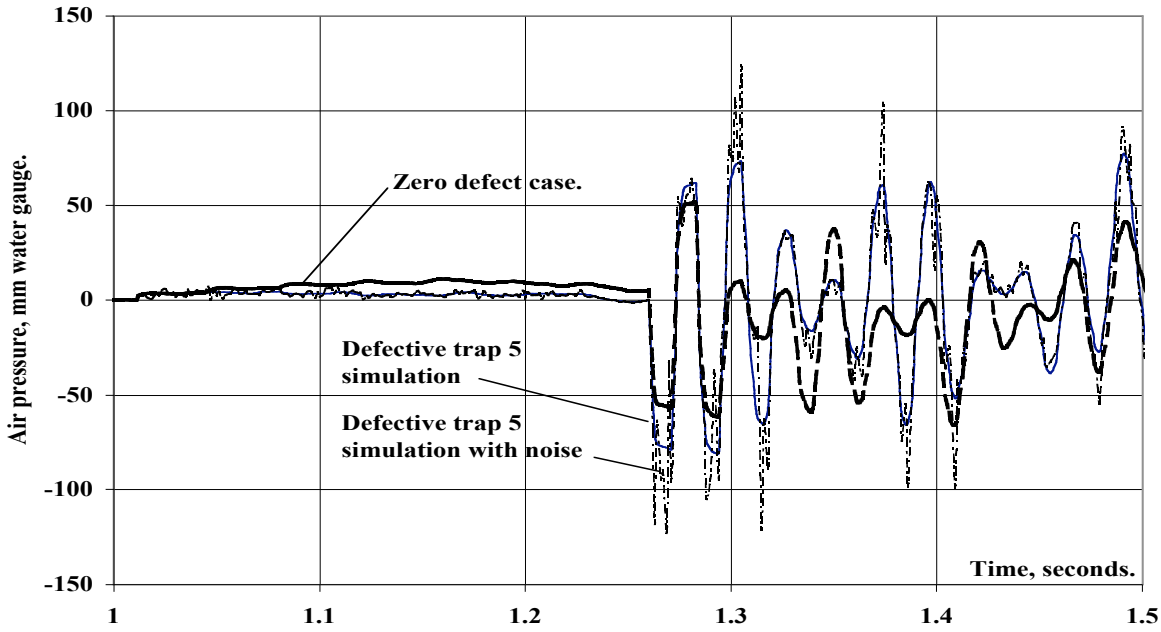

Figure 3 - Effect of noise on the comparison between the zero defect case and defective trap 5 simulation. Note that adding a noise signal to the trap 5 simulation increases the Compliance Function value from zero, Figure 8, to 74.

The simulated transient response is modified by the addition of a noise term described by an expression of the form -

Noise (mm H_2O) = sin(rads(Rand (0-1) time 10^6)(Signal. Rand (0-1)) (5)

The Compliance Function value increases from zero for a perfect fit, Figure 2, to a value of 74 for the example shown. This is still substantially less than the C values for alternate defective traps, Figure 8, indicating that in this case the trap on branch 5 would still have been shown to be defective. The identification of defective traps in close proximity to each other within a sub-system is also an issue. The network discussed here has a single trap on each of 11 floors. In practice it is more likely that a number of traps would be concentrated in a rest room or kitchen facility. In that circumstance, it might be more difficult to identify the actual defective trap. In order to investigate the sensitivity of the proposed methodology the network considered here was modified to include, on Floor 11, a simulated rest room with three traps. In this case, the Compliance Function values illustrate that while the w.c. trap was clearly identifiable as defective, it was not possible to distinguish between the bath and sink respectively - unless the sub-system included branches of differing lengths. **Figure 4** illustrates an initial laboratory based comparison of the air pressure transient measurements at the one location shown following the activation of a fan connected to the network. The upper end of the system is terminated by an AAV while the stack base is open to atmosphere.

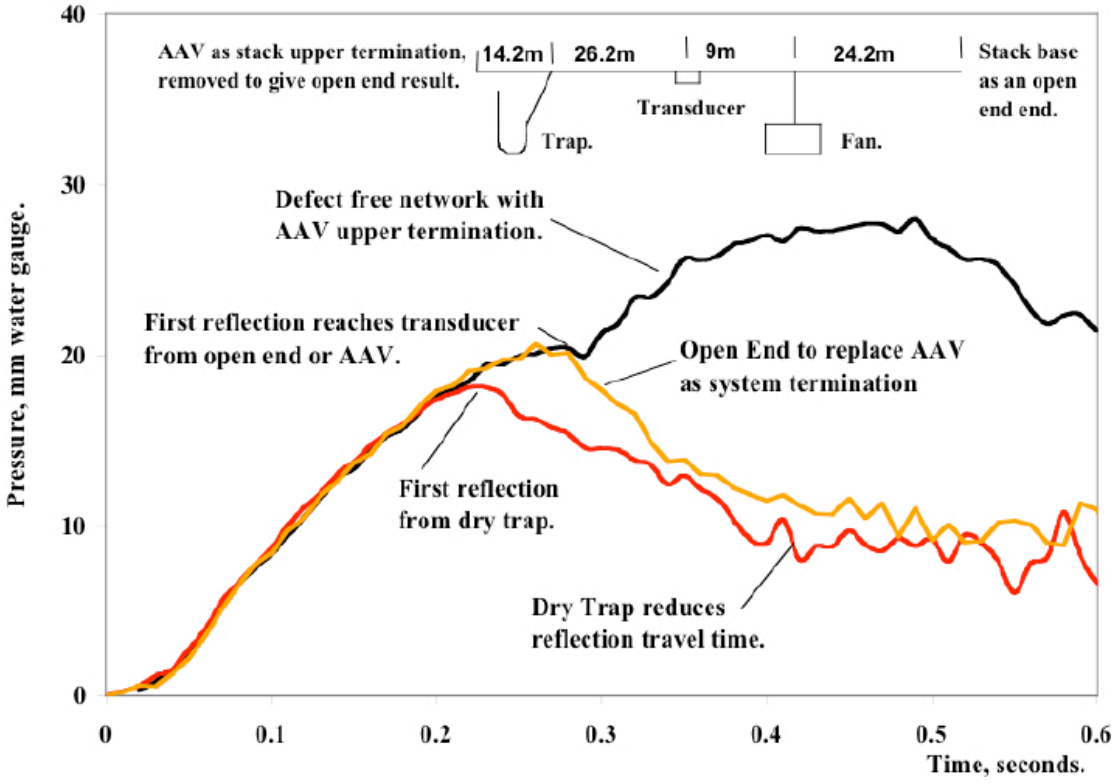

Figure 4 - Laboratory comparison of system response with and without a dry trap.

Comparison traces for a defect free system and sequentially a dry trap and a an open end to replace the AAV are illustrated in Figure 4, demonstrating the predicted differences due to changed system boundary conditions and reinforcing the potential of the technique. In the defect free case the positive reflection from the closed AAV is seen to arrive at the transducer at 0.28 seconds after first pressure rise, consistent with a 320 m/s wave speed over the 89.8 m of duct. Similarly in the case of an open stack termination the negative reflection generated by an open end is seen to arrive at the same time, 0.28 seconds into the recording. However the introduction of a dry trap 14.2 m short of the stack termination generates a negative reflection that arrives at 0.195 seconds, consistent with a 330 m/s acoustic velocity over the 28.4 m shorter travel distance for the first reflection to reach the transducer. This result underlines the potential of the methodology, both through the clear divergence illustrated between the defect free and dry trap pressure traces and the time – wave speed corroboration of the defect location.

6. Conclusion

This paper has demonstrated that the proven ability to simulate air pressure transient propagation within building drainage and vent systems may be used to identify defective trap seals and that the divergence in transient response predicted may be replicated by laboratory testing. Identification of persistent trap seal depletion would allow local installation of active control devices to prevent further failures – including the addition of either Aavs to limit trap seal loss to negative transients or variable volume containment Positive Air Pressure Attenuators that limit trap seal loss due to positive pressure transients by providing a transient storage volume that absorbs the positive wave by allowing an initially deflated ‘bag’ to expand to a predetermined maximum value – currently such devices have an 8 litre volume. The proposed methodology relies on the measurement of the system response to an applied transient and subsequent comparison to earlier simulated or measured defect free data for the same excitation. The proposed Compliance Function identifies the closeness of fit between these two signals and hence identifies the defect location. The simulations presented clearly indicate that this methodology would be capable of defect identification, both for a whole network or its sub-systems. In addition the simulated application has included the effect of randomized noise on the comparison of the transient responses and has shown that the underlying approach remains valid.

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Presentation of Author

Dr. David Campbell is a seniour lecturer in the School of the Built Environmentand is research active in the field of building drainage and detergency.

Investigation of the effect of swept entry configuration on the air entrainment and self-siphoning behaviour in gravity drainage systems

A. Öngören (1), R. Materna(2), M. Tanner(3)
(1) abdullah.oengoeren@geberit.com
(2) ralf.materna@geberit.com
(3) markus.tanner@geberit.com
Sanitary and Construction Technics, Geberit International AG, Switzerland

Abstract

In this study, a typical wastewater drainage system composed of different swept entry configurations are systematically investigated. A high tower test stand, which allows the installation of a 24 m high stack combined with a 3 m side branch is available to conduct the tests. The drainage through the side branch is simulated by pumping water into a flushing appliance which then flows into the lateral branch pipe in order to create the flow conditions representing the actual drainage system installed in a building. Here, it is primarily reported on the seal loss as affected by the variation of branch pipe offset and the ratio of flow rates in these two pipes. The ratio of branch pipe size to main stack size is also considered as a relevant parameter to effect the seal loss behaviour.

The results are presented in the form of spatial seal loss distributions on the stack with and without a side branch connection. In addition to the experimental analysis, various configurations of the tested system are simulated utilizing a computational fluid dynamic (CFD) method in this study. The use of this method, on one hand displays the important characteristics of the drainage flow visually; on the other hand it provides extensive flow data including flow velocities and transient pressures.

Keywords

swept entry configuration; transient drainage flow; self-siphoning; seal loss

1 Introduction

Layout and dimensioning of gravity drainage systems are well described by European standards [1]. According to these standards the maximum discharge rate of the stack depends on the design of the junction between branch and stack pipe [1]. For angled flow into the stack (swept entry) the standards allow a higher flow rate than for a straight (perpendicular) entry. This aspect has been discussed extensively in the

literature [3,7] and this solution has been widely adopted by the sanitary equipment industry. Despite its widely spread application of this solution in the industry, the standards still don't describe a particular configuration for the swept entry fitting, and therefore there is an ongoing dispute on the definition of the ideal junction design. Moreover, previous investigations have shown that the junction design has a substantial effect on the self-siphoning behavior in the branch pipe [2,4,8].

This study focuses on enlightening the reasons behind the effect of the most relevant parameters on the functioning of the traps and increasing or reducing the seal loss accordingly. It is expected that a detailed examination of flow related activities especially near the side branch junction can help to define an optimal configuration for the fitting geometry. It is also expected that a systematic collection of experimental data in this study can provide a basis for the development of a reasonable methodology to assess swept entry drainage pipe fittings in the future.

Computational fluid dynamics (CFD) has emerge as one of the powerful methods to be used to predict and analyse flow related problems in sanitary applications. The same technique is used in this study to simulate the flow in a junction model representing the side branch entry configuration, thereby exploiting the characteristics of flow activities which are closely related to trap seal loss.

2 Experimental and Computational Techniques

2.1 Experimental set-up

The tests have been conducted in the high tower test stand of Geberit Labs, which allows the installation of a 24 m high 8 story stack combined with a 3 m long side branch as the discharge pipe. The distance between the stories is 2.65m except the bottom and the top stories where the height increases to 3.31 and 3.35m, respectively. The main stack is made of a 110 mm diameter PE-pipe. Either a 110 mm (D110) or a 90 mm (D90) PE-pipe has been used as the side branch in order to be able to observe the effect of branch pipe size on the seal loss. A sketch displaying the overall configuration of the piping system in the test tower is given in Figure 1(a).

The water is supplied to the stack at two locations as indicated in this figure. The main supply is from the straight entry on the 7^{th} floor. The second supply is from the side branch located on the 4^{th} floor. The water supply from both the main and the side branch entries is provided by means of a feed pump. Two valves mounted on the two feed pipes separating from the pump discharge line regulate the flow rate required for each entry. On the branch pipe side, the water is fed first into a cistern from which it flows freely into the branch pipe in order to simulate a flushing process. By this way it has been possible to create the flow conditions, which represent an actual drainage system in a building. During the tests both the discharge rate in the main stack and the branch pipe has been adjusted so that the total discharge from the stack is kept at a constant level of 5.2 lt/s throughout the tests. The discharge rate in the main stack is adjusted to 2.7, 3.6, 4.4 and 5.2 lt/s, whereas the discharge in the side branch is varied in four steps to 2.5, 1.6, 0.8 and 0.0 lt/s, respectively depending on the test case. The flow rates were

monitored continuously during the tests by two flow meters mounted on the feed lines.

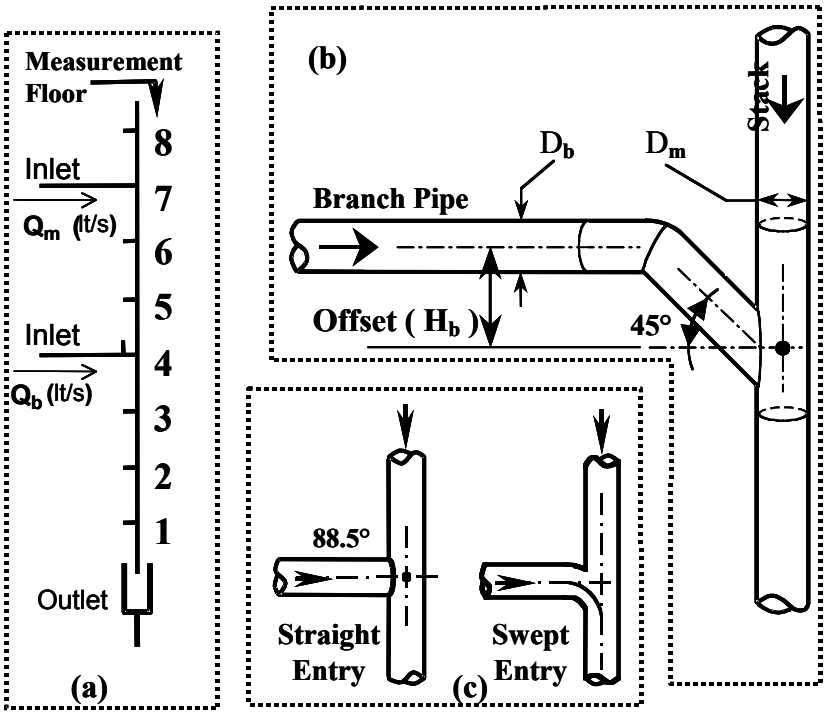

Figure 1 - Sketches illustrating (a) overall configuration of the test stack with discharge locations and measurement floors; (b) a general view of branch pipe inlet and (c) two special branch pipe inlet configurations, tested in this study.

The maximum discharges 2.5 and 5.2 lt/s correspond to the maximum allowable values according to the requirements of the related standards [1] for the selected side branch and the main stack pipes, respectively.

The investigation of the influence of swept entry configuration on seal loss has been carried out by implementing a variety of commonly used entry fittings on the branch

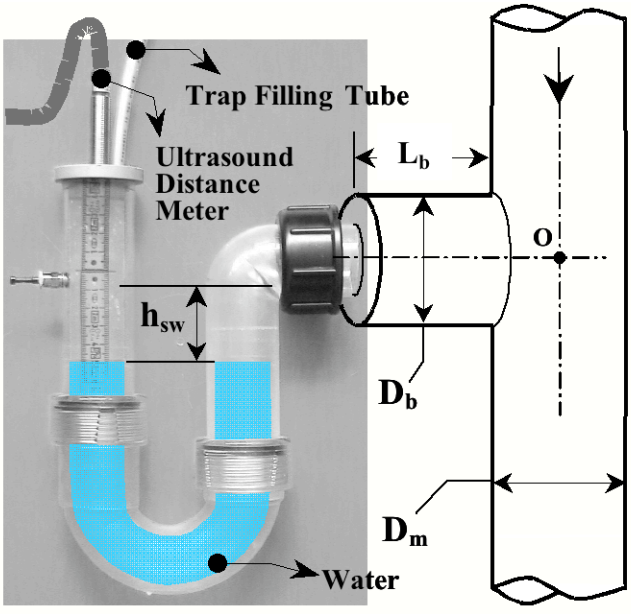

Figure 2 – A typical trap connection used to measure the seal loss distrib ution along the main discharge stack.

pipe at the 4th floor. Most of the tests have been carried out with 45° angled entry type of joint, a sketch of which has been given in Figure 1(b). Some of the relevant geometrical parameters are also indicated in this figure. The geometry of the standard 45° joint has been changed by varying either the branch pipe diameter, D_b, or the branch pipe offset, H_b. In addition to the 45° joint, two special entry configurations, a straight entry and a curved swept entry, have been used for comparison. The sketches of these two special cases are illustrated in Figure 1(c).

2.2 Measurement technique

The measurement of seal loss has been accomplished utilizing a series of instrumented traps mounted on the main stack at 7 of the test tower floors. The traps at floors 1-3 and 5-6 have been connected directly to the stack through an adaptor piece which is 0.3m long as shown in Figure 2. The trap mounted on the side branch is 1 m apart from the stack. A second trap is added to branch located 1 m away from the first one in order to monitor the transient activities inside the branch itself. The free end of each trap is closed with a cap, which allows mounting an ultrasound distance meter, and a water fill pipe and possesses an air vent. The traps are filled up to the rim with water before each test under standstill conditions. The pump is run up to the predetermined flow rate gradually and slowly enough so that an excessive seal loss due to start-up transients is prevented. Duration of the tests has been set to 3 minutes for each case, which is followed by a 1 minute settling period for the trap water. By this method it is possible to determine the maximum seal loss level reached during the tests. The trap water level as detected by the ultrasound meter on each trap has been recorded on a portable computer at the end of this period.

3 Results

The seal water loss is used as a means to determine the severity of the dynamic pressure pulsations in the drainage piping system. This method is used widely in the literature [6, 7] for such purposes because of its simplicity to install and being a direct instrument indicating the level of trap water suction. The seal water height, h_{sw}, given in this study, can easily be converted into maximum suction pressure level when it is required.

3.1 Characteristics of trap suction in a single stack discharge without a side branch

A series of measurements has been carried out in order to determine the distribution of seal water loss along the discharge stack which provides a basis for comparison with the succeeding measurements in the following sections. The seal loss distributions for a flow rate range of $2.7 < Q_m < 5.2$ lt/s are given in Figure 3. As examined in the distributions of this figure a local seal loss maxima is reached immediately after the discharge inlet near the 6th floor, which gradually decreases in the downstream to about 30 percent of the maximum level. The same set of data are normalized with respect to the local maxima and plotted in Figure 3(b). All the data are very well correlated and collapse on a characteristic distribution as it is clearly observed in this figure. This characteristic distribution is typical for similar type of discharge stacks which have been reported many times in the literature [2,5].

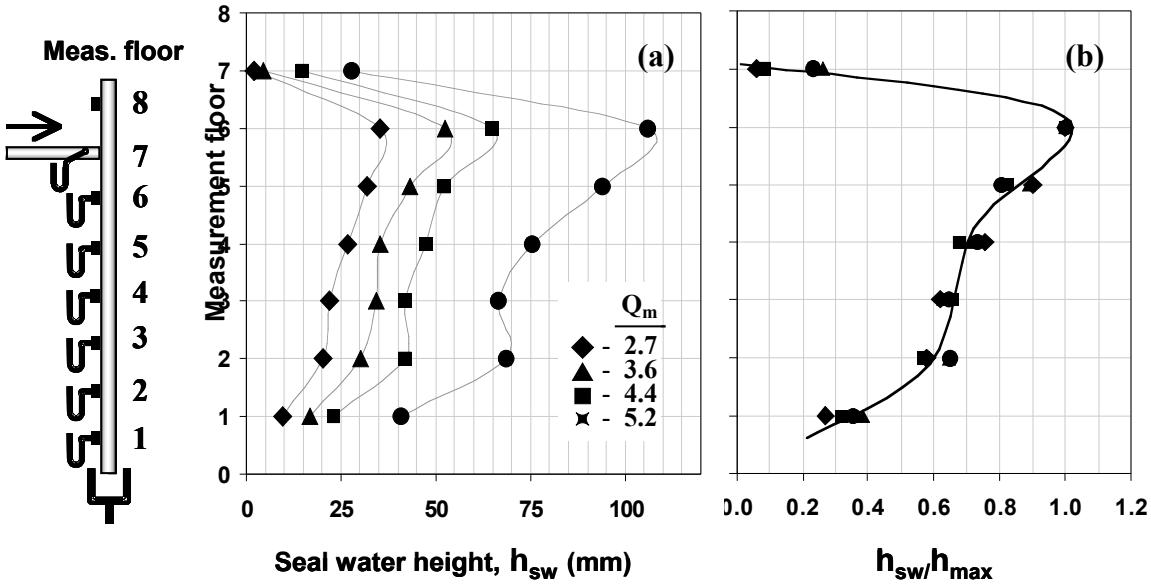

Figure 3 – The reference seal loss measurements in a discharge stack without a side branch. (a) Distributions of absolute seal loss level for 4 different discharges and (b) seal loss distribution as normalized by the maximum level of each case.

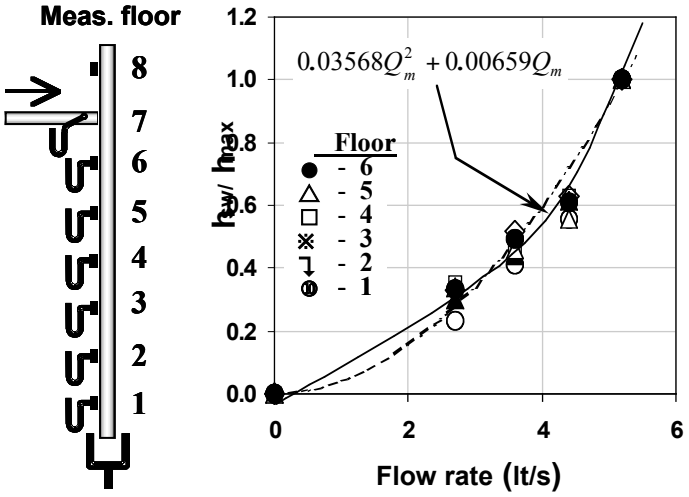

Figure 4 – Variation of seal loss in the reference discharge stack without a side branch as a function of flow rate.

The characteristics of seal loss has been further displayed in Figure 4 where the variation of normalized seal loss measured at all floors are given as a function of flow rate. The solid curve given on the same figure represents the best fit to the data, whereas the dotted line has been determined by applying the empirical methodology presented by Lu et al. [6]. The equation describing this line is given as :

$$\frac{h_{sw}}{h_{max}} = 0.03568 \cdot Q_m^2 + 0.00659 \cdot Q_m \qquad (1)$$

and has the same form as that of Lu et al. which is given to calculate the peak negative air pressure, p_{na}, occurring in a single stack discharge pipe. Although Lu et al. [5,6] have used this approach to predict p_{na}, it should be recalled that seal water suction from

the traps connected on such a system is directly proportional to p_{na}. Therefore, the application of the same methodology for seal loss prediction in this study is clearly justified. In fact, it is examined in Figure 4 that Equation (1) represents the measured data quite well. The analysis of the results in this section proves that both the experimental set-up and the measurement method adopted to be utilized in this study are suitable for a detailed and an accurate examination of the problems investigated.

3.2 Trap suction on a stack combined with standard side branch junctions

The characteristics of seal water suction from the traps connected on a single stack discharge pipe combined with a side branch having three different types of commonly used standard junction geometries, a straight entry, a swept entry and a 45° angled entry with H_b /D_b=1 (see Figure 1), have been examined as the first case of this study. The

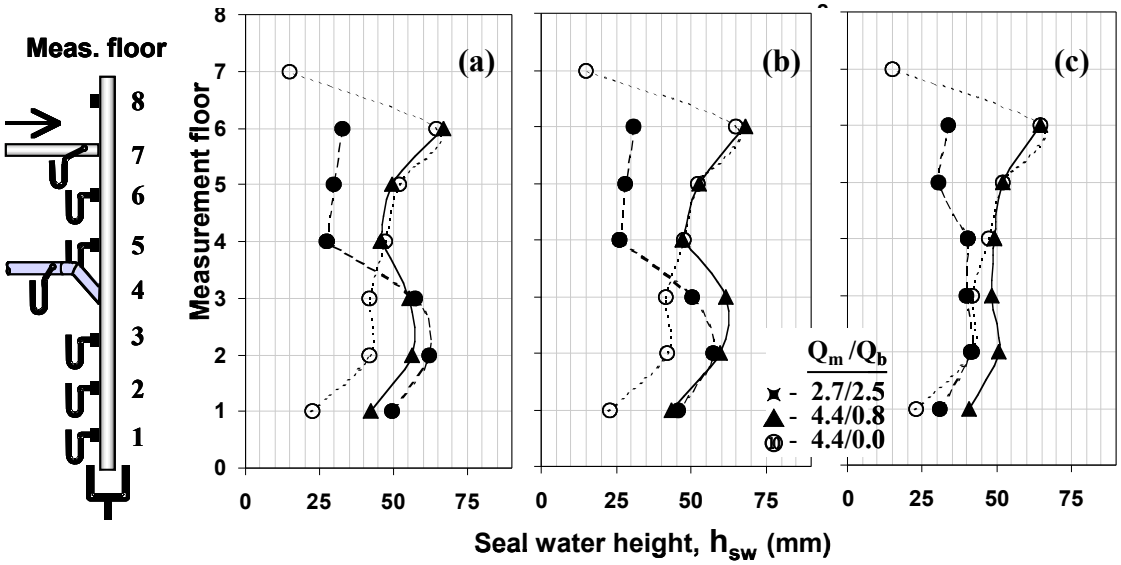

Figure 5 – Distribution of seal loss along the stack with (a) a straight entry, (b) a swept entry and (c) 45° angled entry junction for Q_m=2.7 and 4.4 lt/s in comparison to the reference case without a side branch under the same flow conditions.

seal loss distribution along the stack in the vicinity of these junction elements are given in Figure 5 for two different discharge combinations of Q_m/Q_b=2.7/2.5 and 4.4/0.8 lt/s, in the main stack and in the side branch, respectively. Here it should be recalled that the sum of the discharges of each combination is 5.2 lt/s which is the maximum allowable level for the main stack size used. The third curve resembled by open symbols added to all three plots belongs to the reference case of discharge stack without the side branch for a discharge rate of 4.4 lt/s.

In all three cases, the seal loss distribution shows similar characteristics from the main discharge at the 7th floor up to the side branch discharge at the 4th floor. Especially the data belonging to the flow rate of 4.4 lt/s follow the same curve at the upstream of this junction A significant deviation from this distribution is first examined at the downstream of this junction where an appreciable increase is observed in the seal loss. This increase in the seal loss can be attributed partly to the increase in the total discharge as a result of merging of the flow from the side branch into the main stack discharge, and partly to the strong changes in the flow activities because of the

differences in the junction geometry. The effect of the junction geometry is examined best by comparing the straight and swept entry cases of figures 5(a) and 5(b) with the 45° entry configuration given in Figure 5(c). It is interesting to note that the most significant difference occurs when the proportion of the flow from the side branch approaches to that of the main stack, i.e. $Q_m/Q_b \sim 1$.

3.3 The effect of side branch offset on the trap suction characteristics

The effect of junction geometry on the seal loss is examined further by changing the offset of a 45° angled entry on the side branch as sketched above in Figure 1(c). The investigation of this aspect of entry configuration is particularly important in this study since a binding definition of the junction is not provided in the standards, therefore implementing a fitting with an optimal geometry depends solely on the experience.

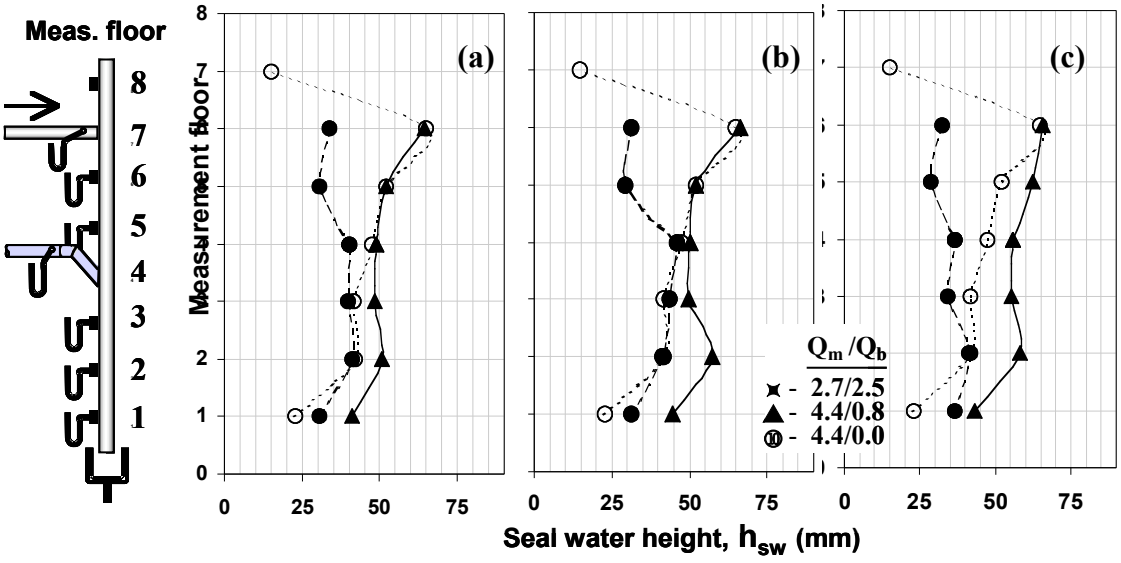

Figure 6 –Seal loss distribution along the stack with a 45° angled junction having an offset of (a) H_b/D_b=1, (b) H_b/D_b=1.3 (c) H_b/D_b=3.12 for Q_m=2.7 and 4.4 lt/s as compared to the ref. case without a side branch under the same flow conditions.

The seal loss distributions for three different offset ratios from H_b/D_b=1 to 3.12 are displayed in Figure 6. Although a behavior similar to that discussed in the previous section is observed at the upstream of the side branch junction, a significant difference is examined in comparing the cases corresponding to the lower discharge range of 2.7/2.5 lt/s at the downstream of the junction. It is important to mention here that the seal loss tends to increase gradually in this zone in the offset range of $H_b/D_b<1.5$ whereas it is reduced to lower levels thereafter in the range $H_b/D_b>1.5$. This behavior is best displayed in Figure 7 where the seal loss is presented as a function of branch pipe offset in the range of $0 < H_b/D_b < 3.12$ for the flow rate ratio of Q_m/Q_b = 2.7/2.5 lt/s. The data in this figure indicates that in the upstream zone (5th_F) the dependency of the seal loss on the offset ratio disappears. However, in the downstream zone (3^{rd}_F and 4^{th}_F), a relatively strong dependency on the offset ratio exists. In this zone a significant increase occurs in the seal loss as the offset is increased to about $1.5D_b$. At the 3^{rd} floor just behind the junction the seal loss tends to increase further as the offset is reduced to

a level below $H_b/D_b < 1$. The data points corresponding to the two lowest offset ratios in this plot belongs to the straight and swept entry configurations where $H_b/D_b=0$ and $H_b/D_b = 0.2$, respectively.

On the other hand, the seal loss tends to decrease again as the offset ratio is increased over $H_b/D_b>1.5$ reaching to about the same level as that measured at the upstream floors. The appearance of such a critical offset range causing excess seal loss can be attributed to the strong changes in the flow activities developing near the junction. These issues will be further assessed in the following sections.

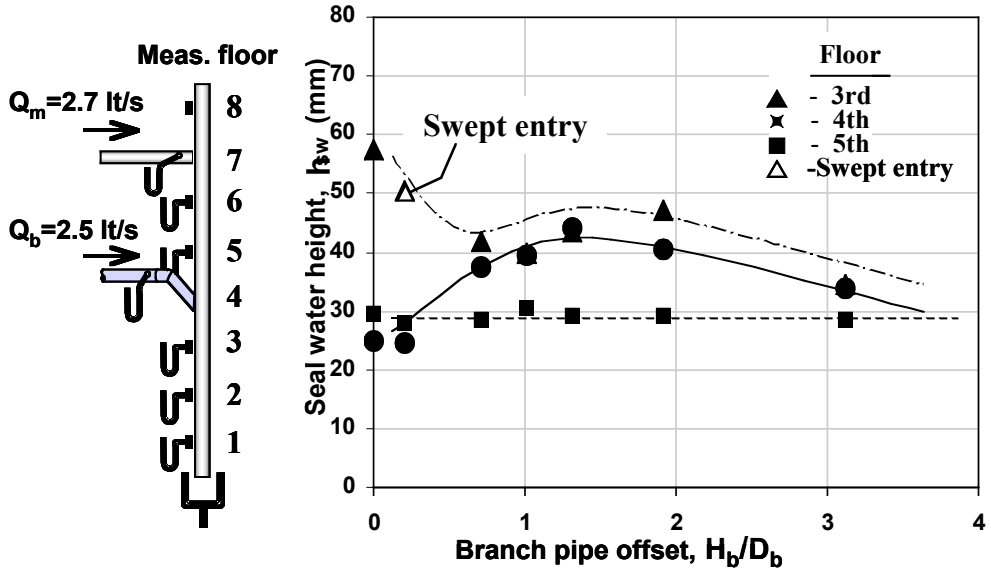

Figure 7 –Seal loss measured at the 3rd, 4th and 5th floors as a function of side branch offset in the vicinity of flow condition Q_m/Q_b = 2.7/2.5.

3.3 Characteristics of flow activities in the stack near the side branch junction

The behaviour of flow activities which are directly related to the changes in the seal loss is investigated utilizing computational fluid dynamics (CFD) methods in his study. A piping model which covers the most relevant flow conditions has been used in the

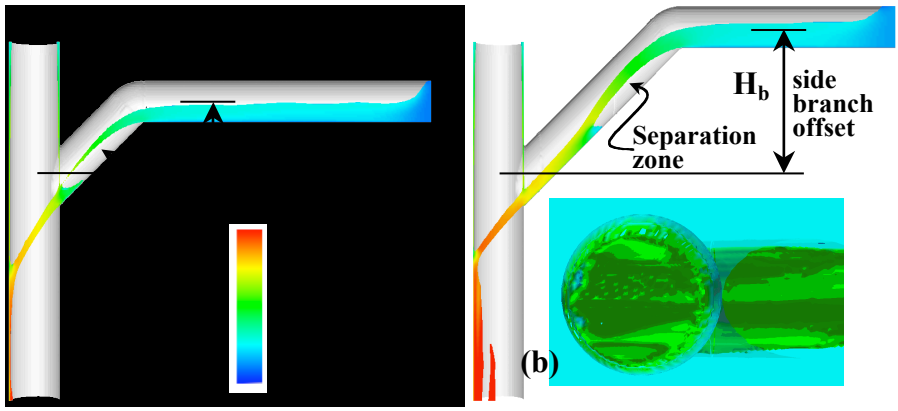

Figure 8 –Main flow activities in the stack with a 45° angled junction having an offset of (a) H_b/D_b=1.3 and (b) H_b/D_b=3.12 for Q_m/Q_b=2.7/2.5.

simulations. This model allows a conduit flow inlet at the main stack border whereas it possesses a full flow entry at the side branch border. A set of simulation results is presented in Figure 8 corresponding to the flow condition of Q_m/Q_b = 2.7/2.5. The coloring of the flowing water corresponds to the speed of the flow in the piping. In Figure 8, the side view of the steady state flow at the mid-cross-section of the side branch junction for an 45° angled entry having an offset ratio of H_b/D_b=1.3 and 3.12 are displayed. Both pictures indicate that the flow entering the side branch settles first in the horizontal part of the branch and then it is accelerated into the angled portion from which it enters into the junction and merges with the conduit flow. Due to the combined effect of relatively strong acceleration and the 45° slope of the junction pipe, the flow is separated from the turning corner of the side branch as it flows over the corner. Although the separation zone is clearly apparent in both cases given in Figure 8, a slightly larger zone which is extending into the junction is observed in the picture corresponding to H_b/D_b=1.3. The reattachment of the separation zone is hardly detected in this case meaning that the unsteady separated flow activities are directly coupled with the main stack flow near the junction region. The occurrence of such a coupling enhances the unsteady pressure fluctuations and result in higher seal losses in this particular case.

A direct mixing of the separation zone with the junction flow is not observed in the simulation picture corresponding to the offset case of H_b/D_b=3.12 in Figure 8(b). The relatively long junction pipe causes the reattachment of the separated flow to the pipe wall in this case and allows the flow to settle back to a relatively stationary pipe flow. The lack of a direct coupling of the separation zone with the main stack flow results in occurrence of less unsteady flow activities and hence weaker pressure pulsations resulting in lower seal losses. This finding is in comply with the previous examinations presented in section 3.2.

4. Conclusions

This paper investigates the effect of the most relevant geometrical and flow related parameters on seal loss from traps implemented on a single stack discharge piping containing a side branch connection. It has been shown that the experimental methodology utilized in this study in order to collect data and analyse the results conforms very well with those provided in the literature. This study particularly attempts to examine the effect of side branch offset and main stack to side branch flow ratio on the seal loss. A dependency of seal loss on these parameters can be clearly displayed through the results of the experiments carried out in this study.

The investigation of these parameters is very important since they are not included extensively under the regulating standards. It is assumed that the results obtained in this study can be used in connection with those of similar studies in the literature as a reference to define the geometrical constraints and flow ranges for optimal junction configuration which are not provided in the standards.

The experimental measurements carried out in this study can be supported by the results of computational fluid dynamic simulations which is capable of enlightening many features of complicated flow activities related to these measurements.

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6 Presentation of Authors

Dr. Abdullah Öngören is working at Geberit International A.G. (Switzerland) in the department of Sanitary and Construction Technics where he is involved in research and development of sanitary equipment, and rain and waste water drainage systems. He is specialised in flow induced vibration and noise and CFD applications in sanitary equipment and systems.

Dr. Ralf Materna is the head of Technology Department at Geberit International A.G. (Switzerland) where he has been involved in many projects related to sanitary and construction technologies. His special interests are in the field of building physics with main focus on acoustics in sanitary applications as well as hydraulics of waste water and syphonic drainage systems.

Mr. Markus Tanner is working at Geberit International AG in the department of Sanitary and Construction Technics as the head of the Sanitary Engineering Laboratory. He is specialized in mechanical building services with main focus on water supply, heating-, flushing- and waste water drainage systems.

Study on How to Improve the Capacity of a Drainage System with Air Admittance Valves

Koichi KAWASAKI(1), Masayuki OTSUKA(2),
Kazuhiro SHIGETA(3), Norihiro HONGO(4)
(1) k-kawasaki@kitz.co.jp, KITZ Corporation, JAPAN
(2) dmotsuka@kanto-gakuin.ac.jp, Prof.
(3) m0443015@kanto-gakuin.ac.jp
Dep. of Architecture, College of Engineering, Kanto Gakuin University, JAPAN
(4) hongou@astro.yamagata-cit.ac.jp ,Lect.
Dep. of Architectural Environment System Engineering, Yamagata College of Industry and Technology, JAPAN

Abstract

The experiments reported in this paper was aimed to practically study how to attenuate the positive pressure often observed on the drainage system installed with air admittance valves in apartment houses. Air admittance valves are known effective generally for air intake, due to its structural design. However, where several of them are installed on horizontal drain branches, air intake volume will become too much and cause an excessively high positive pressure to the lower floors of a building, often breaking the seal water. In this report, loading both the steady drainage flow and the sanitary fixture drainage flow are studied for comparison to know the effect of horizontal branch vent system. Reportedly positive pressure attenuators are introduced in a few countries. A structural model of our newly developed positive pressure attenuator has been tested to find how it can be practically meaningful in drainage systems of apartment house buildings.

Keywords

Drainage system; air admittance valve (AAV); horizontal branch system; positive pressure attenuator (PPA)

1 Introduction

In Japan, air admittance valves (AAVs in brief below) used for interior drainage systems of buildings are usually mounted on top of stack vent pipes. The negative

pressure caused by sanitary fixture drainage is moderated by the air taken through an AAV mounted on top of a stack vent pipe to prevent seal water break. AAVs designed to prevent emission of bad smelling gas from drain pipes may be mounted onto a horizontal drain branch on every floor of a building. Such a drainage system may attenuate the negative pressure of each floor and help improve the capacity of the drainage system, while eliminating the need of installation of vertical vent pipes.

One problem, however, is that installation of several vent valves results in an excessive air intake and causes a considerable vent resistance to lower levels of a building. And this generates an excessive positive pressure and breaks the seal water. We have tried several laboratory tests to quantitatively evaluate the effect of the horizontal branch vent system, deploying AAVs and a proto-type positive pressure attenuator (PPA in brief below), to moderate an excessive positive pressure caused to lower levels of a building.

Our laboratory tests were done specifically for the following objectives:

1. Observing pressure fluctuation within pipes of horizontal vent branch systems;

   AAVs were mounted onto the ends of horizontal drain branches and drainages of a steady flow rate were loaded, to evaluate its drainage capacity.

2. Evaluation of the effect of our positive pressure attenuator (PPA);

   A structural model of our PPA was installed to the above horizontal vent branch system and drainages of a steady flow rate was loaded to the system. Also sanitary fixture drainages were loaded. And both test results were evaluated to know the effect of our new positive pressure attenuation device.

2 Outline of experiments

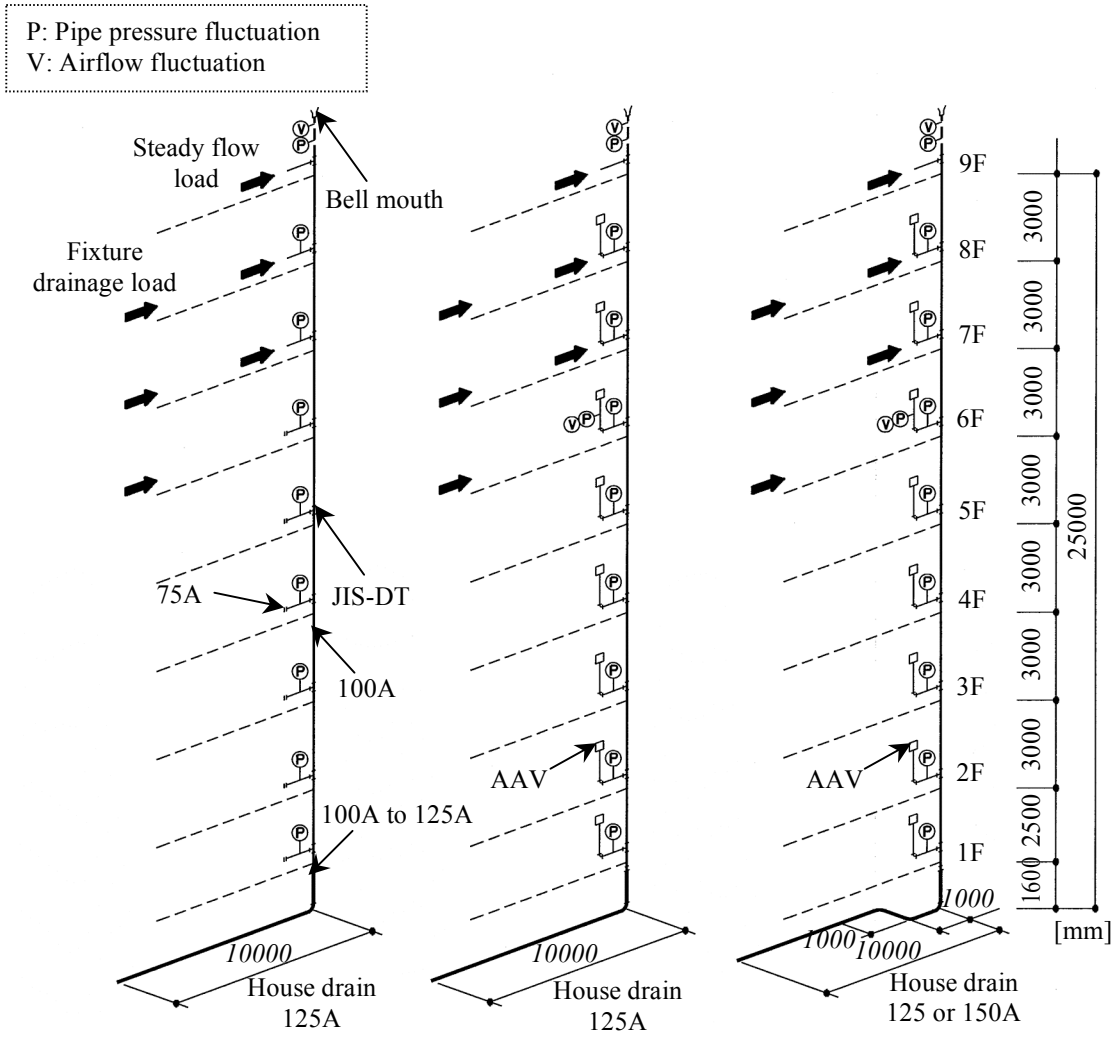
2.1 Drainage load experiments

2.1.1 Tested horizontal branch vent systems

Our experiments were done for the concepts of three stack drainage systems with 100mm piping diameter shown in **Fig.1**. Diameters of main house drain pipes were 125A with straight piping, and 125A or 150A (146mm actual inside diameter) with bent piping. Stack vent system without horizontal vent branch is identified as Basic System A-1, while the systems with an AAV installed onto the end of a horizontal drain branch of every floor, except the top floor, are identified as Modified Horizontal Vent Branch System or merely Modified System B-1, B-2 and B-3, which are shown in the lowest column of **Table 1**.

Nominal diameters of AAVs were 40A, 50A, 65A and 75A, and tested horizontal vent branch systems were provided with one particular size of AAVs selected among them for all floors. A main house drainage system with bent piping was provided with 1m straight pipe and 1m horizontal bent pipe to intentionally test more stringent service conditions than those specified in SHASE-S 206-2000. They are identified as Modified

System B-2 for 125mm diameter piping, or Modified System B-3 for 150mm diameter piping in **Table 1**. Detail of a horizontal drain branch installed on the 6th floor is shown in **Fig.2**. For horizontal vent branch systems, AAVs were installed on all floors except the top floor.



(1) Basic system (A-1) **(2) Modified system (B-1)** **(3) Modified system (B-2 and B-3)**

Figure 1 – Tested drainage stack systems

Table 1 – Tested drainage stack systems

House drain piping	Straight piping	Bent piping	
House drain size	125 mm	125 mm	150 mm
With stack vent only	Basic system **A-1**		
With vent branch	Modified system **B-1**	Modified system **B-2**	Modified system **B-3**

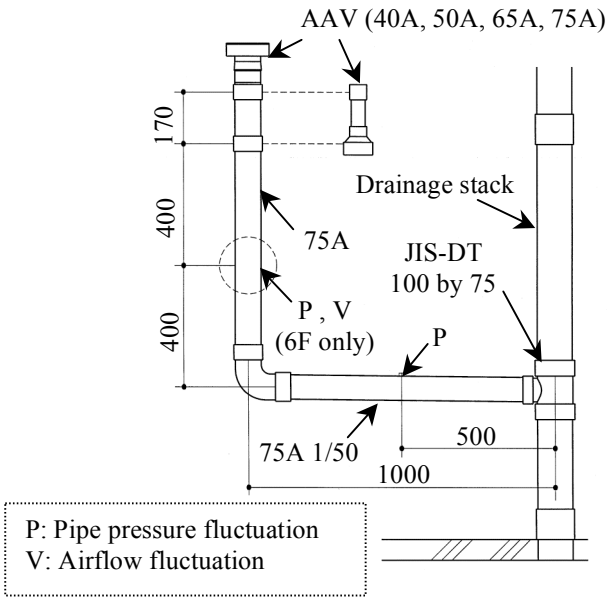


Figure 2 – The detail of a horizontal drain branch

2.1.2 Method of test drainage loading

Steady drainage loads and sanitary fixture drainage loads were tested. Steady loads were applied from the 9th, 8th and 7th floors by the steps specified in SHASE-S 218-1999 Test Methods. The total flow rates were minimum 1.0L/s. and maximum 7.0L/s. as shown in **Table 2**. Fixture loads were applied from water closets installed on the 8th, 7th and 6th floors; from one water closet, or two, or three at a time.

Table 2 – Test patterns of steady drainage loads

Load from each floor [L/s]			Total drainage flow Σ Qw [L/s]
9F	8F	7F	
1.0 – 2.5			1.0 – 2.5
1.0 – 2.5	1.0 – 2.5		3.0 – 5.0
1.0 – 2.5	1.0 – 2.5	1.0 – 2.0	5.5 – 7.0

According to SHASE-S 218 -1999

Fig.3 shows the water level fluctuation within a main house drain piping actually measured at typical apartment houses (Ref.4). As known from the data, it is practically usual that the system is simultaneously subjected to both nearly steady drainage flows discharged from bathroom fixtures and instantaneous drainage flows discharged from water closets. This practical condition was therefore added as our experiment item.

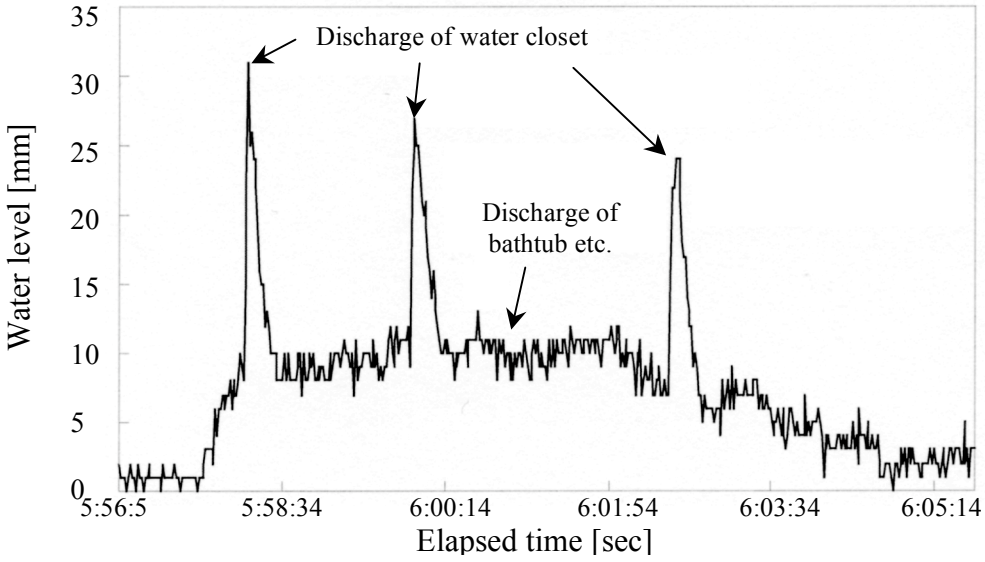


Figure 3 – Water level fluctuation in a main house drain piping of typical apartment houses

2.1.3 Evaluation of positive pressure attenuators (PPAs)

Modified horizontal vent branch system B-2 with bent piping was used for our experiment. For comparative performance tests, a proto-type sample of our PPA was installed on the horizontal drain branch of the lowest floor of a building, and then removed. Refer to **Fig.4** on the test facilities. The system was subjected to (1) steady drainage loads, (2) sanitary fixture drainage loads discharged from the water closets installed on the 8th, 7th and 6th floors, and (3) These steady and fixture drainage loads applied simultaneously [(1)+(2)]. A profile of the tested seal trap with 50mm deep seal water is also shown in **Fig.4**.

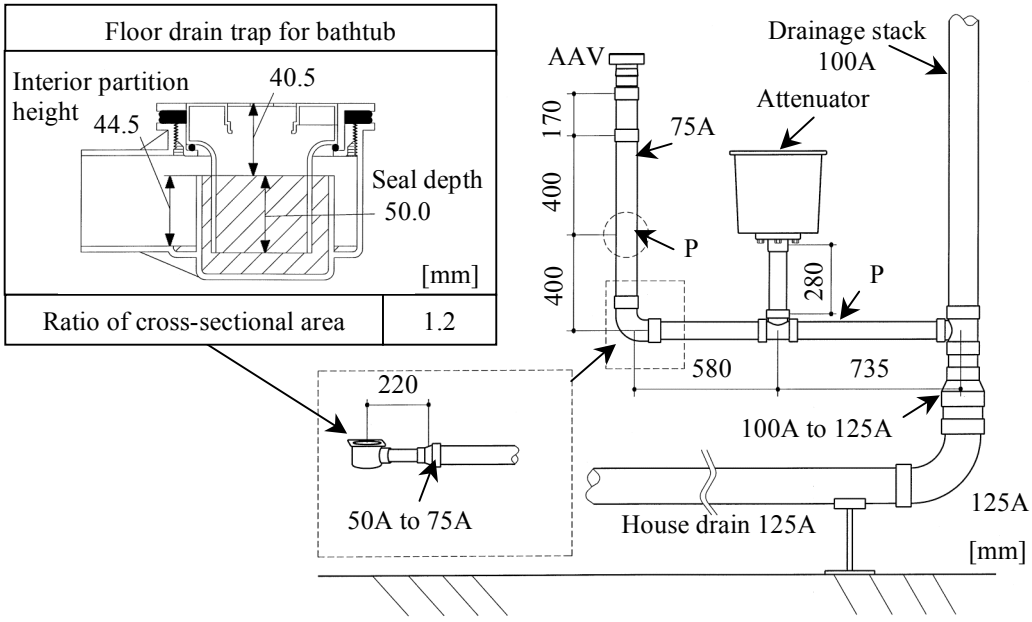


Figure 4 – Test facility with a positive pressure attenuator (PPA)

2.1.4 Measuring method

To measure fluctuation of the pressure within piping, a small pressure sensor was installed on the horizontal drain branch at a location 500mm away from the stack drain piping, according to SHASE-S 218-1999 requirement. To measure the vent velocity within piping, anemometers were installed on the top of stack vent piping and near the end of the horizontal drain branch of the 6th floor as shown in **Fig.2**. Measured wind velocities in the center of piping were converted to vent flow rates. For other floors where anemometers were not installed, the vent characteristics of horizontal drain branches and the pressure within piping were measured to calculate vent flow rates.

2.2 Vent characteristics of air admittance valves

Fig.5 shows the configuration of a test fixture prepared with the same structure as that of the horizontal drainage branch shown in **Fig.2**. This was used to measure the vent characteristics of a horizontal vent branch. Sucking the air through stack drain piping with a blower enabled us to examine the relationship between the pressure within horizontal drain branch piping and the averaged wind velocity within piping (vent flow rate) when an AAV was deployed. Measurement was carried out by change of vent flow rates, using orifice plates of various sizes or a flow control valve mounted in front of the blower.

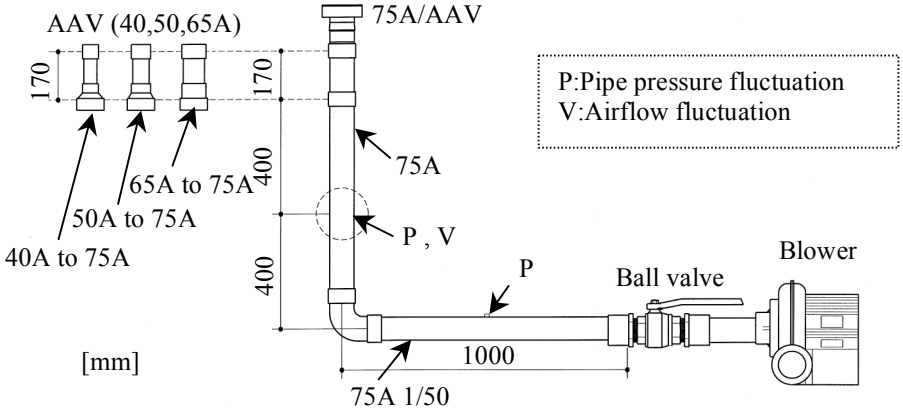


Figure 5 – Test model prepared for measurement of vent characteristics

3. Study of experiment results

3.1 Pressure fluctuation within horizontal vent branch systems

Fig.6 exhibits an example of compared pressure distributions of Basic System A-1, Modified System B-1 with straight piping, and another Modified System B-2 with bent piping. They were loaded with 5.0L/s drain, which was the total of 2.5L/s each steadily released from the 9th and 8th floors. Compared with Basic System A-1, Modified System B-1 showed efficient moderation of the negative pressure. In case of another Modified System B-2, however, the local resistance caused by bent piping generated the positive pressure on lower floors, exceeding +400Pa, which is the maximum pressure

allowed by SHASE-S 218-1999. As a result, seal break occurred momentarily on the lowest floor.

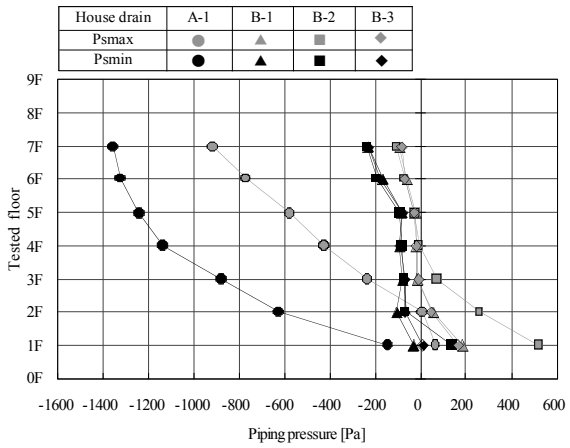


Figure 6 – Piping pressure distribution by tested floors

Fig.7 shows the relationship between the total flow rate of drain loads (Σ Qw), the highest positive pressure (Psmax) and the lowest negative pressure (Psmin), where 40A/AAVs were installed. When System B-1 and B-2 are compared, their lowest negative pressures fluctuate in almost the same pattern within -400Pa, the lowest limit. However, the highest positive pressure of System B-2 exceeds +400Pa, the highest limit, due to the local resistance caused by bent piping. While SHASE-S 206-2000 Plumbing Code of Japan sets 6.7L/s as the maximum allowable flow rate for conventional two-pipe systems, the drainage capacity of System B-1 was found over 7.0L/s, but that of System B-2 was found only 4.7L/s, which is mere 68% of the maximum level. Although this still exceeds 3.9L/s, the maximum allowable limit for conventional stack vent systems, its bent piping resistance apparently lowered the drainage capacity. Test of System B-3 resulted in recovery of the drainage capacity to over 7.0L/s, the same level as that of System B-1, due to the pipe diameter having been enlarged to 150mm. The highest positive pressure was also found as acceptable as +380Pa. The drainage capacities of these tested systems are summarized in **Table 3**.

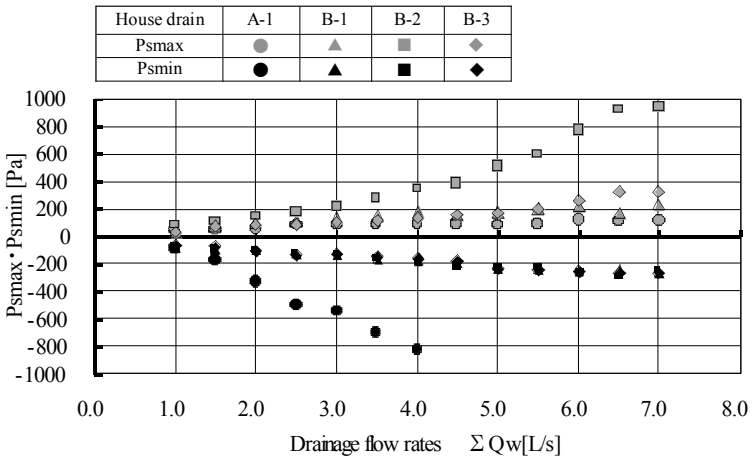


Figure 7 – Piping pressure fluctuation by total drainage flow rates (40A/AAV)

Table 3 – Compared drainage capacities

Piping system	(1) Drainage capacity [L/s]	(2)SHASE-S206 Maximum level [L/s]	(1)/(2) [%]
A-1	2.0	3.9	51
B-1	7.0	6.7	105
B-2	4.7		68
B-3	7.0		105

Our experiments resulted in finding the relationship between the vent flow rate (Qa) and the averaged piping pressure, as exhibited in **Fig.8**. Approximation formulas are also introduced here for each of differently sized AAVs installed on these horizontal vent branch systems. Negative pressures in the range of 0Pa to -300Pa were used as the data, to acquire as practical approximation formulas as possible, so that the total vent flow rates may be accurately predicted. The averaged vent flow rates (Qa) of all tested systems calculated according to these formulas are shown in **Fig.9**, to know the relationship with the drainage flow rates. In case of Modified System B-2, the provision of bent piping increased local vent resistance at the lower floors of the building. This made the vent flow rate for each drainage flow rate some 10% lower than that of Modified System B-1.

Marks	Local resistance	Approximation formulas	Coefficients of determination
◆	AAV-75	$Qa = -0.0012P^2 + 0.4631P - 12.89$	$R^2 = 0.92$
●	AAV-65	$Qa = -0.0011P^2 + 0.4689P - 14.619$	$R^2 = 0.92$
■	AAV-50	$Qa = -0.0003P^2 + 0.1585P - 2.9464$	$R^2 = 0.97$
▲	AAV-40	$Qa = -0.0002P^2 + 0.1195P - 2.1236$	$R^2 = 0.95$

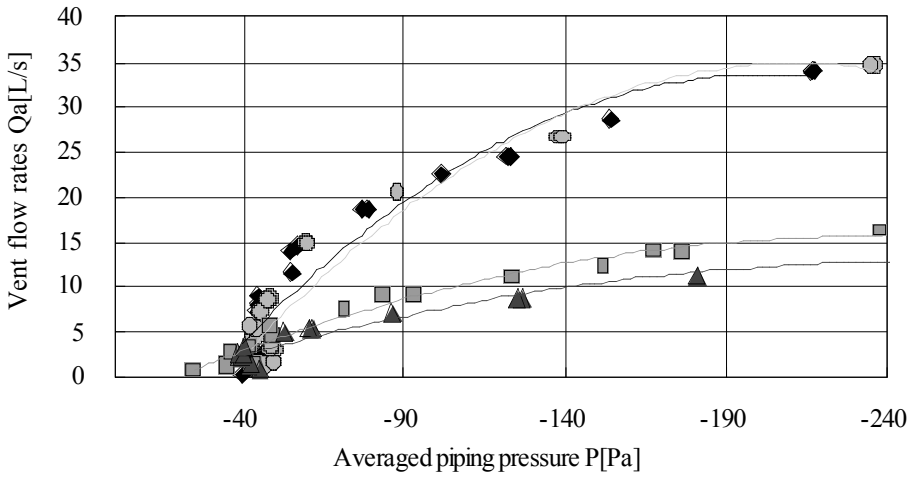


Figure 8 – Total vent flow rates by averaged piping pressure

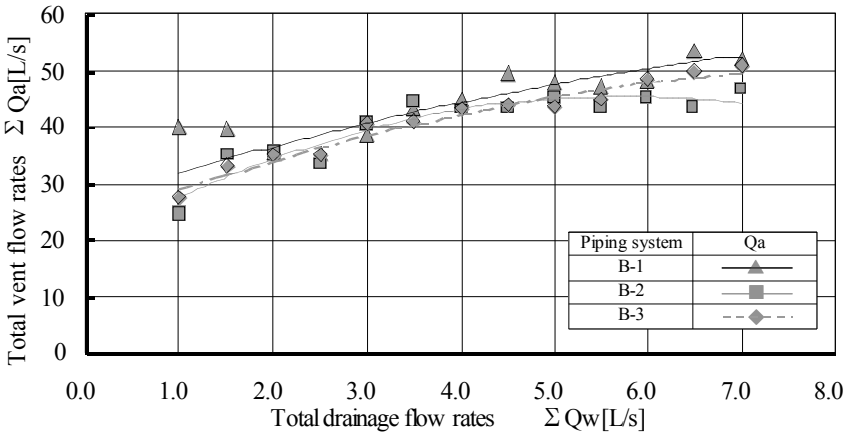


Figure 9 – Total vent flow rates by total drainage flow rates

3.2 Evaluating positive piping pressure attenuation

In **Fig.10**, piping pressure fluctuation waves of Modified System B-2 at the lowest floor are compared where the system is provided with or without a PPA. The system was loaded with a steady drainage flow of 4.0L/s. **Fig.11** shows how the piping pressure at the lowest floor varied, following increases of the total drainage flow rate. As verified with these data, the maximum and minimum piping pressure at the lowest floor were found moderated by means of a PPA, although the average pressure was found almost equal with or without PPA provision. This led us to an assumption that our PPA is quite effective to reduce an instantaneous rise of piping pressure.

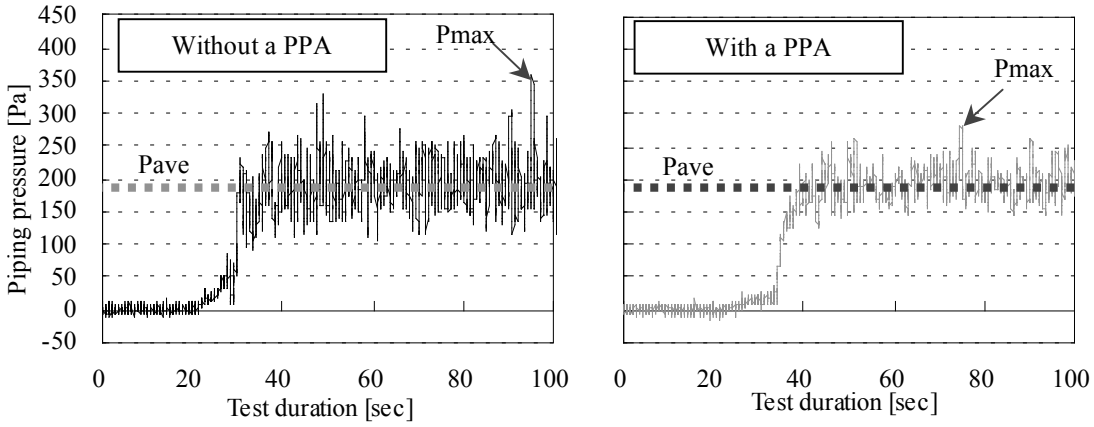


Figure 10 – Piping pressure fluctuation waves with steady drainage loads
(System B-2 installed with 75A/AAV on 1F: ∑Qw=4.0[L/s])

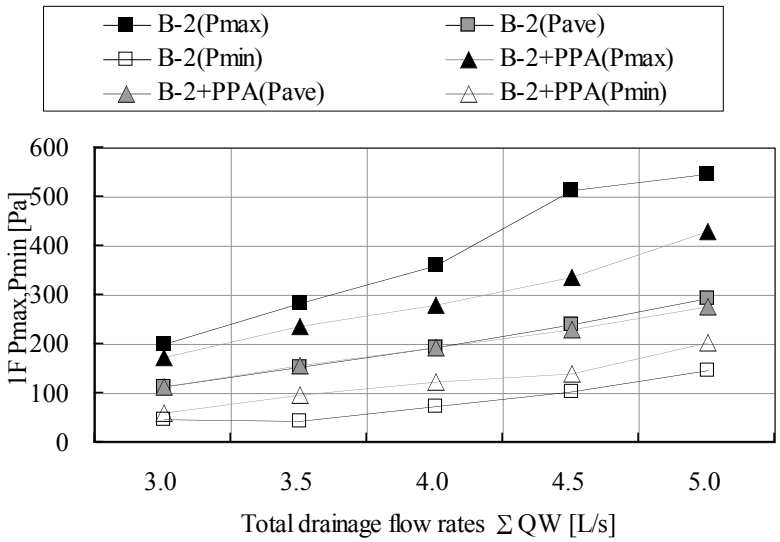


Figure 11 – 1st floor piping pressures against total drainage flow rates
(Average of two experiments measured)

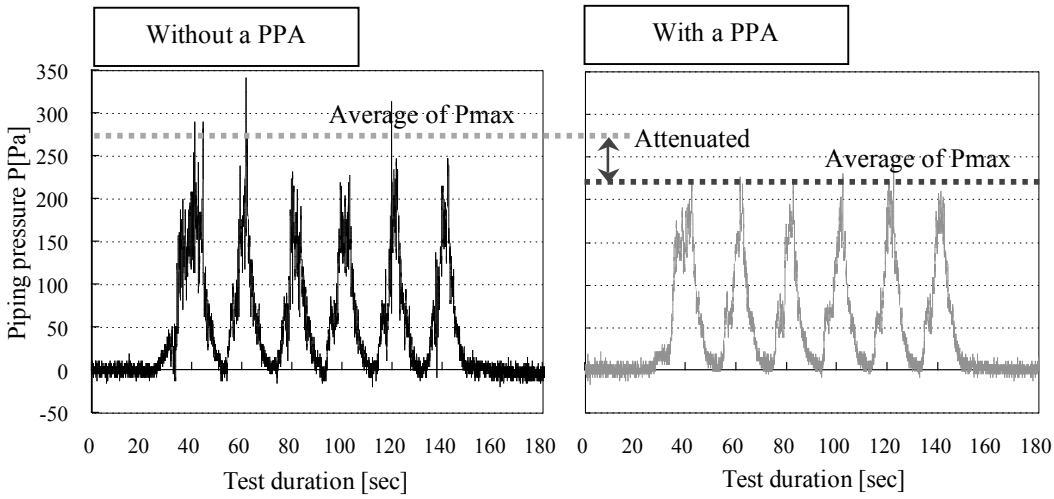


Figure 12 – Piping pressure fluctuation waves (Drainage load every 10 seconds)
(System B-2 installed with 75A/AAV on 1F:∑Qw=4.0[L/s])

Fig.12 shows compared piping pressure fluctuation waves measured on the lowest floor, when the test system was subjected to steady drainage flows every 10 seconds intermittently, with or without PPA provision. Valves mounted on higher floors to generate the drainage flow were controlled to vary the flow rate to simulate the practical condition where the system would be additionally subjected to sanitary fixture drainage load at the same time. Our finding was that the average piping pressure on the lowest floor could be moderated from +275Pa down to +225Pa under the total flow rate of 4.0L/s.

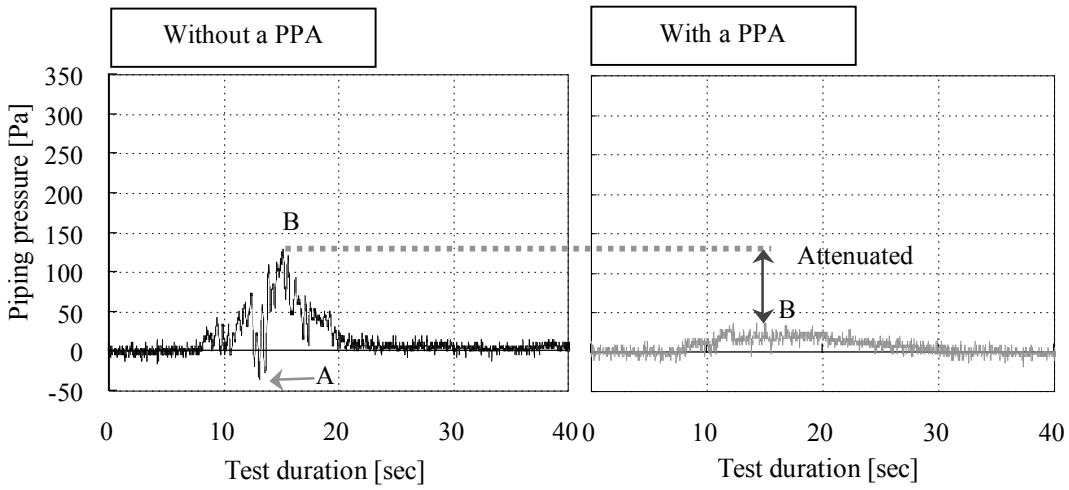


Figure 13 – Piping pressure fluctuation waves with drainage loads from 3 water closet
(System B-2 installed with 75A/AAV on 1F)

Fig.13 shows piping pressure fluctuation waves caused by drainage loads discharged from 3 water closets. Without PPA provision, piping pressure became instantaneously negative at Point A, and then became positive at Point B a few seconds later. With PPA provision, it was moderated by 100Pa, a remarkable effect of pressure attenuation. In a case of 8 floor building, it is reported that simultaneous fixture drainage occurs on two floors (Ref.4). Although simultaneous drainage loaded from 3 water closets seems very stringent, this test result verified that piping pressure could be controlled within +400Pa, the acceptance criteria, with zero seal loss.

In general, a drainage flow of bathroom fixtures needs longer discharge time with lower flow rate, while that of water closets takes much shorter discharge time with an instantaneously higher flow rate. **Fig.14** shows the result of tests where these two types of drainage flows were combined in simulation of a practical condition of typical apartment house buildings. Without PPA provision, piping pressure was measured +1785Pa with 25mm seal loss at Point B. PPA provision could moderate it down to +628Pa with almost zero seal loss, at the same point.

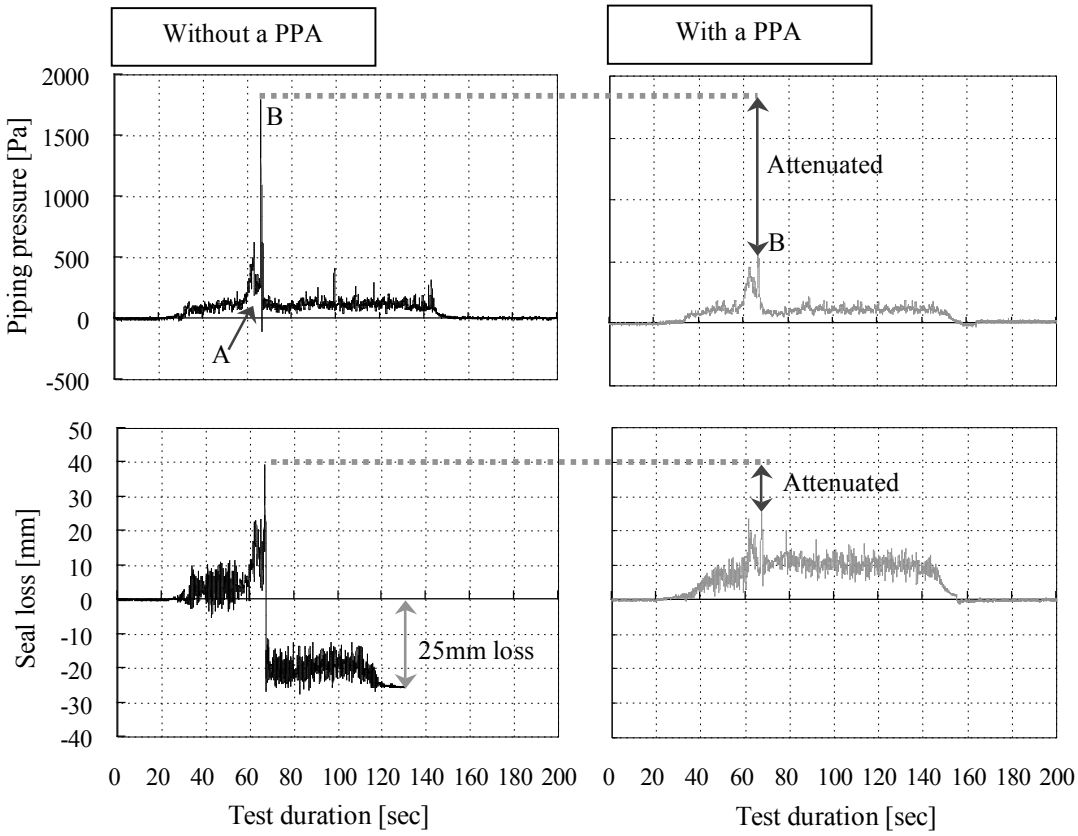
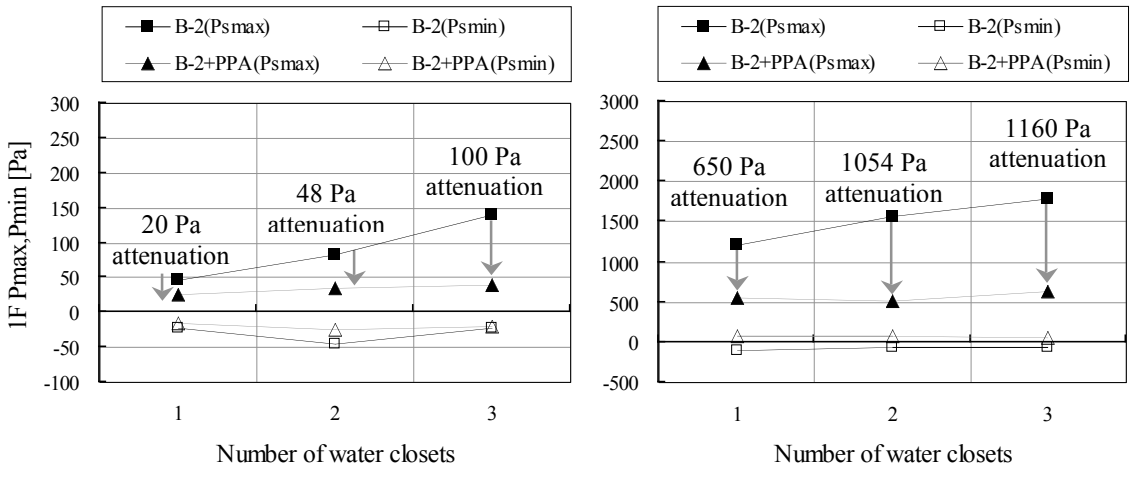


Figure 14 –Piping pressure fluctuation waves and seal loss waves
[Steady drainage flow + 3 fixture drainage flows]
(System B-2 installed with 75A/AAV on 1F)



(1) Fixture discharge load (2) Steady load + fixture discharge load

Figure 15 – Compared piping pressures on 1F
(System B-2 installed with 75A/AAV on 1F)

As shown in **Fig.15**, the highest and lowest piping pressure were measured on the lowest floor where drainage system was subjected, first to the fixture drainage load only, and then to the steady drainage load plus the fixture load, using different number of water closets, either one, two or three at the same time. PPA provision could moderate the highest pressure by 20Pa, 48Pa and 100Pa, depending on the number of the water closet. With PPA provision, where the steady load and the fixture load were applied simultaneously, the pressure moderation was as significant as 650Pa, 1054Pa and 1160Pa, depending on the number of the water closet.

Fig.16 indicates the percentage of piping pressure moderation facilitated by PPA provision. In case of the fixture drainage load only, attenuation rate was 45%, 58% and 72% respectively, with one, two or three water closets used to discharge the flow. Where 2.5L/s steady flow and the fixture flows were combined, attenuation rate varied between 54% and 67%, depending on the number of water closets used.

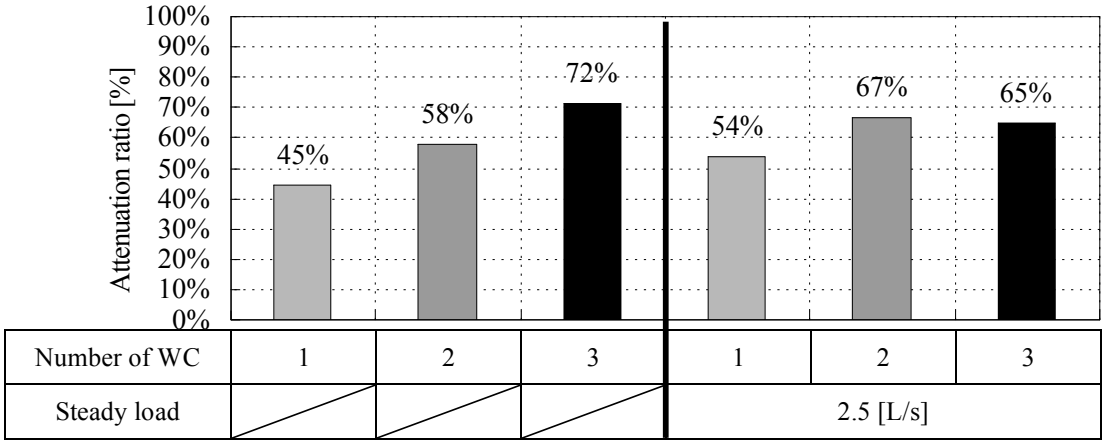


Figure 16 – Compared pressure attenuation rates (1F)
(System B-2 installed with 75A/AAV on 1F)

4 Summary

As the results of these experiments, we could understand the basic characteristics of drainage systems installed in high-rise buildings with a provision of AAVs. We could also conclude that installation of a positive pressure attenuator (PPA) is recommended to safely handle instantaneous pressure fluctuation caused by drainage loads released from water closets in apartment houses. On the other hand, the practical effect of the pressure attenuators to safely handle steady drainage flows could not be verified by the conventional test method. This discrepancy remains a subject to be studied in the future.

Acknowledgements

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Personal Data of the Authors

Koichi Kawasaki is an engineer of Product Development Department, KITZ Corporation, Japan. He is a member of SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His assignments at KITZ Corporation include development of plumbing products for residential buildings.

Masayuki Otsuka is a professor at Department of Architectural Environmental Engineering, Kanto Gakuin University. He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan). His current research interests are performance evaluation of plumbing systems, drainage systems with food waste disposers in high-rise apartment houses and drainage piping system for SI (Support and Infill) housings.

Kazuhiro Shigeta is a graduate student (Second year master's course) of Graduate School of Architectural Engineering Department, Kanto Gakuin University. He conducts researches on performance evaluation of drainage systems for SI housings.

Norihiro Hongo is a lecturer at Department of Architectural Environment System Engineering, Yamagata College of Industry and Technology. His current research interests are trap seals by ventilation position of horizontal drain branch for drainage system.

Modelling the impact of a sealed building drainage and vent system on the propagation of air pressure transients

J.A. Swaffield
j.a.swaffield@hw.ac.uk
Drainage Research Group, School of the Built Environment, Heriot Watt University, Edinburgh, Scotland.

Abstract

Air pressure transient propagation has been of concern to drainage designers due the possibility of trap seal depletion. The development of active control strategies provide modern solutions beyond the traditional passive vent system approach, while the development of numerical modeling simulations of transient propagation within complex networks has both supported and initiated advances in active control design and application. Active control allows consideration to be given to sealing a building for both design and security reasons. Simulations will be presented to demonstrate that trap seal retention within complex networks without the traditional roof penetration and open stack termination above the roof line.

Keywords

Air pressure transients, trap seal depletion, active control, sealed buildings.

1. Introduction – air pressure transient control and suppression

Air pressure transients generated within building drainage and vent systems as a natural consequence of system operation may lead to trap seal depletion and cross contamination of habitable space[(1)]. Traditional modes of trap seal protection, based on the Victorian engineer's obsession with odour exclusion[(2)], depend predominantly on passive solutions where reliance is placed on cross connections and vertical stacks vented to atmosphere[(3)]. This approach, while both proven and traditional, has inherent weaknesses, including the remoteness of the vent terminations delaying the arrival of relieving reflections, and the multiplicity of open roof level stack terminations inherent within complex buildings. The complexity of the vent system required also has significant cost and space implications.

The use of air admittance valves (AAV) and variable volume containment devices, or positive air pressure attenuators (PAPA), allow the designer to alleviate both the negative and positive transients generated by random appliance discharges. Active control responds to local pressure conditions by allowing a relief air inflow as pressure drops or absorbing diverted flows as pressure rises to limit the pressure excursions at the trap[4].

The introduction of active air pressure transient control and suppression has implications for both 'standard' buildings and those requiring particular attention to be paid to the security implications of multiple roof level open stack terminations, allowing consideration of a fully sealed building drainage and vent system. It allows for localized intervention to protect trap seals from both positive and negative pressure excursions and has distinct advantages over the traditional passive approach. The time delay prior to the return of a relieving reflection from a vent open to atmosphere is removed and the effect of the transient on all the other system traps passed during its propagation is avoided.

2. Mathematical basis for the simulation of transient propagation in multi-stack building drainage networks

Air pressure transient propagation within building drainage systems may be defined by the St Venant equations of continuity and momentum, solvable via a finite difference scheme utilizing the method of characteristics. Air pressure transients are propagated due to air entrainment by the falling annular water film in the vertical stack and by transient reflection and transmission at the system boundaries, e.g. open terminations, sewer connections, trap seals and AAV and PAPA devices. The simulation[5] calculates air pressure, velocity and wave speed throughout a network at intervals, typically 0.001 seconds and 300 mm, to predict trap seal oscillations, record the operation of active control devices and identify system failures. While the simulation has been extensively validated, its use to independently confirm the mechanism of SARS virus spread within the Amoy Gardens outbreak in 2003 has provided further confidence in its predictions[6].

Transient propagation depends on the rate of change of system conditions. Increasing annular downflow increases the entrained airflow and lowers system pressure. Retarding entrained airflow generates positive transients. External events may also propagate transients into the network. The annular water flow in the 'wet' stack entrains an airflow due to the 'no slip' condition between the water film and the air core. Pressure falls from atmospheric above the stack entry due to friction and local losses as air flow passes through the water curtains at discharging branch junctions. In the lower wet stack the pressure recovers to above atmospheric due to the traction forces exerted on the airflow prior to falling across the water curtain at the stack base.

The application of the method of characteristics to unsteady flow analysis dates from the 1960s[7]. Relationships, Jack[8], allow the simulation of the traction force exerted on the entrained air via an experimentally defined 'pseudo-friction factor' applicable in the wet stack and operable across the annular waterflow / entrained air core interface. This allows

combined discharge flows and their effect on air entrainment to be modelled. The airflow entrained in the lower levels of the wet stack may exceed that appropriate to the water flows present at upper levels, however the variable friction factor allows the lower level annular flow to provide airflow entrainment and hence a rising air pressure while in the upper levels this air is effectively drawn down past a slower moving water film that impedes its entrainment, and leads to an observed reduction in air core pressure.

Air pressure transient propagation in drainage systems is defined by the St Venant equations of continuity and momentum[5], a pair of quasi-linear hyperbolic partial differential equations amenable to finite difference solution via the Method of Characteristics[7]. Equations 1 to 4 link conditions at a node one time step in the future to current conditions at adjacent upstream and downstream nodes, Figure 1.

For the C^+ characteristic : $$u_P - u_R + \frac{2}{\gamma - 1}\left(c_P - c_R\right) + 4 f_R u_R |u_R| \frac{\Delta t}{2D} = 0 \quad (1)$$

when $$\frac{dx}{dt} = u + c \quad (2)$$

and the C^- characteristic : $$u_P - u_S - \frac{2}{\gamma - 1}\left(c_P - c_S\right) + 4 f_S u_S |u_S| \frac{\Delta t}{2D} = 0 \quad (3)$$

when $$\frac{dx}{dt} = u - c \quad (4)$$

where the wave speed c is given by $c = (\gamma p/\rho)^{0.5}$ (5)

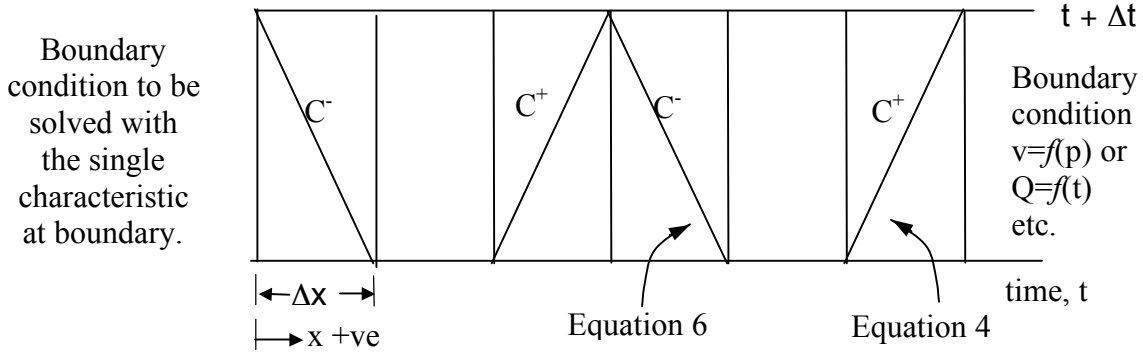

Figure 1 - St Venant equations of continuity and momentum allow airflow velocity and wave speed to be predicted. Note Δx<1.0 m, Δt < 0.003s

In the dry stack f_R and f_S are determined from the Colebrook White relationship, however in the wet stack f_R and f_S are functions of time, location and annular water downflow and hence act as drivers in the simulation by generating the entrained air flow within the stack[8]. Local pressure is subsequently determined as

$$p_{local} = [\,(p_{atm} / \rho_{atm})\ (\gamma / c^2_{local})^{\gamma}\,]^{1/(1-\gamma)} \quad (6)$$

Figure 1 implies that only one St Venant characteristic exists at a boundary, so equations linking airflow to applied water flow or other system parameters are necessary at each pipe termination. These boundary conditions determine transient transmission and reflection within the network and may be determined by local conditions, e.g. the AAV opening and subsequent loss coefficient depends on the local line pressure prediction.

Boundary conditions may be categorised as active or passive – active boundaries depend on local conditions while passive boundaries depend on system specification. The relief of negative pressures is traditionally provided by vent connections to atmosphere – a passive solution. Active control would be an AAV that opened in response to local line pressure. Appliance trap seal oscillation is an active boundary condition dependent on local pressure where the deflection of the trap seal may allow an airpath to, or from, the appliance or may lead to column oscillation and possible water seal loss alone. The variable volume flexible bag containment device or PAPA is an active boundary condition where the 'bag' is held deflated by the suction pressure in the stack. Rising pressure due to the arrival of a positive transient causes the bag to open and partially inflate. Once fully inflated the bag acts as a pressurized boundary obeying the Gas Laws.

2.1. Role of diversity in system operation.

In complex building drainage networks the operation of the system appliances, and hence the conditions necessary for air entrainment and pressure transient propagation, are entirely random. No two systems will be identical in terms of their usage at any time. This diversity of operation implies that inter-stack venting paths would be established if the individual stacks within a complex building network were themselves interconnected. This diversity would provide venting and allows serious consideration to be given to sealed drainage systems. The stack interconnections required would be within that sector of the system that would be normally described as the dry stack region.

To implement a sealed building drainage and vent system it would be necessary for negative transients to be alleviated by drawing air into the network from a secure internal space, and not from the external atmosphere, via air admittance valves local to appliances or at a predetermined location within the building, for example an accessible loft space.

Positive air pressure transients would be controlled by PAPA devices mounted within the building. It might be considered that this would be problematic as positive pressure could build within the PAPA installations and therefore negate their ability to absorb transient airflows. However, linking the vertical stacks in a complex building and utilizing the diversity of use inherent in building drainage systems will ensure that PAPA pressures are themselves alleviated by allowing trapped air to vent through the interconnected stacks to the sewer network.
Diversity also protects the proposed sealed system from sewer driven overpressure and positive transients. A complex building will be interconnected to the main sewer network via a number of connecting smaller bore drains. Adverse pressure conditions will be distributed and the network interconnection will continue to provide venting routes.

These concepts will be demonstrated by a multi-stack network subjected to both appliance discharge driven and imposed sewer transients.

3. Simulation of a multi-stack sealed building drainage system.

Figure 2 illustrates a four-stack network linked at high level by a manifold PAPA and AAV installation. Water downflow in any stack generates negative transients that deflate the PAPA and open the AAV to provide an airflow into the network and out to the sewer system. Positive pressure generated by either stack surcharge or sewer transients are attenuated by the PAPA and by the diversity of use that allows one stack to sewer route to act as a relief path for the other stacks. The network has an overall height of 12 m. The pressure transients generated will propagate at the acoustic velocity in air, 320 m/s, so the system pipe periods are 0.08 and 0.15 seconds from stack base to PAPA or stack base to stack base. To simplify the simulation no local trap seal protection is included. Traditional networks would include passive venting where separate vent stacks connect to atmosphere, however a sealed building would dispense with this venting arrangement.

The four sewer connections to separate collection drains allow diversity in the sewer network to aid system self venting. In a complex building this would be the norm. The network shown is meant to be representative and the simulation will allow the following appliance discharge and sewer imposed transient conditions to be investigated -

1. Simultaneous w.c. discharges to stacks 1 to 3 over a period 1 to 7 seconds and a separate w.c. discharge to stack 4 between 2 and 8 seconds,

2. a minimum water flow of 0.1 *l* / s continues in each stack throughout the simulation to represent trailing water following earlier multiple appliance discharges,

3. a one second duration stack base surcharge occurs in stack 1 from 2.5 seconds,

4. sequential sewer pressures are imposed at the base of each stack for 1.5 seconds from 12 to 18 seconds.

The simulation will demonstrate the efficacy of active control and inter-stack venting in enabling the system to operate with no vent stack open to atmosphere outside the building envelope. The water flows are representative of current w.c. characteristics while the imposed sewer transients are not excessive, Table 1. System heights are measured positive upwards from the stack base so entrained airflow down the stack is negative. Airflow entering the network via an AAV and exiting to the sewer will be negative, while airflow entering the network from the sewer connection or induced to flow up any stack will be positive, as will water downflow in a vertical stack.

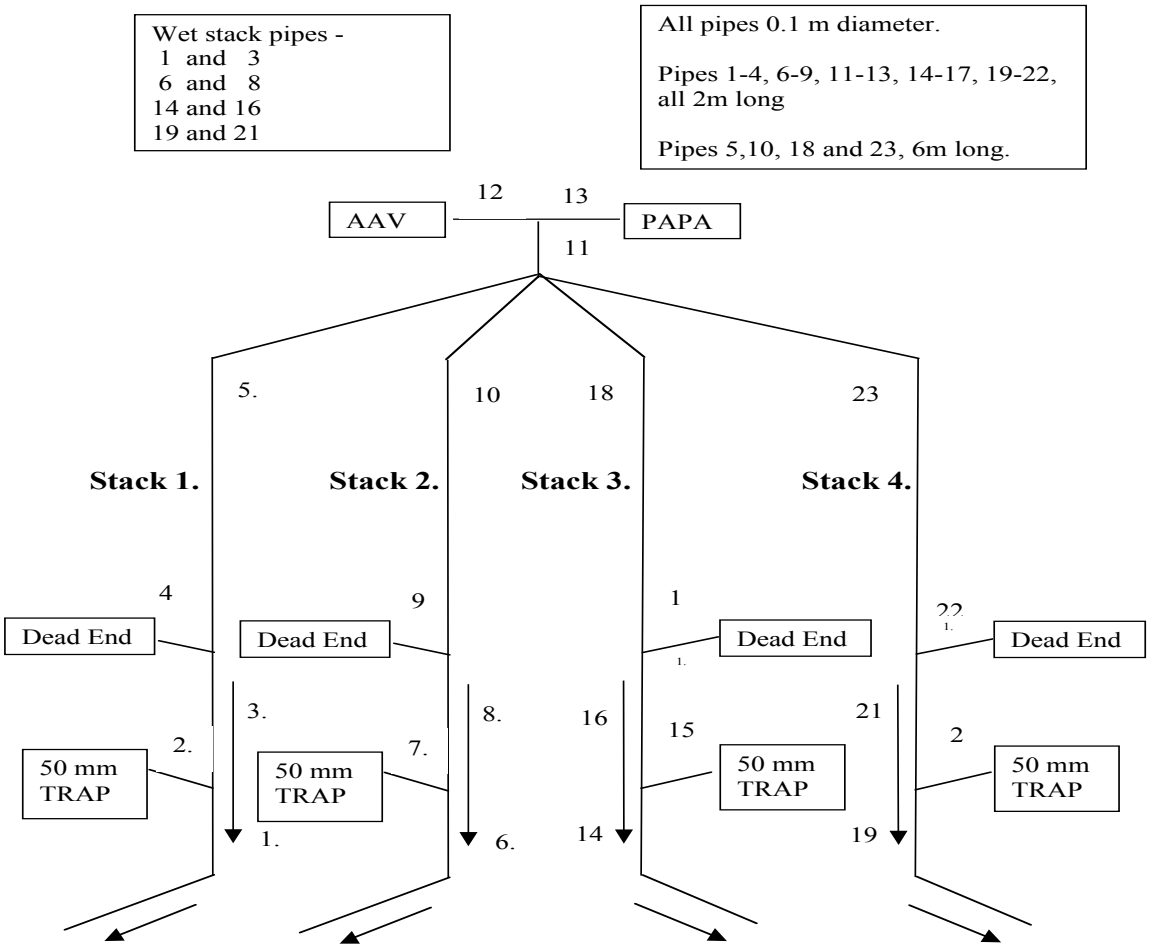

Figure 2 - Four stack building drainage and vent system to demonstrate the viability of a sealed building system.

Table 1 - Applied water downflow and imposed stack base sewer pressures

Time seconds.	Start time	+2	+4	+6
W.c. discharge flow, litre/s.	0.0	2.0	2.0	0.0
Time seconds.	Start time	+0.5	+0.5	+0.5
Applied sewer pressure, mm water gauge.	0.0	30.0	30.0	0.0

3.1 Water discharge to the network.

Simultaneous w.c. discharges result in entrained airflows down pipes 1, 6 and 14. The induced airflow in pipe 19 flows upwards from the sewer as the suction pressure in pipes 1, 6 and 14 is sufficient to overcome the traction effect of the trickle water flow in Pipe 19. This contributes to the entrained airflow demand in pipes 1, 6 and 14. The AAV on pipe 12 only contributes a small proportion of the required airflow as the pipe 19 path has a lower loss; the AAV flutters in response to local pressure conditions, Figure 3.

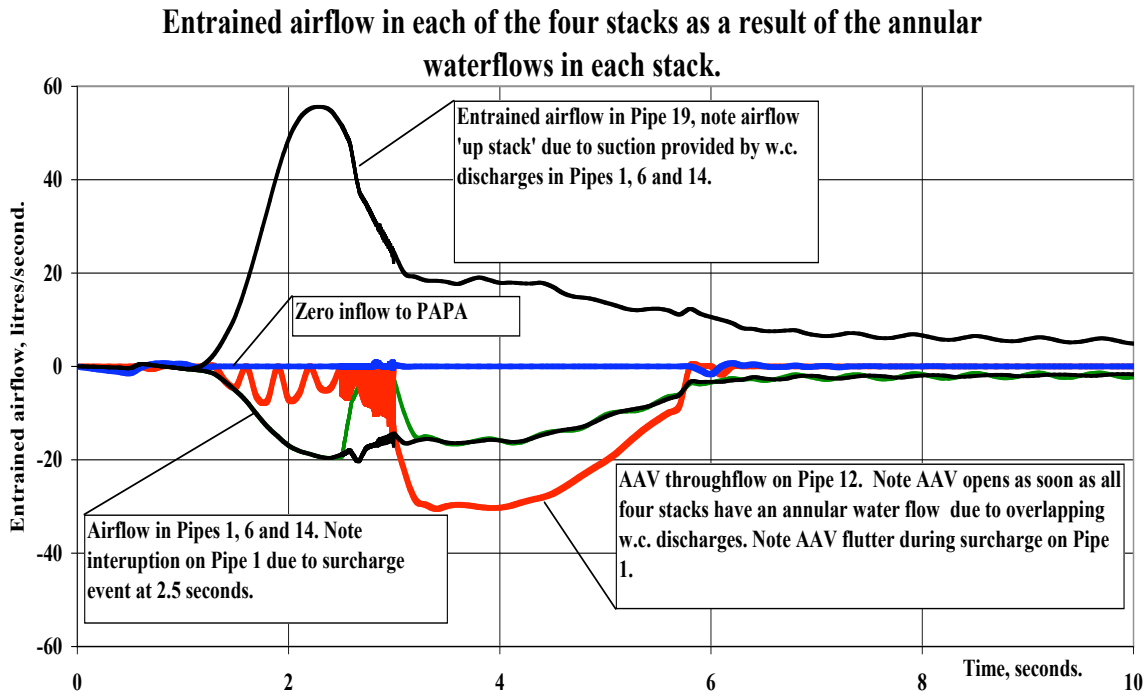

Figure 3 - Entrained airflows during appliance discharge

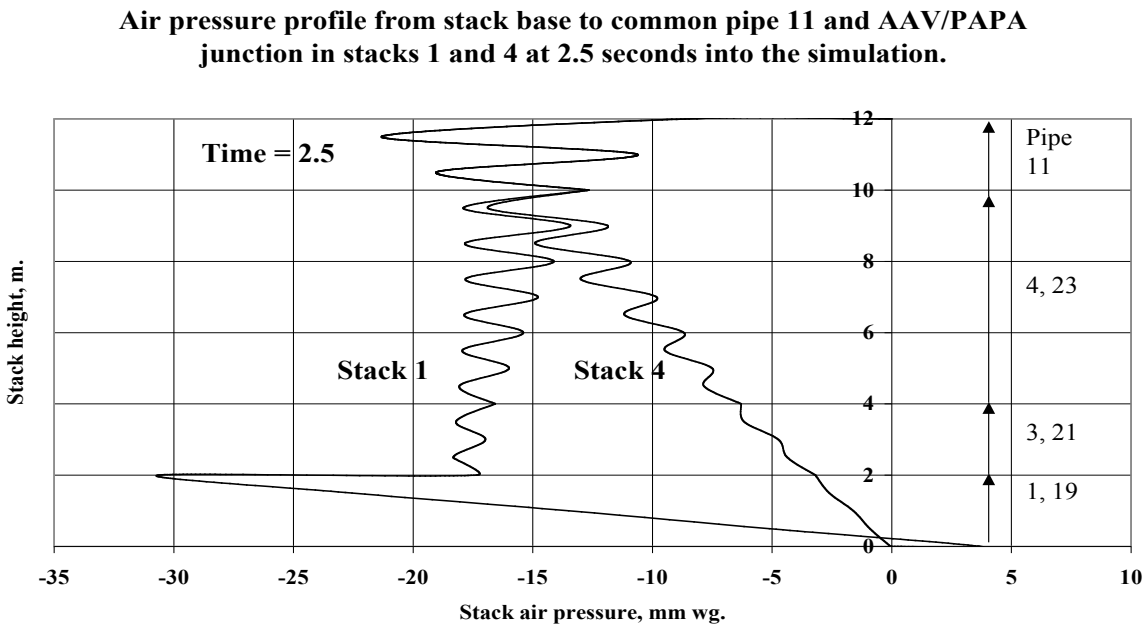

Figure 4 - Air pressure profile in Stacks 1 and 4 illustrating the pressure gradient driving the reversed airflow in pipe 19

Subsequent w.c. discharge to stack 4 provides water downflow in pipe 19 from 2 seconds onwards. The reversed airflow diminishes due to the traction applied by the falling water film in that pipe. As the water downflow in pipe 19 reaches its maximum value, from 3 seconds onwards, the AAV on pipe 12 opens fully, increasing the local inflow. AAV flutter is replaced by a fully open period from 3.5 to 5.5 seconds, however the airflow in pipe 19 remains slightly positive throughout. On completion of w.c. discharge the airflows attenuates due to the frictional resistance of the network, however as a 'trickle' flow continues in each stack the rate of attenuation of the entrained airflows is low.

Figure 4 illustrates the air pressure profile from the stack base in both stacks 1 and 4 at 2.5 seconds into the simulation. The air pressure in stack 4 demonstrates a pressure gradient compatible with the reversed airflow mentioned above. The air pressure profile in stack 1 is typical for a stack carrying an annular water downflow and demonstrates the establishment of a positive backpressure due to the water curtain at the base of the stack.

3.2 Surcharge at base of stack 1, pipe 1

A surcharge at the base of pipe 1 from 2.5 to 3 seconds reduces the entrained airflow to zero at the stack base, propagating a positive pressure transient up that stack, Figure 5. The predicted pressure at the base of pipes 1, 6 and 14 are positive as entrained air is forced through the stack base water curtain into the sewer. In pipe 19 the reversed airflow drawn into the stack results in a pressure drop as it traverses the water curtain. Figure 6 presents air pressures in the stack from 2.5 to 2.6 seconds, illustrating the propagation of the positive transient up the stack as well as the pressure oscillations due to the reflection of the transient at the stack termination at the AAV/PAPA junction.

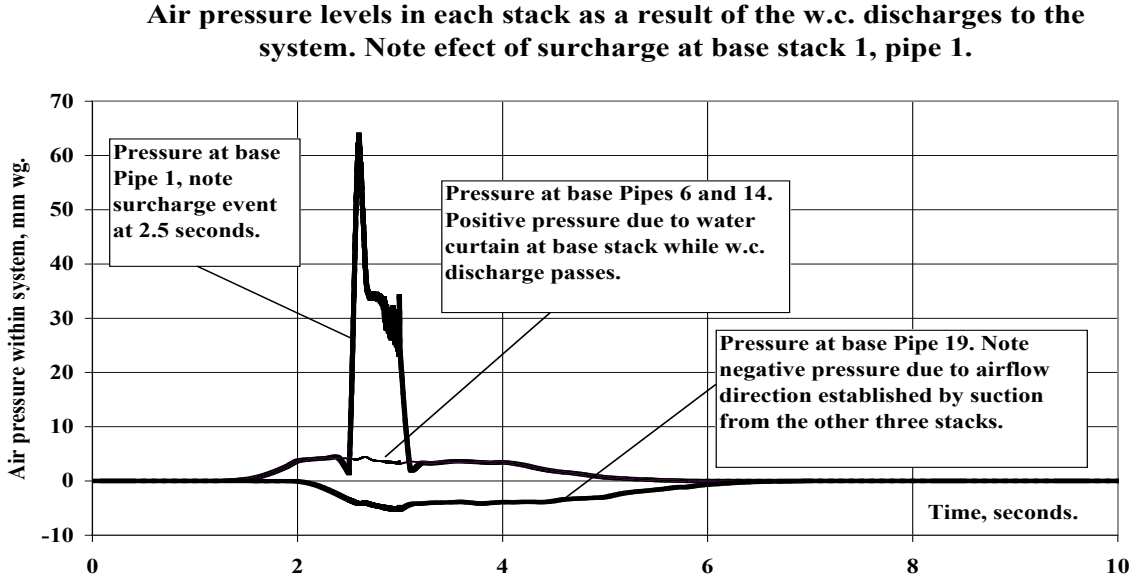

Figure 5 - Air pressure levels within the network during surcharge at base stack 1, pipe 1 at 2.5 seconds

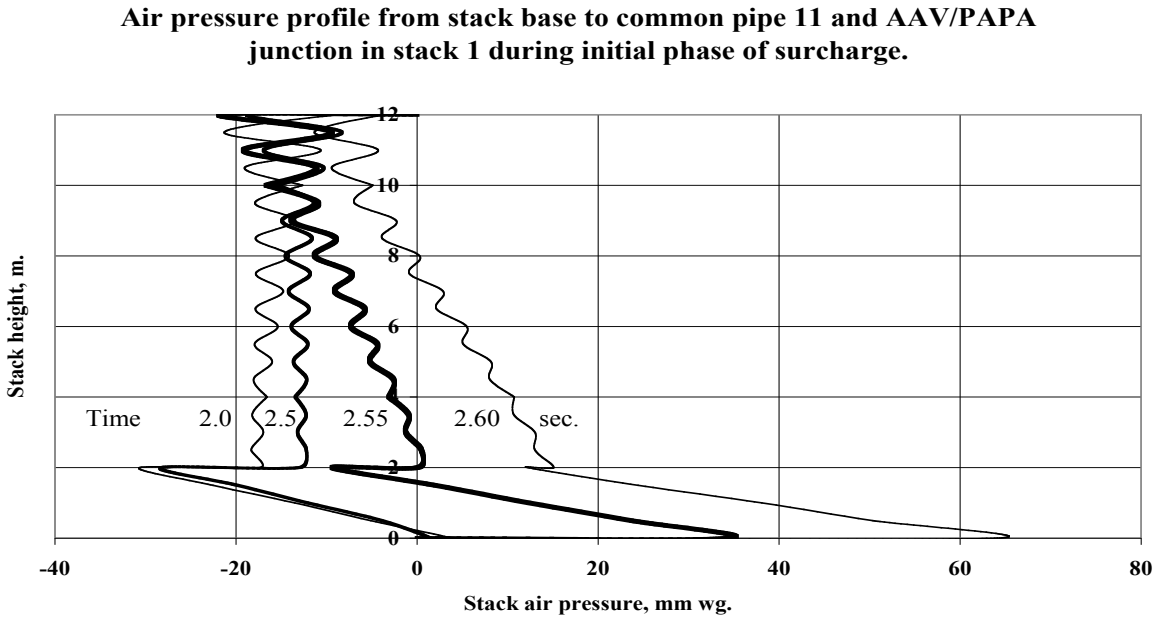

Figure 6 - Sequential air pressure profiles in stack 1 duing initial phase of stack base surcharge

3.3 Sewer imposed transients

The imposition of sequential sewer transients at the base of each stack, Figure 7, results in a pattern that indicates the operation of both the PAPA installed on pipe 13 and the self-venting provided by stack interconnection. At 12 seconds airflow is driven up stack 1 towards the PAPA connection. However as the base of the other stacks have not a yet had positive sewer pressure levels imposed, a secondary airflow path is established downwards to the sewer connection in each of stacks 2 to 4, as shown by the negative airflows in Figure 8. As the imposed transient abates so the reversed flow reduces and the PAPA discharges air to the network. This pattern repeats as each of the stacks is subjected to a sewer transient. Diversity implies that simultaneous sewer transient imposition would not be likely and would be avoided by ensuring connection to a range of sewer outlets, common for a large complex building.

The PAPA installation reacts to the sewer transients by absorbing airflow, Figure 8, expanding until the accumulated air inflow reaches its assumed 40 litre volume, thereafter it will pressurize and assist the airflow out of the network via the stacks unaffected by the imposed positive sewer pressure.

As the sewer transient is applied sequentially from stack 1 to 4 this pattern is repeated. The volume of the high level PAPA, together with any others introduced into a more complex network, would be adapted to ensure that no system pressurization occurred. The effect of sequential transients at each of the stacks is identifiable as the PAPA volume decreases between transients.

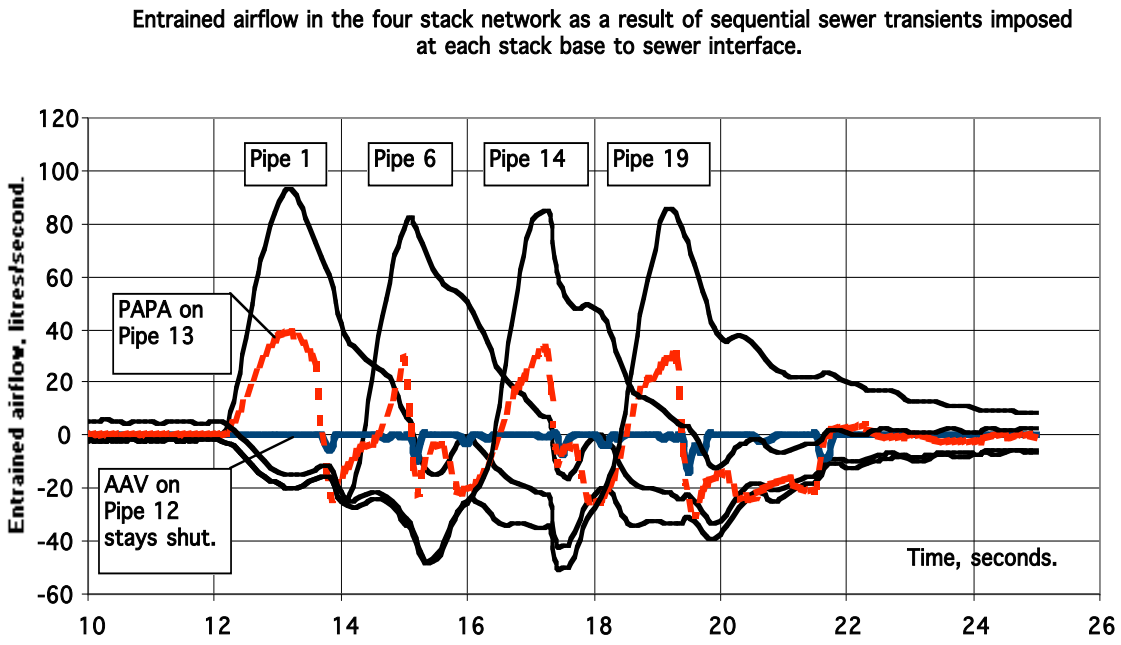

Figure 7 - Entrained airflows as a result of sewer imposed pressure transients.

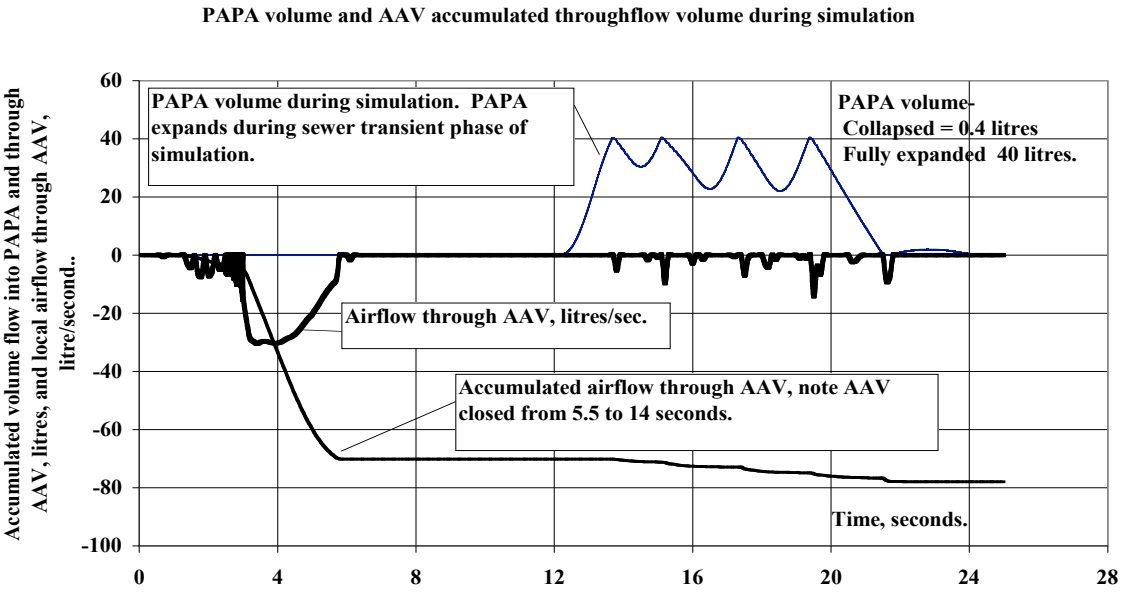

Figure 8 - PAPA volume and AAV throughflow during simulation.

3.4 Trap seal oscillation and retention.

The appliance traps connected to the network monitor and respond to the local branch air pressures. Figure 9, representing the trap on pipe 2, illustrates the expected induced siphonage of trap seal water into the network as the stack pressure falls. The surcharge event in stack 1 interrupts this process at 2 seconds into the simulation.

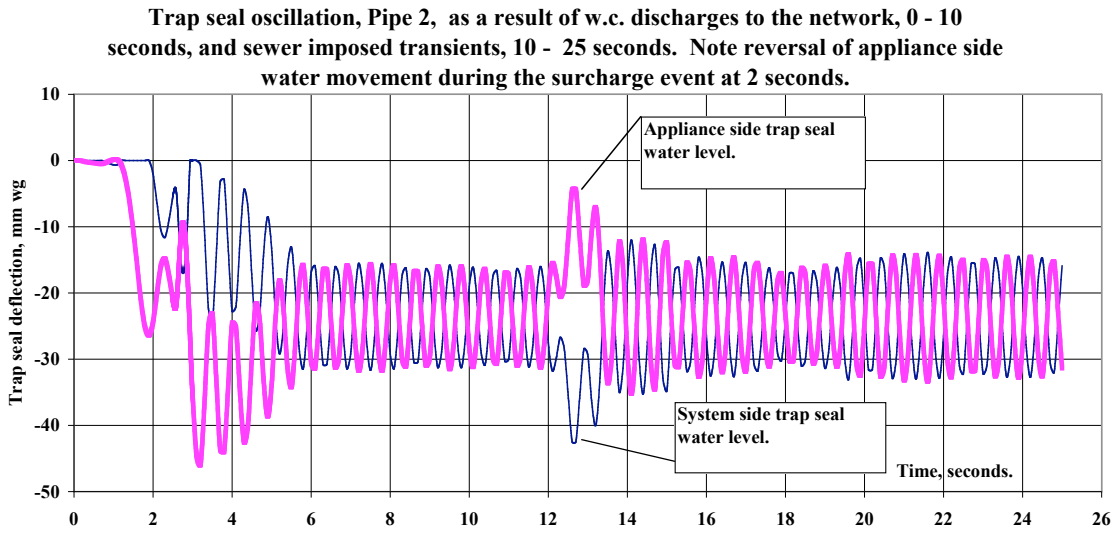

Figure 9 - Trap seal oscillation, trap 2

The trap oscillations abate following the cessation of water downflow in stack 1. The sewer transient is seen at 12 seconds as the water level rises in the applaince side of the trap. A more severe transient could have resulted in 'bubbling through' if the trap system side water level fell to the lowest point of the U bend. At the end of the simulation each trap displays an individual water seal retention that depends on the usage of the network, Trap 2 retains 32mm, Traps 7 and 15 retain 33mm and Trap 20 is reduced to 26 mm .

4. Conclusion - Viability of a sealed building drainage and vent system.

The simulation presented confirms that a sealed building drainage system utilizing active transient control would be a viable design option. A sealed building drainage system would offer the following advantages:

- system security would be immeasurably enhanced as all high-level open system terminations would be redundant,
- system complexity would be reduced while system predictability would increase,
- space and material savings would be achieved in the construction of any installation.

These benefits would be realised provided that active transient control and suppression was incorporated into the design in the form of both air admittance valves (AAV) to suppress negative transients and variable volume containment devices (PAPA) to control positive transients. The diversity inherent in the operation of both building drainage and vent systems and the sewers connected to the building have a role in providing interconnected relief paths as part of the system solution.

The method of characteristics based finite difference simulation presented has provided output consistent with expectations for the operation of the sealed system studied. The

accuracy of the simulation in other recent applications, including the accurate corroboration of the SARS spread mechanism within the Amoy Gardens complex in Hong Kong in 2003, provides a confidence level in the results presented.

Due to the random mode of operation of building drainage and vent systems further simulations, laboratory and site investigations will be undertaken to ensure that the concept is wholly viable.

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Notation

				Suffix	
C^{+-}	Characteristic equations.	c	Wave speed, m/s.	atm	Atmospheric pressure
D	Branch or stack dia.r, m.	f	Friction factor	local	Conditions at node.
p	Air pressure, N/m^2	t	Time, seconds.	P	Unknown conditions
u	Mean air velocity m/s.	x	Distance, m.		at node at $t+\Delta t$
γ	Ratio specific heats.	Δt	Time step, s.	R,S	Conditions at
Δx	Internodal length, m.	ρ	Density, kg/m^3		nodes at time t.

Professor John Swaffield is Head of the School of the Built Environment and leads the Drainage Research Group at Heriot Watt University, Edinburgh. His research interests include water conservation and the development of mathematical simulations for drainage and vent system flows. He has been involved in drainage and water conservation research for 30 years and has contributed regularly to CIBW62 since 1975.

Airflow distribution in complex building drainage networks: An electrical analogy to aid understanding.

Dr. M. Gormley (1) and Dr. D.P.Campbell (2)
(1) m.gormley@sbe.hw.ac.uk
(2) d.p.campbell@sbe.hw.ac.uk
Drainage Research Group
The School of the Built Environment
Heriot Watt University
Edinburgh EH14 4AS

Abstract
Airflow distribution in complex building networks plays an important part in the equalization of pressure fluctuations, the protection of water trap seals and ultimately the protection of habitable spaces from the ingress of foul sewer gases.

The mechanisms governing airflow in building drainage systems are well understood and have lent themselves to numerical models based on method of characteristics and the solution of the St.Venant equations of momentum and continuity, the basis for the computer prediction program AIRNET.

AIRNET can accurately predict the ingress of air entering the system through open terminations and air admittance devices such as air admittance valves (AAV) and waterless traps, subject to a restriction placed on the airflow by the type of termination. It is possible to show that the restriction placed on the airflow by these configurations follows the same laws governing electrical current flow and electrical resistance.

The methodology employed is to use data obtained from the validated program AIRNET to verify that airflow though a range of terminations and pipe configurations follows the laws of electrical circuit theory. The results show that venting arrangements can be appraised by inspection, and that the introduction of the electrical resistance analogy aids understanding of airflow distribution in complex networks, particularly where additional venting is required to overcome existing problems.

Keywords
Air pressure, drainage design, electrical analogy.

1. Introduction

The application of electrical circuit analysis methods to fluid systems is not without precedence. One of the seminal works on waterhammer analysis by graphical means was shown to be equally as valid for surge waves in electrical circuits as pressure surges in pipelines [1]. Closer to the field of building drainage systems is the work carried out by the National Bureau of Standards in the U.S.A. in the 1980s, which applied Hardy-Cross network analysis to a study of a Veterans Administration Hospital in the Bronx, New York [2].The method used a loop circuit approach, applying rules equivalent to Kirchoff's laws in electrical d.c. circuit theory, and was used to predict optimum vent sizes for the building drainage system.

The purpose of describing the electrical analogy proposed in this paper is help to demystify the operation of drainage networks. There are many misconceptions about the effectiveness of venting configurations, which inevitably lead to either an over estimation or under estimation of requirements or no difference at all.

It might be considered that an electrical d.c. analogy would not be representative of the processes involved in building drainage systems. The processes in a building drainage system are inherently dynamic, requiring predictions of the propagation of transient pressure waves and unsteady fluid flows. The d.c. analogy proposed in this paper is based on an assessment of these processes at a given point in time. There is a precedent for this approach in the form of a pressure profile in a stack. Consider the pressure profile in Figure 1. This graph represents the profile in a stack at a given point in time, it does not represent transient behaviour and is not a permanent pressure profile. It is used as an aid to understanding some of the important processes in a drainage system, and has been very successful at doing so. It is hoped that the electrical analogy can also aid understanding, using a snapshot approach also.

It is important to note that this paper does not describe a model for predicting airflows or pressure regimes, that is best left to numerical models such as AIRNET, it is simply intended act as an aid to understanding, using methods adopted by the author to quickly assess venting arrangements in a wide range of simulations carried out in recent research. The approach is to assess different configurations, and to predict, using equivalent electrical circuit analysis, whether one configuration is more effective than the other.

2. The AIRNET simulation tool

The computer program AIRNET has been used extensively in this research. The program's strength lies in the extensive loss coefficients and boundary conditions developed in ongoing research at Heriot-Watt University to accurately represent real drainage system boundaries and appliances.

The program simulates the propagation of low amplitude air pressure transients using the fundamental St. Venant equations of motion and continuity and by the numerical solution of these equations, via the method of characteristics. The method is used to yield air pressure and velocity within a duct system subjected to air pressure transient propagation. [3],[4]. As the air pressure and density are linked, the defining finite difference equations have to be recast in terms of air velocity and wave speed.

2.1. Entrained airflow analysis

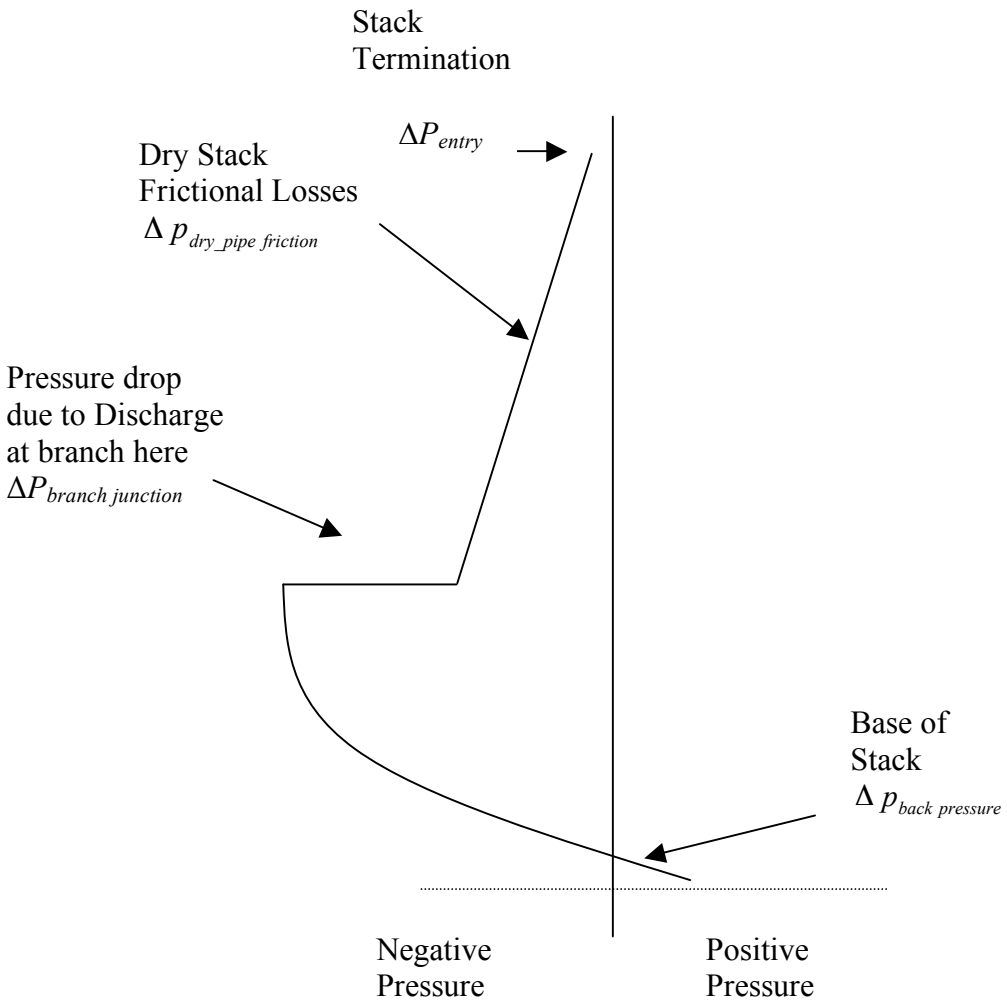
The basic principles governing the model's operation can be seen by looking at the example of an entrained airflow analysis as illustrated in Figure 1. As water enters the stack from a branch, an airflow is entrained into the network and leads to a suction pressure in the vertical stack. Pressure drops are experienced at the termination at the top of the stack due to separation losses associated with the method of termination the airflow passes through (AAV or open end). Frictional losses in the dry stack lead to a further pressure drop and can be calculated from an application of D'arcy's equation. A further pressure drop is evident as the water from the branch forces its way through the air core.

Figure 1 also shows the positive pressure at the base of the stack as the airflow is forced through the water curtain formed at the bend at the base of the stack.

These pressure losses in the stack may be combined as

$$\Delta p_{total} = \Delta p_{entry} + \Delta p_{dry_pipe\ friction} + \Delta p_{branch\ junction} + \Delta p_{back\ pressure} \qquad 1$$

The 'motive force' to entrain this airflow and compensate for these `pressure losses' is derived from the shear force between the annular terminal velocity water layer and the air in the wet portion of the stack. This can be considered as a `negative' friction factor that generates an equal pressure rise to that determined from equation 1 - the equivalent to a fan characteristic drawing air through the stack. Ongoing research has identified the format and relationships governing this shear force representation, and allows the prediction of the transient response of the stack network to variations in applied water downflows [5]



$$\Delta p_{total} = \Delta p_{entry} + \Delta p_{dry_pipe\ friction} + \Delta p_{branch\ junction} + \Delta p_{back\ pressure}$$

Figure 1 - Entrained Airflow Analysis for AIRNET Model

3. Airflow and system pressure analogy

The entrained airflow analysis example outlined above can be thought of as a network of pressure losses that are induced by the motive force of the work down on the air by the water. This is analogous to the relationship between applied voltage, circuit resistance and current flow in a simple d.c. electrical circuit.

The basis for the analogy can be explained with the use of a few very simple electrical circuits and their drainage equivalents. Firstly, it is necessary to define the analogous terms used in this paper.

Electrical Property		**Air flow property**
Voltage	→	Pressure
Current	→	Airflow
Resistance	→	Friction

3.1 Simple rules about Voltage and current and their application to drainage

Voltage

Voltage is also known as potential difference or electro-motive force (EMF) and is essentially the cost in energy (work done) required to move a unit of positive charge from the more negative point (lower potential) to the more positive point (higher potential). Equivilantly, it is the energy released when a unit of charge moves 'downhill' from the higher potential to the lower. A joule of work is needed to move a coloumb of charge through a potential difference of one volt. The coloumb is the unit of electric charge and it equals the charge of 6 x 10^8 electrons, approximately [6].

The analogue of voltage in a drainage system is Pressure. Pressure or more accurately pressure difference is usually measured between two points, or at a single point if it is referenced to a known pressure, e.g. atmospheric pressure. A pressure difference can induce an airflow, or the pressure difference can occur as a result of an airflow induced by other means, as in the case where an airflow is induced by water falling down a stack.

Current

Current is the rate of flow of electric charge past a point. It is quantified in amperes (amp). where 1 amp = flow of one culoumb per second. By convention, current moves from a positive to negative point in a circuit, even though the actual electron flow is negative to positive.

In a building drainage system the analogue of current is airflow rate, measured in m^3/s or more usually l/s. The quantity of air moved through a system is related to the pressure difference across the system and the friction of its component parts. A significant difference between the two being that $\Delta p \propto Q_a^2$ in a drainage context, where $V \propto I$ in an electrical circuit.

OHMS Law

Ohms law states that the voltage, V, current, I, and Resistance R, in an electrical circuit are related, such;

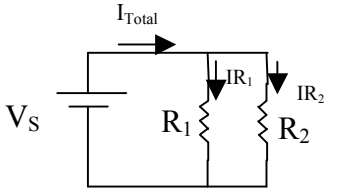
$V = IR$ which leads to an expression for power; $P=VI$

This is a fundamental relationship for all electrical circuitry.

In a drainage system this would relate pressure difference, airflow rate and system friction such that there is a balance between the three. For example, for a given system with a constant driving force (Q_w) if the friction is increased (decrease in pipe diameter) then to maintain the same airflow rate there would need to be an increase is pressure difference.

Kirchoffs current law

States that he sum of currents into a node equals the sum of all the currents out of the node, conservation of charge (conservation of energy). For a series circuit the current is the same everywhere. This law also applies to drainage networks as will be shown in section 5.2 of this paper.



$I_{Total} = IR_1 + IR_2$

$I_{Total} = V_S / R_{Total}$

$R_{Total} = (R1.R2)/(R1+R2)$

$VR_1 = VR_2 = V_S$

Figure 2 - Kirchoff and Ohms Laws applied to a simple

Kirchoffs voltage law

For parallel circuits the voltage is the same across all branches and the sum of the voltage drops around the circuit is zero. This is also true for pressure drops in a system.

Thévenin's theorem

This theorem states that any complex circuit (Figure 3(a)) can be represented by a single voltage source V_{TH} and an equivalent circuit resistance R_{TH} as shown in Figure 3(b).

Norton's theorem

Norton's theorem is closely related to Thévenin's theorem as it states that any complex circuit can be represented by a current source in parallel with the Norton equivalent resistance of the circuit as illustrated in Figure 3(c)

The main use of Kirchoff's laws and the Thévenin and Norton theorems are that when applied to a drainage system they suggest that it is the entire system that determines the air and pressure regimes, not just a path between the motive force of the water and atmosphere. This is a powerful conclusion since it means that drainage designs must be assessed in their entirety. Equivalent circuits for building drainage systems are shown in section 5.

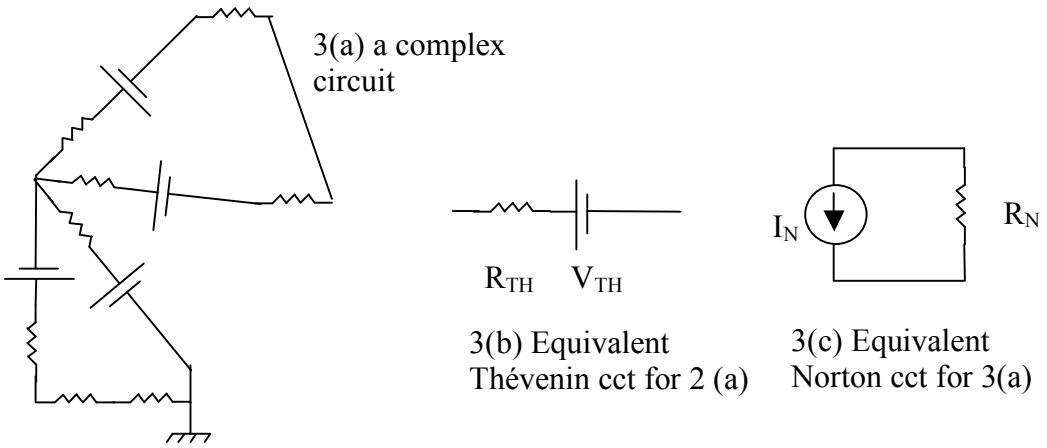


Figure 3 - Thévenin and Norton equivalent circuits

3.2 Resistance to airflow

Frictional resistance to airflow in a drainage system is analogous to resistance in electrical circuits in that they both impede the flow of current (electrical or air) and both cause a drop in potential (voltage or pressure) in their respective networks. It is informative to assess the resistive properties of different components found in drainage systems in order to apply the analogy to real designs.

Various drainage components display a resistance to flow which can give an indication of their effectiveness. Air admittance valves will display an infinite resistance to flow until its opening pressure is reached, after which this resistance to flow will vary with applied suction pressure as shown by Figure 4 which shows the general form of the loss coefficient against applied suction pressure curve for an AAV.

An air pressure attenuator poses an interesting situation. Under negative pressures it will present an infinite resistance to air flow. Under a positive pressure however, it will open and act as a reservoir, analogous to a smoothing capacitor in the electrical model. The purpose of a smoothing capacitor is to intercept and attenuate surges in d.c. circuits.

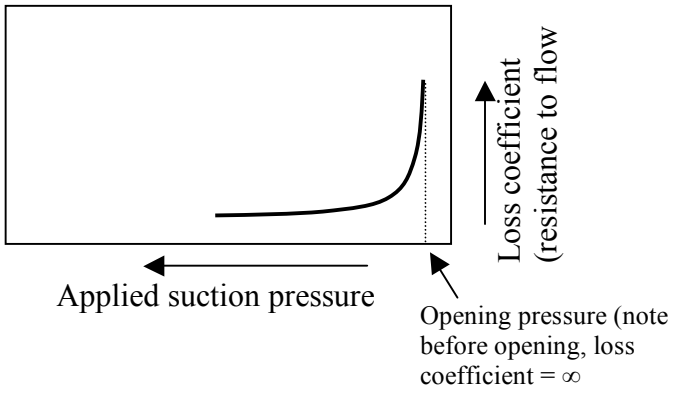


Figure 4 - General form of loss Coefficient for AAV

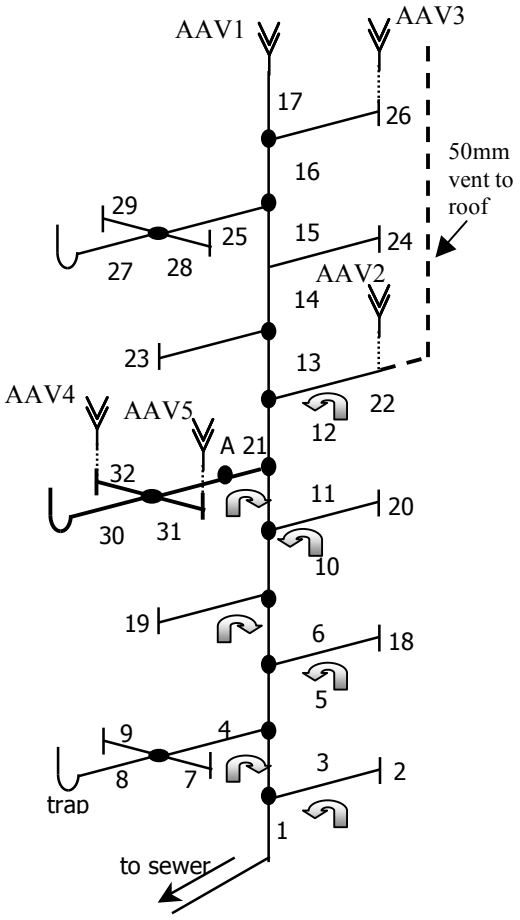
4. Assessing designs: comparing output AIRNET with analogous electrical circuits

The application of the electrical analogy highlights a few important points and will be discussed below. The scenarios chosen are as follows;

1. Airflow in a stack
2. Additional venting on branches.

4.1 Airflow in a stack

The design under consideration is shown in Figure 5. This single stack system has been singled out for analysis. The system includes provision for secondary venting on branches containing fixtures, connected to the main stack. The fixtures are represented in this example as a single water trap seal on the end of the branch, however this could be a group of fixtures connected to the branch, or connected to the main stack individually.



Key
= Discharging branch
= Air Admittance Valve (AAV)
= 50mmWater trap seal
Pipes 1,2,5,6,11,12,13,14,15,16,17 are 3m long 100mm diameter
Pipes 4,21,25 are 2m long 100mm diameter
Pipes 2,7,8,9,18,19,20,22,23,24,26,27, 28,29,30,31,32 are 0.25m long and 100mm diameter

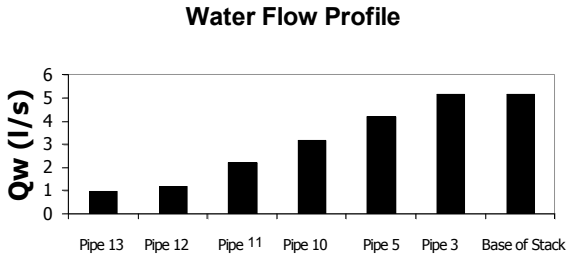


Figure 6 - Water flow profile for simulation

Figure 5 - A single stack system

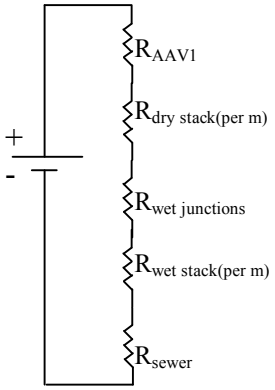


Figure 7 (a) Equivalent circuit for Stack with

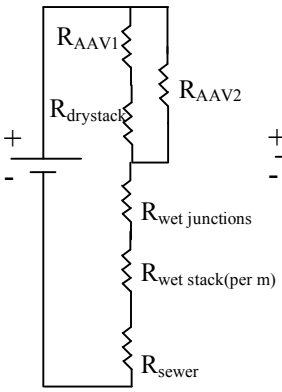


Figure 7 (b) Equivalent circuit for Stack with AAV1 and AAV2

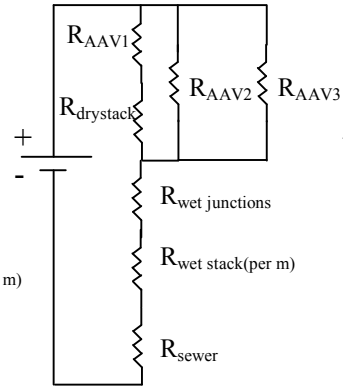


Figure 7 (c) Equivalent circuit for Stack With AAV1,2&3

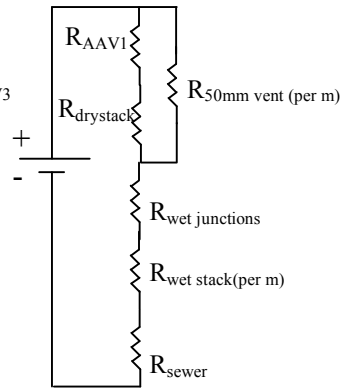


Figure 7 (d) Equivalent circuit for Stack 50mm vent pipe

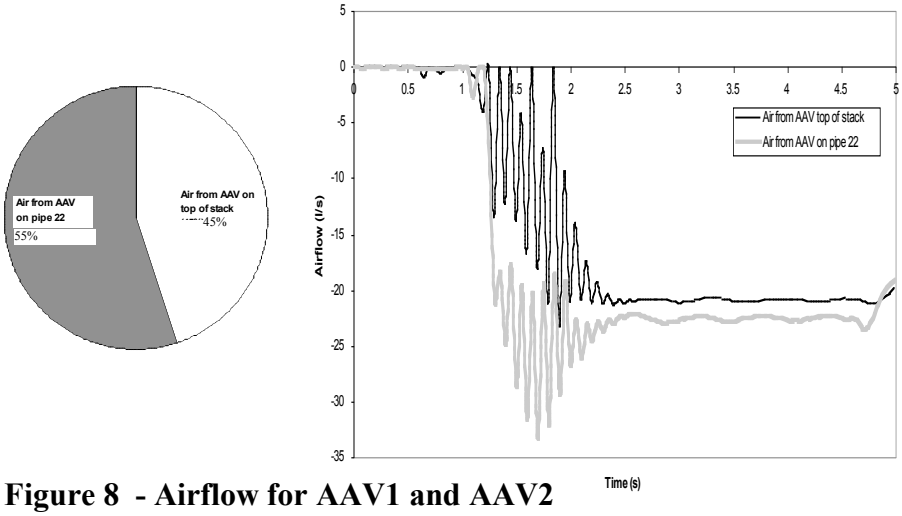


Figure 8 - Airflow for AAV1 and AAV2

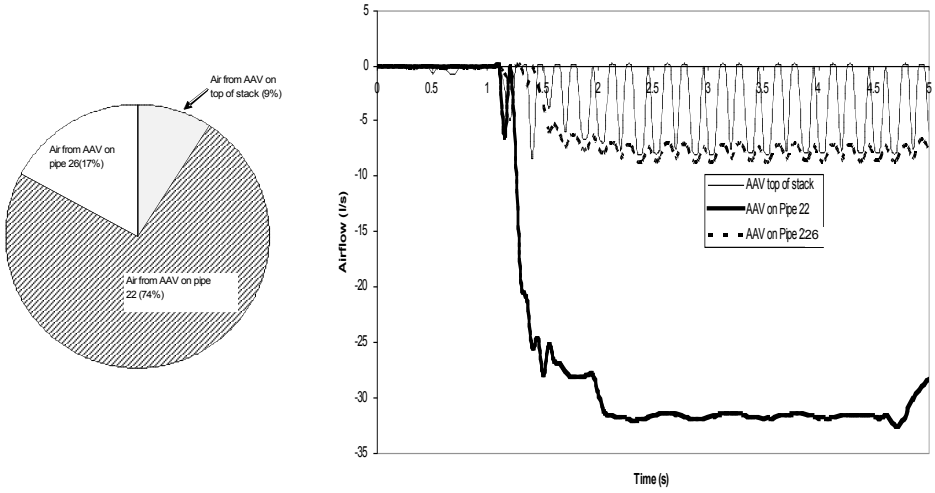


Figure 9 - Airflow for AAV1, AAV2 and AAV3

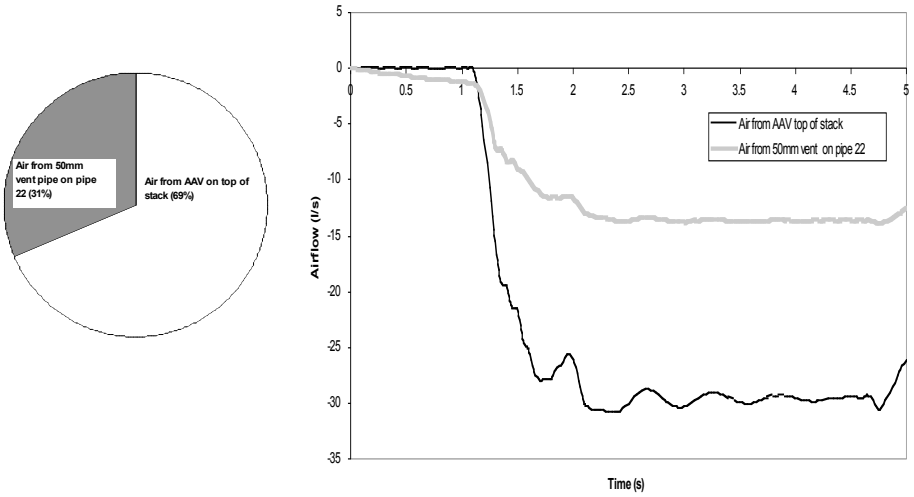


Figure 10 - Airflow data for 50mm vent pipe

Figure 5 shows a single stack system which is subjected to the maximum design flow permitted for this size of system according to EN12056-2 [7]. The water profile used together with the distribution of water inlet is shown in Figure 6. The equivalent electrical circuit for this configuration is shown in Figure 7(a). It can be seen that the main resistance to airflow are seen as series resistances due to entry losses from AAV1, the dry stack and wet stack friction and an interesting additional resistive source from the main sewer. It is possible to represent the interface as a 'bulked' resistance to flow since the sewer may not be at atmospheric pressure. There may even be an airflow source from the sewer which may reduce the airflow in through the top of the system. In this system all of the air will enter through AAV1, and the pressure drops along the system will be such as to maintain this airflow. In reality the wet stack friction can be thought of as the internal resistance of the motive force (the water flow in the stack or the battery in the analogy) and is included here for completeness as it will contribute to the overall resistance of the circuit.

Figure 5 shows the same system with an additional AAV2 on a branch (pipe 22) just above the highest branch with a water flow, pipe 14. Because the additional AAV is connected to the stack via a branch and that the space outside the AAV is at atmospheric pressure an equivalent circuit as shown in Figure 7(b) can be postulated. This is effectively a parallel circuit. Assuming both AAV have the same loss coefficient (effective resistance) then there will be a slightly higher resistance in the stack leg of the parallel circuit which would lead to a prediction that more air will enter the system via the AAV2 on pipe 22 than through the AAV1 on top of the stack. There is another reason why the this is the path of least resistance; when both AAV are closed they both present a dead end, in effect an infinite resistance, when the pressure drops the AAV will open, thus reducing its resistance, the first AAV to open will present the path of least resistance to airflow, which will be maintained during the event.

The airflows from both AAV are shown in Figure 8. It can be seen that most of the air does enter the system via the AAV2 (55% against 45%). It can also be seen that the AAV2 opens first.

To expand this analysis a little further an additional AAV3 was located on pipe 26 as shown in Figure 5 and a simulation run. The equivalent circuit for this configuration is shown in Figure 7(c). As AAV1 and AAV3 are in parallel with AAV2 it would be expected that some air will enter via AAV3 but still not as much as enters through AAV2. Again, this is due to the higher resistance of the AAV1 and AAV3 route due to AAV2 opening first. Airflows for this scenario are shown in Figure 9.

Finally the AAV were removed from the circuit and a 50mm vent pipe run from pipe 22 to the roof (15m). An equivalent circuit for this is shown in Figure 7(d). The amount of air contributed to the system by the 50mm vent pipe will depend on the pipe friction, which for a small bore pipe is considerable. The results of the simulation are shown in Figure 10. It can be seen that less air enters the system via the 15m long 50mm diameter pipe than the AAV on pipe 22. This highlights the high friction of small diameter vent pipework, rendering it ineffective if 'atmosphere' is a long way away.

4.2 Additional venting on a branch

A popular misconception in the mind of many designers is that more venting can be provided for a system by the addition of more venting to a branch. The electrical analogy is useful in assessing if this is indeed the case. Consider the branch arrangement shown by the highlighted branch in Figure 5, pipes 21, 30, 31 and 32. The trap shown is protected from pressure fluctuations by the venting arrangements, which theoretically could be AAV4 or AAV5 or both.

In the first scenario (a) a single AAV4 is used. The equivalent electrical circuit is shown in Figure 11 and the airflow at point A is shown in Figure 13. If a different scenario (b) is tested with the inclusion of an additional AAV5, then a new electrical equivalent circuit can be postulated, as shown in Figure 12. This time both AAV are in parallel and are subject to an analysis due to Kirchoff's voltage law. The current in both legs of the circuit will be the same, and must necessarily be half of the total current.

The output from AIRNET shows clearly that the airflow from both AAV are the same and no greater than had there been only one AAV in the circuit.

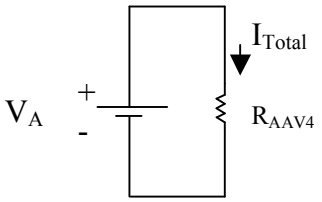


Figure 11 Equivalent Circuit for ranch with AAV4(a)

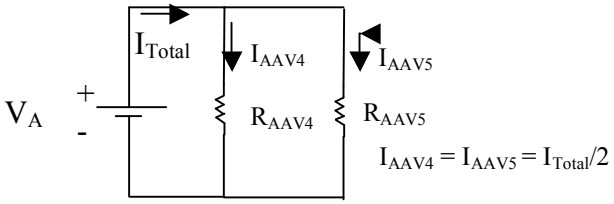


Figure 12 Equivalent Circuit for branch with AAV4 and AAV5 (b)

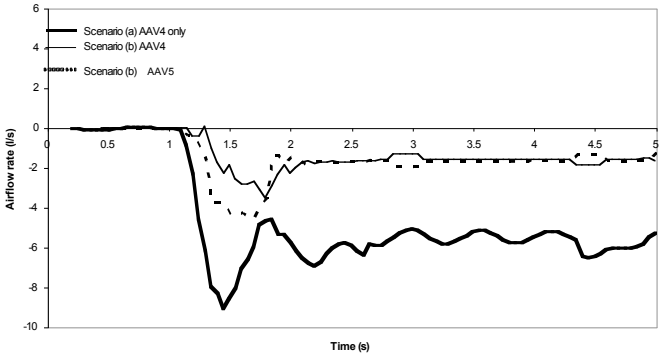


Figure 13 - Airflow for scenario (a) and Scenario (b)

Note that the Airflow contribution from AAV4 is halved when AAV5 is added.

5. Conclusions

This paper has shown that the properties of building drainage networks can be viewed as an analogous electrical circuit. The advantage of using an electrical analogy is that it is much more usual to assess current flow in complex circuits by knowing a few important facts about the components. The tendency in building drainage design has been to stick rigidly to preconceived ideas without the intuition associated with assessment of current flow and voltage across electrical components. While this is method is not a numerical predictive method it has been shown to aid understanding and assess the relative merits of different venting arrangements quickly.

6. References

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7. Authors

Dr. Michael Gormley is a Research Associate and has been a member of the Drainage Research Group since 2000. He specializes in air pressure transient analysis in building drainage systems, solid transport and flushability criteria for commercial products in horizontal drains and the effects of surfactants on drainage systems.

Dr. David Campbell is a Senior Lecturer and has been a member of the Drainage Research Group since 1989. He specializes in air pressure transient analysis in building drainage systems, solid transport in horizontal drains and in the effects of surfactant dosed water on drainage systems.

Performance evaluation for drainage piping systems with food disposers in actual high-rise apartment houses

K. Shimmura (1), M. Otsuka (2), K. Iijima (3)
(1) kouichi_shinmura@eng.sank.co.jp
(2) dmotsuka@kanto-gakuin.ac.jp
(3) kazuaki_iijima@eng.sank.co.jp
(1) R & D Division, Sanki Engineering Co., Ltd., Japan
(2) Department of Architecture, Kanto-Gakuin University, Japan
(3) R & D Division, Sanki Engineering Co., Ltd., Japan

Abstract

In Japan, super high-rise apartment houses with a height 100m are increasing mainly in urban districts, and applications of wastewater treatment systems with food disposers as building equipment are increasing. The purpose of this study is to evaluate and verify this drainage pipe performance of such systems. In this paper, by using actual super high-rise apartment houses, the experiment for performance evaluation was performed. Before habitation, garbage wastewater with some simultaneous drainage units was loaded from upper floors, and initial performance was verified by using index of pressure in the drainage stack. After habitation, the drainage load quantity with habitant's use was assumed, by using index of water level in the house drain pipe. Moreover, pressure in the drainage stack was measured, and running performance was verified.

Keywords

Drainage piping system; food disposers; high-rise apartment houses; performance evaluation; actual building

1. Introduction

In Japan, some redevelopment projects are currently underway mainly in urban districts, and as part of this, super high-rise apartment houses are being built, maximizing the use of land. The application of wastewater treatment systems with food disposers, which are garbage processing equipment, is particularly applicable in super high-rise apartment houses not only for the efficiency of conveyance but also for environmental protection which results from reducing the quantity of trash. The purpose of this study is to evaluate and verify the drainage pipe performance of such systems. We implemented the performance evaluation using a super high-rise experimental tower, and investigated

the drainage pipe performance when influenced by the system components, such as drainage stack fittings and the like and different food disposers while acquiring the knowledge which contributed to the designing of the system[1)]. Moreover, the design and construction of the system is based on this knowledge. In order to check the practicality of the experiments results, it is necessary that the drainage performance be evaluated using an actual building.

It is considered that the drainage performance in an actual building is classified in two kinds depending on the time. The first one is the initial performance upon construction completion before habitation. The second one is the running performance in a certain period after habitation starts, since slime adheres in pipes with long-term use and the performance deteriorates. In order to quantify the input conditions of this running performance, it is important to assume the drainage load quantity with habitant's use[2)]. However, there is almost no concrete study indicating the initial and running performance evaluation methods, which are needed with actual buildings. Therefore, in this paper, the experiment for a series of performance evaluations was performed by using actual super high-rise apartment houses. The purpose of this paper is to show the important knowledge gained from the results of a performance test.

Figure 1 - Actual building

Figure 2 - Experimental tower

2. Experimental method

2.1. Test drainage system

The experiment was performed using high-rise apartment houses (a total of 42 floors above ground, 354 houses with the maximum height of 157m), which are situated in Minato-ku, Tokyo. A test drainage system is shown in Fig.1. The piping system employs a stack vent system and the height of the drainage stack is 123.7m. The 1st house drain with a length of 7.4m is connected to the drainage stack and the 2nd house drain with a length of 59.1m is connected to the end of the 1st house drain. Food disposers with which median diameter of ground garbage is under 0.6mm, are installed in the drainage system. A total of 35 sinks with the food disposers from all floor are connected to the 1st house drain and only the kitchen drain flows through the pipework.

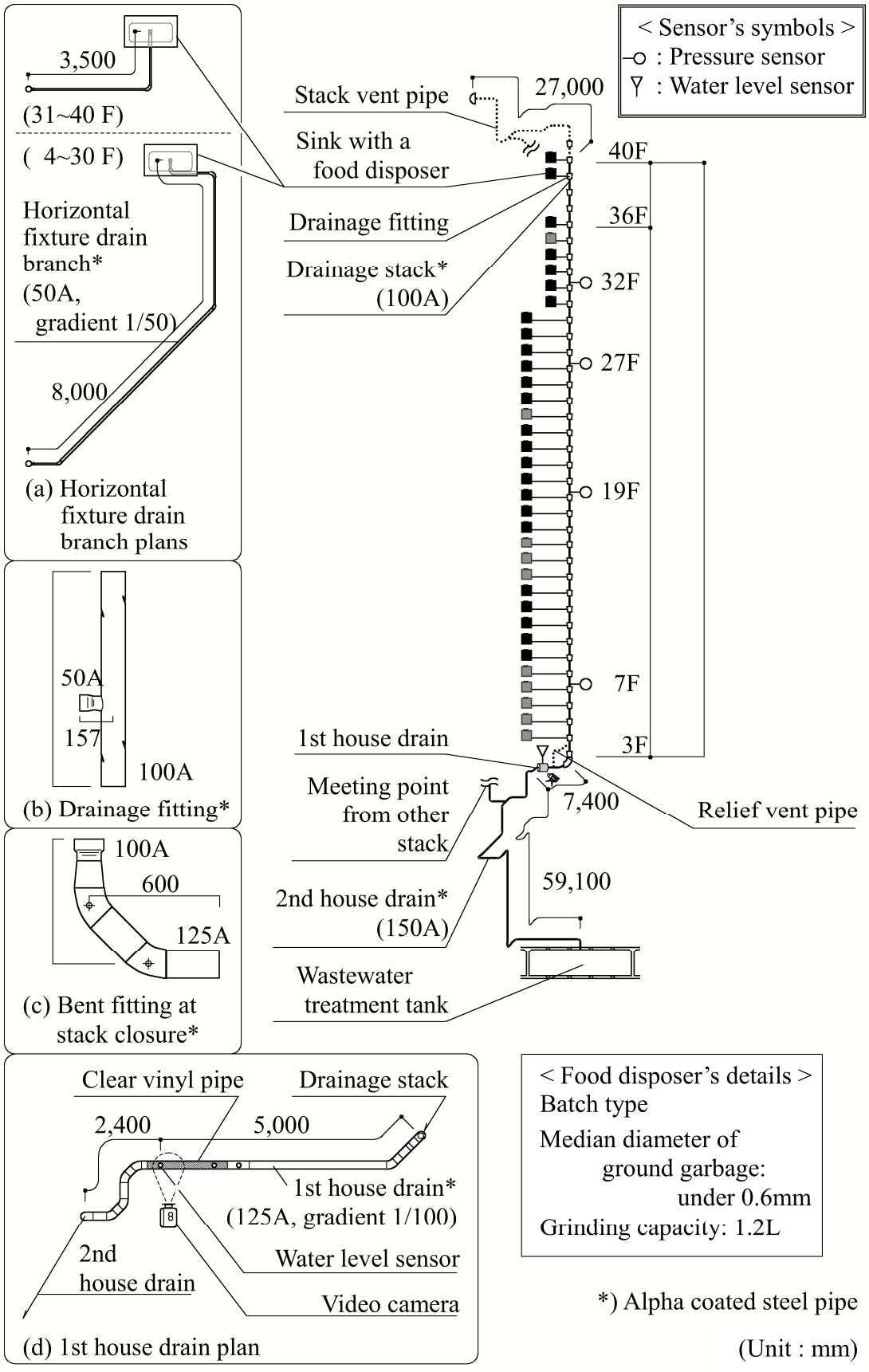

Figure 3 - Test drainage system (Actual building)

As for the details of each part, (a) illustrates the horizontal fixture drain branch plans, (b) displays the drainage fitting, the bent fitting at the stack closure is shown by (c), and the 1st house drain plan by (d) in the figure. The drainage fitting is a special drainage fitting of a circular drain type, and is the same as that of reference drainage system. When comparing results, this reference with a drainage stack height of 93m and a house drain at a length of 107m was quoted.
Reference drainage system using the experimental tower provided by the Urban Renaissance Agency (108m above ground) is shown in Fig.4.

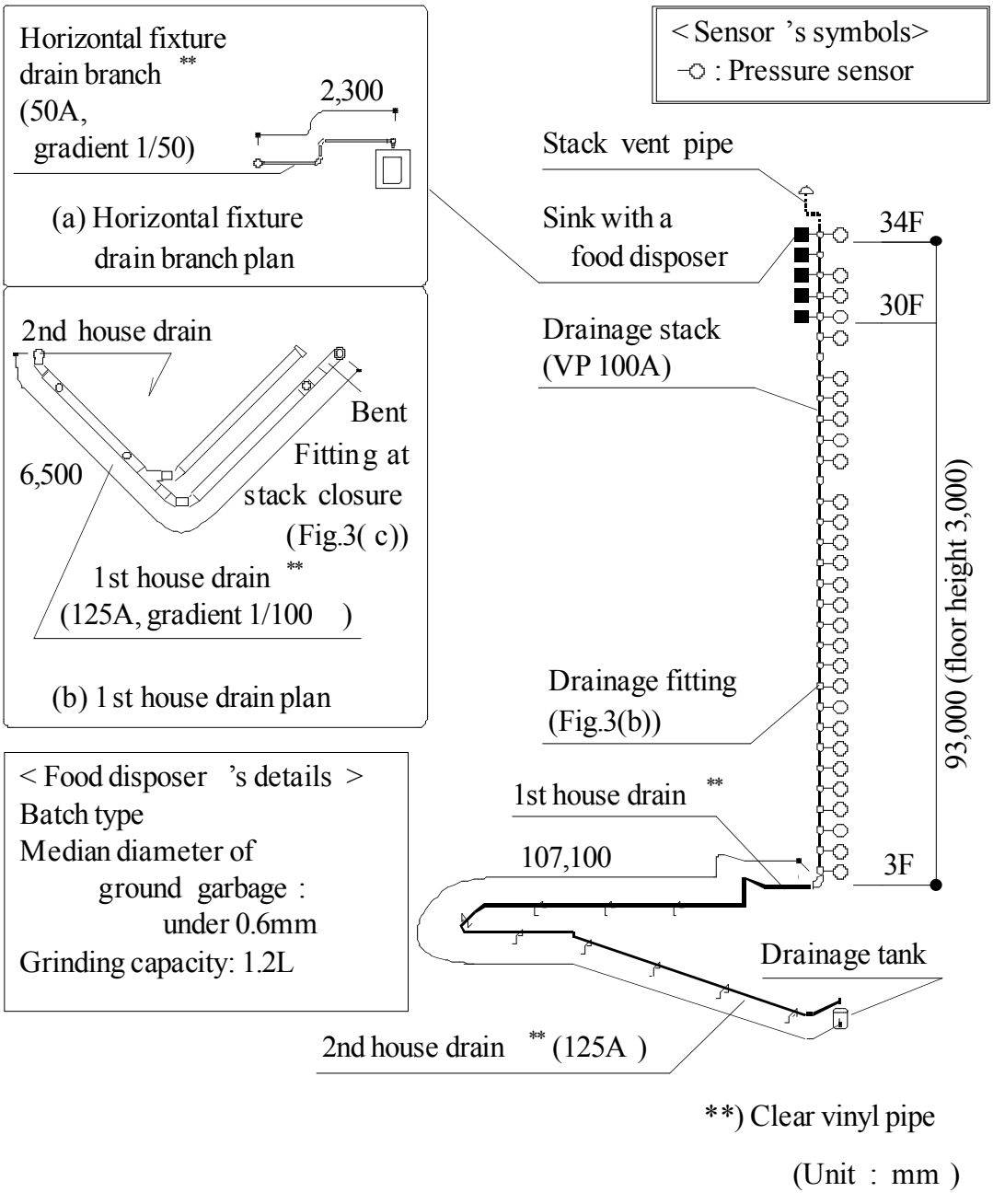

Figure 4 - Reference drainage system (Experimental tower)

2.2. Experimental conditions

The experiment was performed in two parts; the experiment before habitation (1) and the experiment after habitation (2).

(1) The experiment before habitation: Conditions of the experiment before habitation are shown in Table 1. The maximum simultaneous drainage number was 6 calculated by the same method as used in the reference[1]. Garbage wastewater, after 250g garbage was supplied in each food disposer, was drained with supply water simultaneously with the start of grinding. As for the drain of clear water only, 6L water stored in the bowl as one unit was drained as bowl flushing water, and tap running water was drained by constant flow at a flow rate of 0.2L/(s・unit). In these three kinds of drainage, each drainage was loaded with 1~6 simultaneous drainage units from the upper floors (36th ~ 31st floors).

(2) The experiment after habitation: Conditions of the experiment after habitation are shown in Table 2. After 19 months since the start of habitation, the measurement was carried out for 28 days. The habitation conditions during this period of time were 25 houses out of fully occupied 35 houses. Moreover, average water use was 206L/(d・man) as the result of reading water gauges. This value fell within the limit of 200 to 350

Table 1 - Conditions of the experiment before habitation

<table>
<tr><td rowspan="2">Simultaneous drainage number</td><td colspan="4">1~6 units</td></tr>
<tr><td colspan="4">Calculation method of maximum simultaneous drainage number[1] (M) :
$M = Q_L / q_d = 4.2 / 0.75 = 5.6 \rightarrow 6$
Note that Q_L is flow rate load in L/s and q_d is the average flow rate of a sink in L/s. These are by steady flow rate method [3].</td></tr>
<tr><td rowspan="4">Drainage type</td><td colspan="2"></td><td>Standard garbage [4]</td><td>Clear Water</td></tr>
<tr><td>1</td><td>Garbage wastewater[1]</td><td>250g/unit</td><td>0.13L/(s・unit)
for 38 seconds</td></tr>
<tr><td>2</td><td>Bowl flushing water[3]</td><td>---</td><td>6L/unit in bowl</td></tr>
<tr><td>3</td><td>Tap running water [2]</td><td>---</td><td>0.20L/(s・unit)
for 120 seconds</td></tr>
<tr><td>Drainage load by floor</td><td colspan="2">Upper floors</td><td colspan="2">36th~31st floors</td></tr>
</table>

Table 2 - Conditions of the experiment after habitation

Time	28 days (6/15/2003~ 7/12/2003, 19 month after habitation started)
Habitation conditions for experiment period*	25 inhabited houses (Habitation ratio 71% of 35 fully occupied houses), Average 1.64 men/house, Average water use 206L/(d・man)

*) The average number of inhabited houses before the experiment was 17.

L/(d･man), which is water supply quantity for a design of apartment houses and is specified by the reference[5]. Thus, as there is a generality in the resident's use of water, it is suggested that the experiment data is realistic.

2.3. Measurement method

The measurement was narrowed to three items; (1) pipe pressure, (2) water level in a pipe and (3) transport condition. The measurement system is shown in Fig.5.

(1) Pipe pressure: Pressure sensors were installed in the drainage stack of the 7th, 19th, 27th and 32nd floors. The maximum positive pressure and the minimum negative pressure of each floor were read in the pressure changes of each floor. The maximum system pressure value and the minimum system pressure value were read in these pressures, and it verified that these values were within the performance criteria of ±400Pa in compliance with the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE) Standard 218 [6].

(2) Water level in the pipe: A water level sensor employing an ultrasound method was installed in the upper part of the 1st house drain (Fig.1. (d)). According to the reference [2], the drainage frequency was read in the water level changes. Drainage with a water level over 5mm was counted as 1 time. When drainage overlapped with another steady drainage, they were counted respectively as 1 time.

(3) Transport condition: The video camera was set at the measurement point of the water level in the clear vinyl pipe. By observation of the video picture, garbage wastewater (Fig.6) was distinguished from clear water (Fig.7).

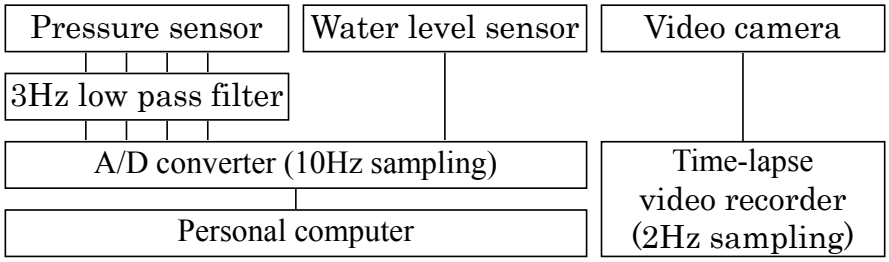

Figure.5 - Measurement system

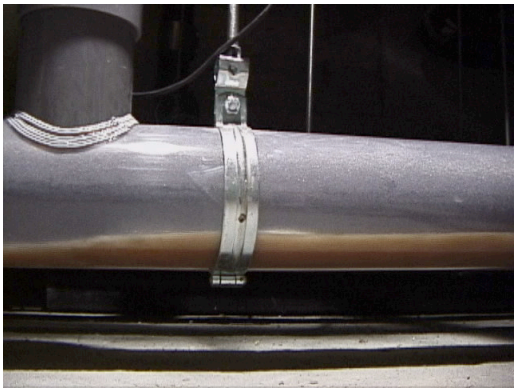

Figure 6 - Garbage wastewater

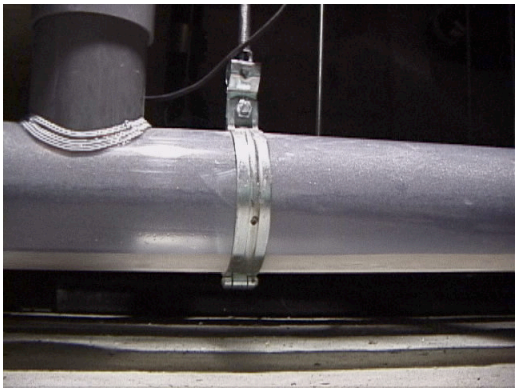

Figure 7 - Clear water

3. Results and discussions

3.1. The experiment before habitation (Initial performance evaluation)

The initial pressure distribution by reading the maximum and minimum values in the pressure change of each floor at the time of draining 6 units from the upper floors is shown in Fig.8. This figure shows that the pressure distribution of bowl flushing water is similar to that of tap running water and the positive and absolute negative pressure of garbage wastewater is the greatest of the three kinds of drainage. The reason why the absolute value of the pressure with bowl flushing water is small is suspected to be attributed to the influence of the decrease of the drainage flow rate caused by the increase of the drainage resistance when the food disposer is installed in the sink.

The maximum and minimum system pressure values are read in this pressure distribution, and the relation between the simultaneous drainage number and each system pressure value is shown in Fig.9. This figure shows that positive and absolute negative pressure increase when the simultaneous drainage number increases. As in the case of the above-mentioned pressure distribution, since the pressure increases caused by the simultaneous drainage number of bowl flushing water is similar to that of tap running water, both can be evaluated as the same clear water drainage. Furthermore, it can be suggested that the garbage wastewater's pressure is larger than that of this clear water drainage. Moreover, the result of the experimental tower was also shown in this figure. Compared to the experimental tower, it transpires that garbage wastewater's positive pressure stated in this paper is smaller by approx. 60Pa, and the negative pressure is graded the same. The cause is speculated to be that the positive pressure resistance stated in this paper is smaller than the figure stated in the experimental tower, as the house drain of 66.5m length mentioned in this paper is shorter than the one with a length of 107m mentioned in the experimental tower. Most importantly, garbage wastewater referred to in this paper falls within the limits of –192Pa to +155Pa. The system pressure value falls within the performance criteria of ±400Pa, and it was verified that the initial performance before habitation was safe.

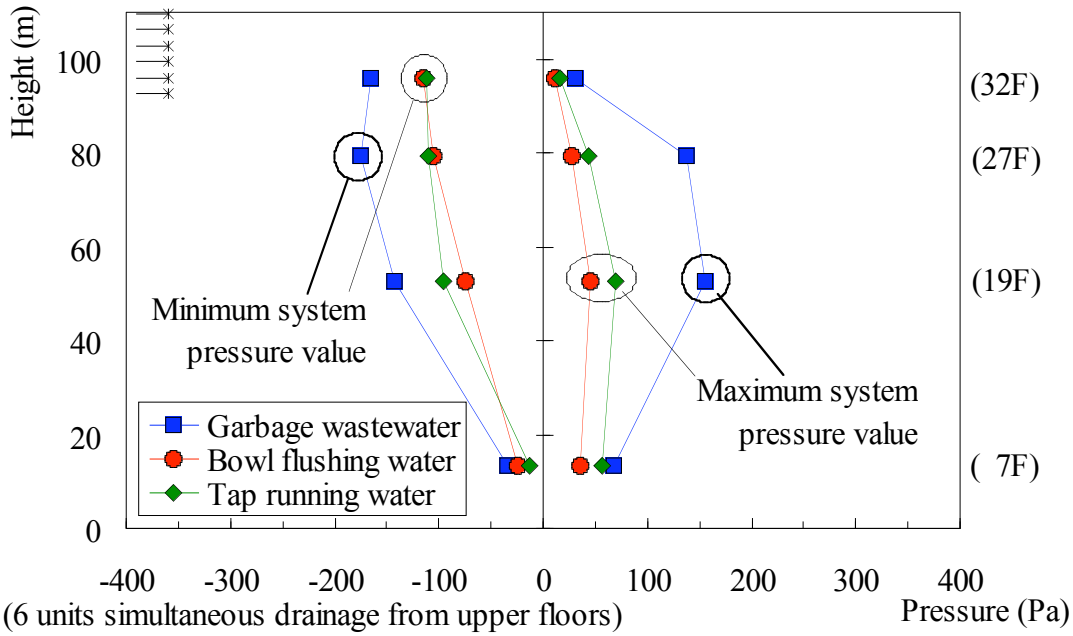

Figure.8 - Initial pressure distribution

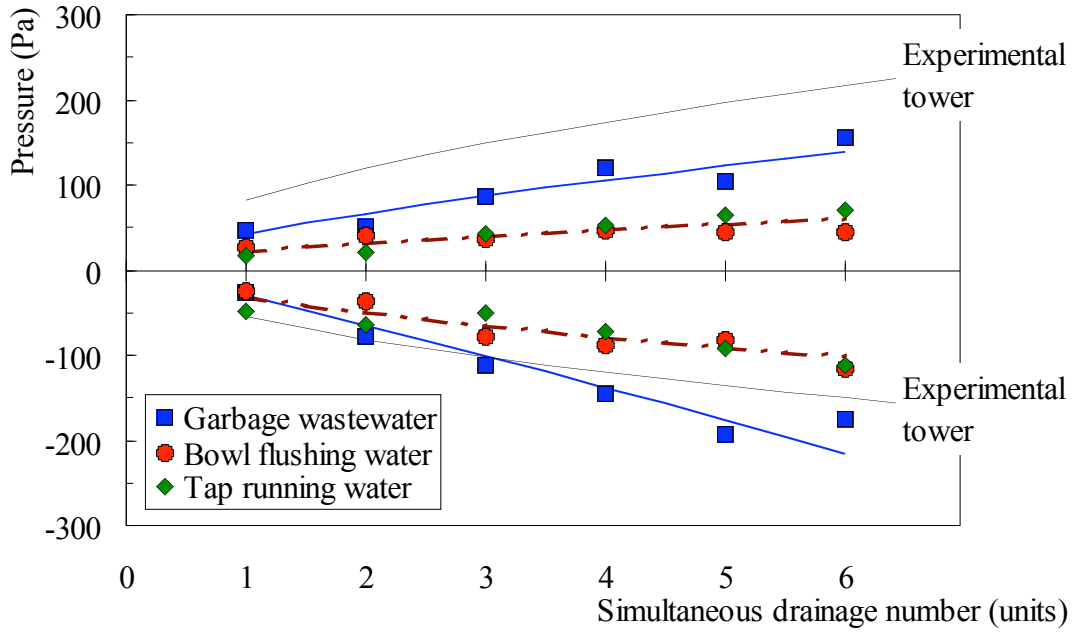

Figure 9 - Relationship between the simultaneous drainage number and the system pressure value

3.2. The experiment after habitation (Running performance evaluation)

The instance of water level changes throughout a day after habitation is shown in Fig.10. Many increases of the water level are seen in this figure. According to the method of above mentioned (2.3.(2)), the drainage frequency was counted from these water level changes. When the drainage frequency is divided into time zones, since the 19th hour zone has the most drainage frequency twelve times in this case, this zone is determined as a peak hour.

All frequency distribution, the drainage of which is distinguished as of either garbage wastewater or clear water, after all drainage during the measurement period were divided by time zones and this is shown in Fig.11. The figure shows that the drainage frequency between the 1st and 6th hour zones is very low, that the drainage frequency between the 18th and 21st hour zones is high, and that the drainage frequency during the 12th hour zone is the highest. As for the garbage wastewater, it is evident that its frequency ratio is 17% of all the drainage frequency, which is a rather small figure when compared with clear water, and that the ratio is comparatively high between the 12th and 19th hour zones.

The instance of pressure and water level changes during a period of thirty minutes is shown in Fig.12. This figure shows that the pressure changes several minutes before the maximum water level occurs.

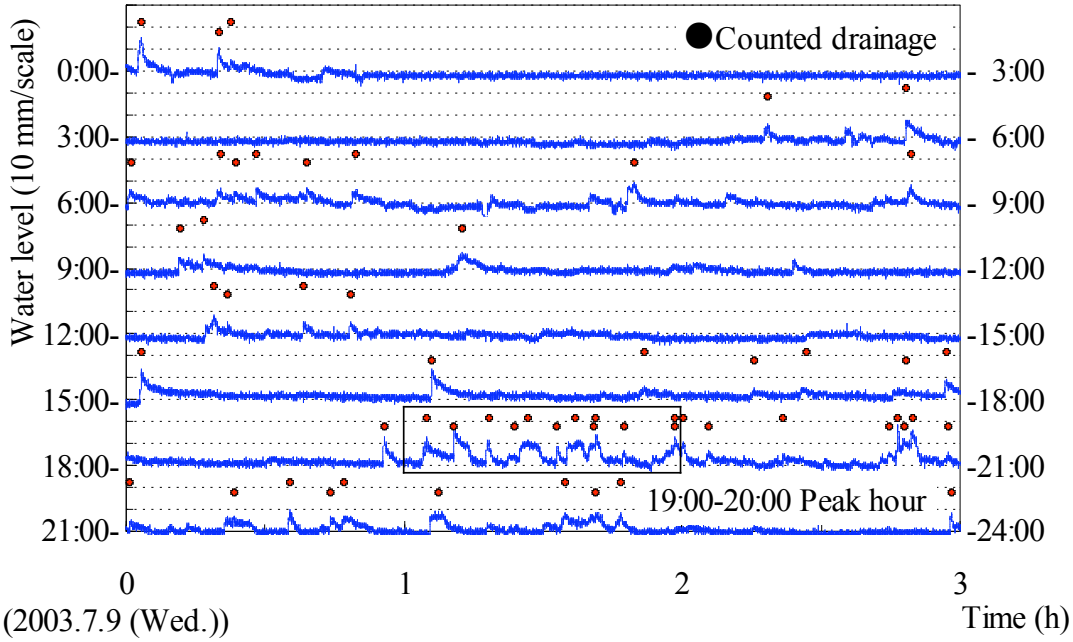

Figure 10 - Instance of water level changes throughout a day

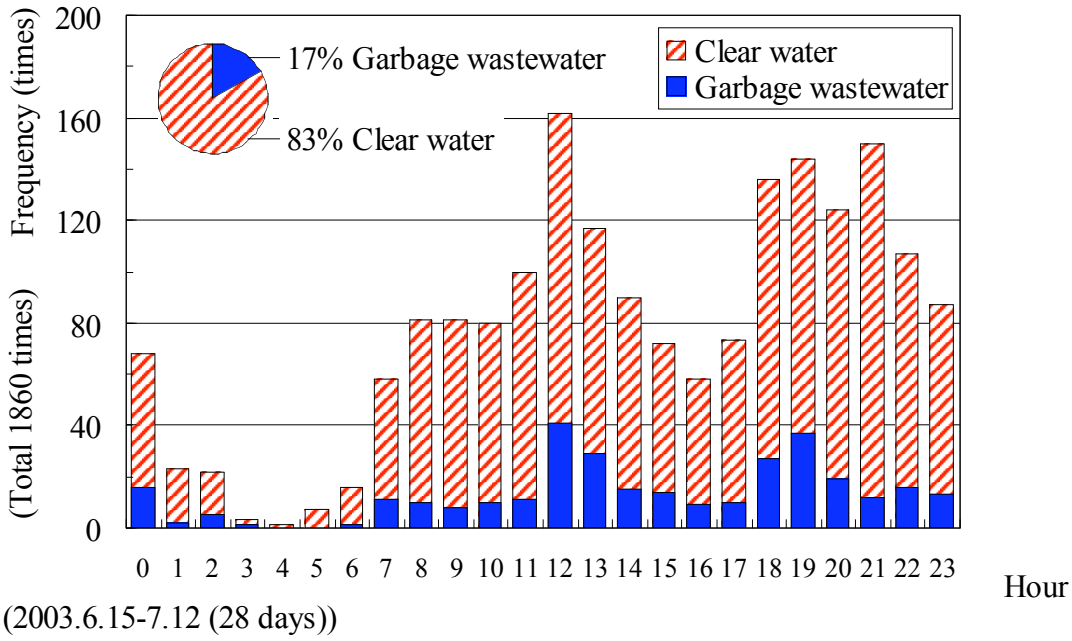

Figure 11 - All drainage frequency distribution by time zones

During the peak hours, the frequency distributions by running system pressure value as read in this pressure change, is shown in Fig.13. This figure shows that most of the system pressure values fall within ±50Pa, and large positive pressure and large absolute negative pressure hardly occur. The suggested causes are that large drainage load did not occur neither did a great deterioration in the performance. About 99% cumulative frequency ratio after excluding 1% from the higher rank contains the maximum system pressure value +147Pa and the minimum system pressure value –103Pa. By this, the system pressure values fall within the performance criteria of ±400Pa, and it was verified that the running performance after 19 months habitation was also safe.

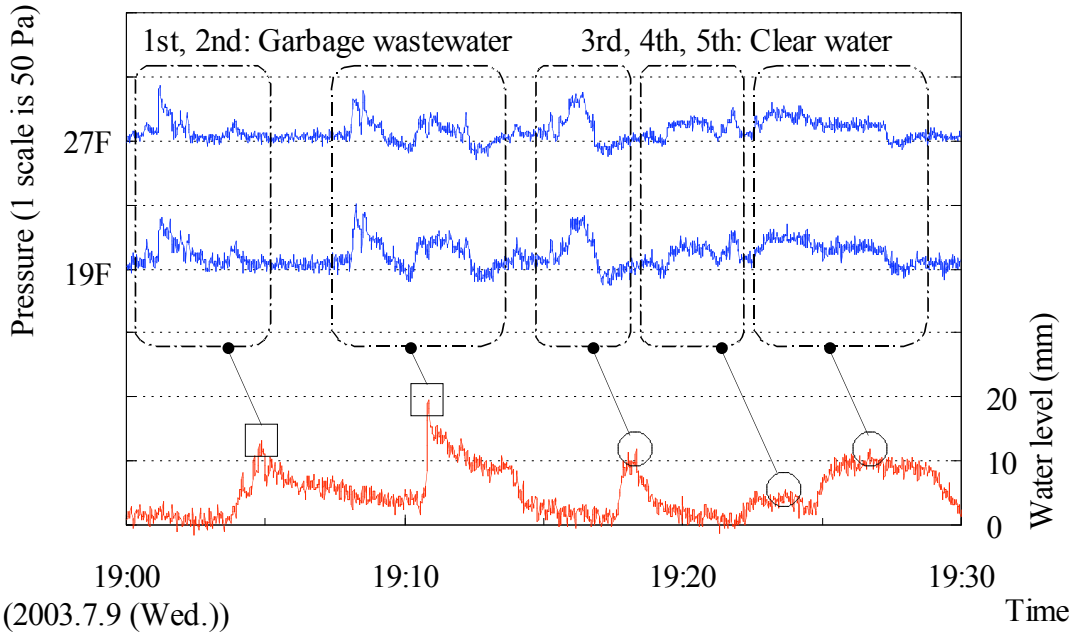

Figure 12 - Instance of pressure and water level changes during a period of thirty minutes

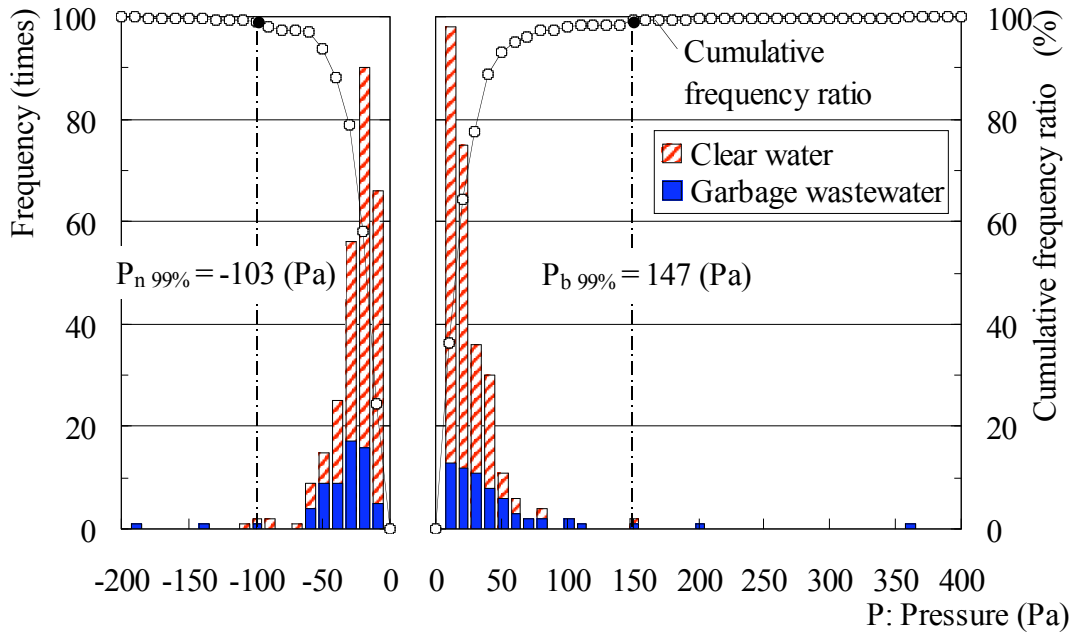

Figure 13 - Frequency distributions by running system pressure value during the peak hours

4. Conclusions

Regarding the drainage piping system with food disposers in the actual super high-rise apartment houses with a height of 100m, results were acquired from the experiment for the initial performance evaluation before habitation as well as from the experiment for the running performance evaluation after habitation using 25 occupied houses (over four weeks after 19 months from the start of habitation). The following knowledge has also been acquired, which contributes to a performance test.

(1) As a result of simultaneously draining the maximum 6 units drainage of garbage wastewater, bowl flushing water and tap running water from the upper floors, the maximum and minimum pressure in pipes were generated by garbage wastewater. These values varied between –192Pa and +155Pa, falling within the performance criteria, and it was verified that the initial performance was safe. During the implementation of the initial performance verification, it is important to measure the system pressure values of garbage wastewater and clear water drainage and to check that the values fall within the performance criteria.

(2) As a result of observing all drainage after habitation by video picture, the garbage wastewater ratio was 17%, and the clear water drainage ratio was 83%. In drainage type prediction, it is effective to take pictures of transport conditions using a video camera.

(3) As a result of clarifying the frequency distribution by running system pressure value, 99% of occurrence probability values were from –103Pa to +147Pa, falling within the performance criteria and it was verified that the running performance was safe. In running performance verification, it is important to check that system pressure values fall within the performance criteria.

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Presentation of Author

Koichi Shimmura is working at Research Laboratories (Japan) in Sanki engineering where he is engaged in research and development for environmental engineering. He received a Ph. D. in architectural engineering from Kanto-Gakuin University. He is specialized in drainage piping systems with food disposer.

A new approach of sizing a drainage stack for residential buildings in Hong Kong

L. T. Wong and K. W. Mui
beltw@polyu.edu.hk
behorace@polyu.edu.hk
Department of Building Services Engineering
The Hong Kong Polytechnic University
Hong Kong, China.

Abstract

In order to design an effective drainage system for buildings, discharge loads at a drainage stack must be determined. A 'fixture unit' approach has been used to determine such loads, with the assumptions of simultaneous operation of all connected appliances and no attenuation effect of flow rate along the drainage pipe that would overestimate the drainage loads and hence the stack size. In this study, empirical expressions are proposed to determine the probable drainage loads for a stack serving a number of domestic washrooms of high-rise buildings in Hong Kong, taking the factors of the attenuation effects of an assigned gradient 1/100 in a horizontal drainage pipe as well as the discharge patterns and simultaneous use of appliances in a typical domestic washroom into account. With reported probable demand patterns of domestic appliances from laboratory testing results, on-site measurements and survey studies, the probable discharge flow patterns in the stack are estimated with Monte-Carlo simulations for the probable maximum discharge flow rates from a number of domestic washrooms at a limiting failure rate. It is shown that, comparing with the estimation method in current practice, a reduction of predicted discharge flow rate at the stack serving a number of typical domestic washrooms would be up to 13% by taking account of the above two factors.

Keywords

Domestic drainage load, horizontal drainage pipe, simultaneous discharge

1 Introduction

In order to design an effective and healthy building drainage system for residential buildings, a reasonably accurate estimation for the drainage loads is necessary. Drainage load estimation for stack sizing based on the probability of using all outlets connected to the stack simultaneously with the design discharge flow rate of an outlet at a limiting failure rate λ (e.g.

0.5-1%) has been adopted in many drainage designs (Plumbing services design guide, 2002; Swaffield and Galowin, 1992; Wise and Swaffield, 2002). Design data based on investigations in residential apartments were used to evaluate the pipe sizes of plumbing and drainage systems characterized by these design parameters, and a 'fixture unit' approach was suggested for the sizing (Webster, 1972). All these works provided the statistical basis for design data formulation in building drainage system designs; later works have attempted to improve the available database for a variety of these designs (Konen, 1985; Friedler *et al.*, 1996, Wong and Mui, 2004).

However, application of the 'fixture unit' approach in determining stack size has two shortcomings which lead to oversize drainage stacks for domestic washrooms in high-rise buildings (Plumbing services design guide, 2002; Swaffield and Galowin, 1992; Wise and Swaffield, 2002). First, the assumptions of simultaneous discharge from all connected appliances might not be suitable for domestic washrooms. Indeed, only one appliance being discharged in an occupied washroom would be the probable usage pattern. Second, the attenuation of flow rate in a horizontal drainage pipe has been examined but the impact has not been quantified for many existing designs of drainage stack (Plumbing services design guide, 2002; Swaffield and Galowin, 1992; Wise and Swaffield, 2002, Pink, 1973). Apart from installation defects, misuse, poor maintenance and workmanship, an inappropriate stack size of the drainage system might cause health, operational and maintenance problems (Plumbing services design guide, 2002; Swaffield and Galowin, 1992; Wise and Swaffield, 2002, Wong, 2002).

Hong Kong is a developed city having a population of 6.8 million and a limited area of about 1,100 km^2. The high population density, 43,000 persons per kilometer in the urban area and 6,300 per kilometer overall, dictates a great demand for high-rise residential buildings. Existing design data with the fixture unit approach might be inappropriate for many of these buildings. Pertinent modifications on the design values for local residential high-rise buildings must be determined carefully and supported by systematic research studies on the drainage system demands of these buildings.

This study, which takes account of the attenuation effects of discharge flow rates along an assigned gradient of a horizontal drainage pipe and simultaneous usage patterns in some high-rise residential buildings, proposes a new approach to determine the probable demands in a drainage stack serving a number of domestic washrooms. A mathematical model using Monte-Carlo sampling techniques is used to determine the probable maximum discharge flow rates at the stack (Wong and Mui, 2005). Model parameters are determined from laboratory tests of typical domestic appliances, field measurements and survey studies of some high-rise residential buildings reported in literature (Plumbing services design guide, 2002; Swaffield and Galowin, 1992; Wise and Swaffield, 2002; Webster, 1972; Konen, 1985; Friedler *et al.*, 1996, Wong and Mui, 2004; Pink, 1973). The results would be useful in updating the drainage load calculation in optimizing the stack size for high-rise residential buildings.

2 Design approach

In this study, a typical washroom of residential buildings in Hong Kong is selected as a reference for investigation. A common stack is used to collect discharges from a number of washrooms j, each of them is installed with a number of appliances i, typically a washbasin, a shower and a water closet (WC). Assuming the appliances in a washroom would not be used at the same time, the transient probable discharge flow rate from the washroom to the stack at any time q_j (Ls^{-1}) in a peak usage period τ_p (h), say 1 hour, is given by Equation (1) where, k_τ

(= 1/3600) is a proportional constant for an arbitrary peak usage period; τ_0 (s) is the total time in the peak period with zero discharge flow rate; q_i (Ls^{-1}) is the transient probable discharge flow rate at time t (h); τ_i (s) is the duration of discharge; N_f (h^{-1}) is the hourly probable number of operations of the appliance,

$$q_j(t) = \sum_i q_i(t) \qquad ; \; t \in \tau_p = k_\tau \left(\tau_0 + \sum_i N_f \tau_i \right) \qquad \ldots (1)$$

The probability of discharge p from an operation of the appliance i is,

$$p_i = \frac{\tau_i}{3600 \tau_p} \qquad \ldots (2)$$

A horizontal drainage pipe would be used to collect effluent from a WC to the stack. It was reported that an attenuation effect on discharge flow rate at the end of the horizontal pipe existed, as compared with that measured at the WC outlet (Swaffield and Galowin, 1992; Wise and Swaffield, 2002; Pink, 1973). As the attenuation effect of flow rate in a stack is relatively less significant than the one in a horizontal drainage pipe (Swaffield and Galowin, 1992; Wise and Swaffield, 2002; Pink, 1973), for simplicity, the discharge flow rate at a stack q_d (Ls^{-1}) at any time $t \in \tau_p$ is approximated by the sum of discharge flow rates entering the stack from appliance i in a domestic washroom j through a horizontal drainage pipe. For a stack serving a number of washrooms N_j, q_d is determined by,

$$q_d \approx \sum_{j=1}^{N_j} \sum_i q_{ij} \qquad \ldots (3)$$

During the peak demand period τ_p, the transient values of parameters τ_i and q_i can be determined by a Monte-Carlo sampling technique from the surveyed distributions $\hat{\zeta}$ (Wong and Mui, 2005), where ζ is a dummy variable for τ_i and q_i to determine q_d,

$$\zeta \in \hat{\zeta} \qquad \ldots (4)$$

With the distribution of probable discharge flow rates at the stack and the arguments imposed on current design practice for drainage pipes, the design criteria would allow a small failure rate λ_i in code with the probable maximum discharge flow rate at the stack q_d^* (Ls^{-1}),

$$\lambda_i(q_d) = 1 - \int_{-\infty}^{q_d^*} f(q_d) dq \le k_\lambda \qquad \ldots (5)$$

where, $f(q_d)$ is a distribution function of probable flow rates at the stack determined from the Monte-Carlo simulations using Equations (4) and (5); q_d (Ls^{-1}) is the design flow rate at q_d^* with a limiting failure k_λ = 1% allowed for some plumbing and drainage engineering designs (Plumbing services design guide, 2002; Swaffield and Galowin, 1992; Wise and Swaffield, 2002; Webster, 1972).

3 Review of discharge patterns of domestic appliances

Discharge patterns and flow rate distributions of various appliances were reported in laboratory tests and field surveys, in terms of discharge flow rates, discharge time and occupant usages (Plumbing services design guide, 2002; Swaffield and Galowin, 1992; Wise and Swaffield, 2002; Webster, 1972; Konen, 1985; Friedler *et al.*, 1996, Wong and Mui,

2004; Pink, 1973). Figure 1(a) shows example discharge flow rates at a stack due to flushing a WC with a 6L cistern through three different drainage connections: (a) without any horizontal drainage pipe; (b) with a 12 m horizontal drainage pipe at a gradient of 1/50; and (c) with the same pipe as (b) at a gradient of 1/100. A significant attenuation effect on the maximum discharge flow rate in a horizontal drainage pipe was recorded (Wise and Swaffield, 2002; Pink, 1973). The cumulative frequency distributions of the example discharge flow rates q_d (Ls^{-1}) are shown in Figure 1(b), with the average rates of 0.99, 0.27 and 0.19 Ls^{-1} for connections (a), (b) and (c) respectively.

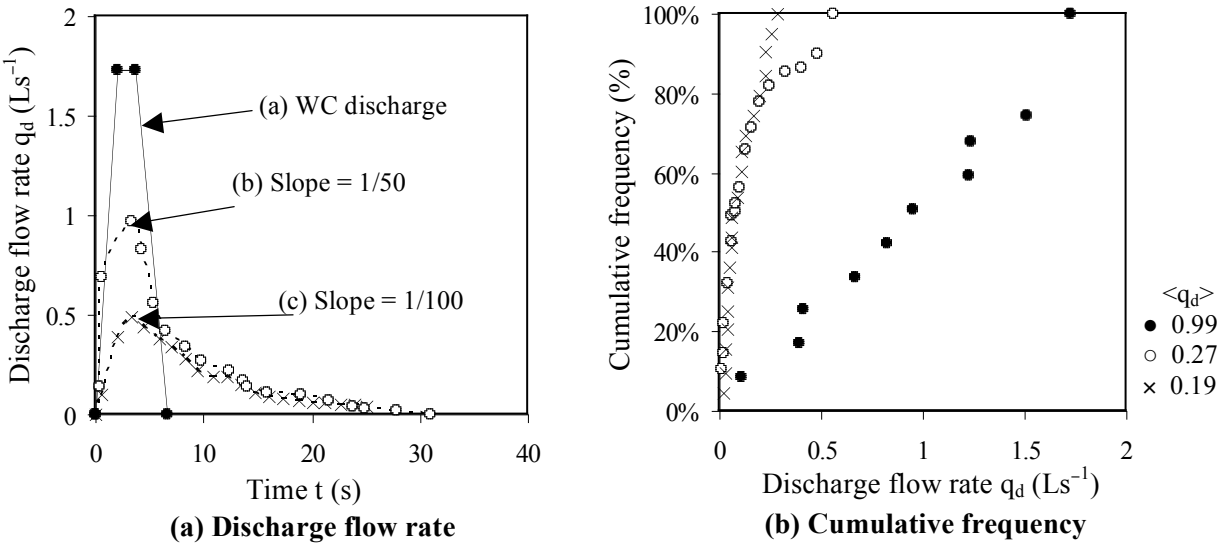


Figure 1 - A WC discharge into a 12 m horizontal drainage pipe from a 6L flushing water cistern (Wise and Swaffield, 2002; Pink, 1973)

Table 1 - Numerical examples for the appliances

Appliance	Connection to stack	*Discharge flow rate q_i (Ls^{-1})	*Discharge time τ_i (s)
Water closet	(a) no horizontal pipe;	1 (0.39 to 1.58)	7.1
	(b) 12 m horizontal pipe 1/50	0.08 (0.02 to 0.4)	45
	(c) 12 m horizontal pipe 1/100	0.06 (0.03 to 0.22)	42
Washbasin	not specified	0.38 (0.22 to 0.54)	11.6 (5.7 to 23.3)
Shower	not specified	0.32 (0.25 to 0.4)	720 (420 to 1260)

*Value of 68% range shown in ( )

In Hong Kong, the probable drainage loads in 14 high-rise buildings of five low-cost residential estates were investigated (Wong and Mui, 2004). A face-to-face interview was conducted in 2003-2004 and the discharge flow rates of the installed sanitary appliances were measured in 597 apartments. The database was developed for high-rise residential buildings in cities having a high population density and was used in this study. In a typical high-rise residential building during peak period of demand, the probable maximum hourly operations of the WC, washbasin and shower were 6, 7 and 1 for a washroom serving 4 occupants, at a limiting failure of 1% (Plumbing services design guide, 2002; Swaffield and Galowin, 1992; Wise and Swaffield, 2002; Wong and Mui, 2004). The discharge flow rate and discharge time

of a typical WC with a 6L flushing water cistern shown in Figure 1 for the three drainage pipe connections (Pink, 1973) are summarized in Table 1. For the typical washbasin installation, the discharge flow rate and discharge time were 0.38 Ls^{-1} (68% range was 0.22 to 0.54 Ls^{-1}) and 11.6 s (68% range was 5.7 to 23.3 s); while for the shower, they were 0.32 Ls^{-1} (68% range was 0.25 to 0.4 Ls^{-1}) and 12 minutes (68% range was 7 to 21 minutes) respectively (Wong and Mui, 2004, 2005).

4 Illustrative examples

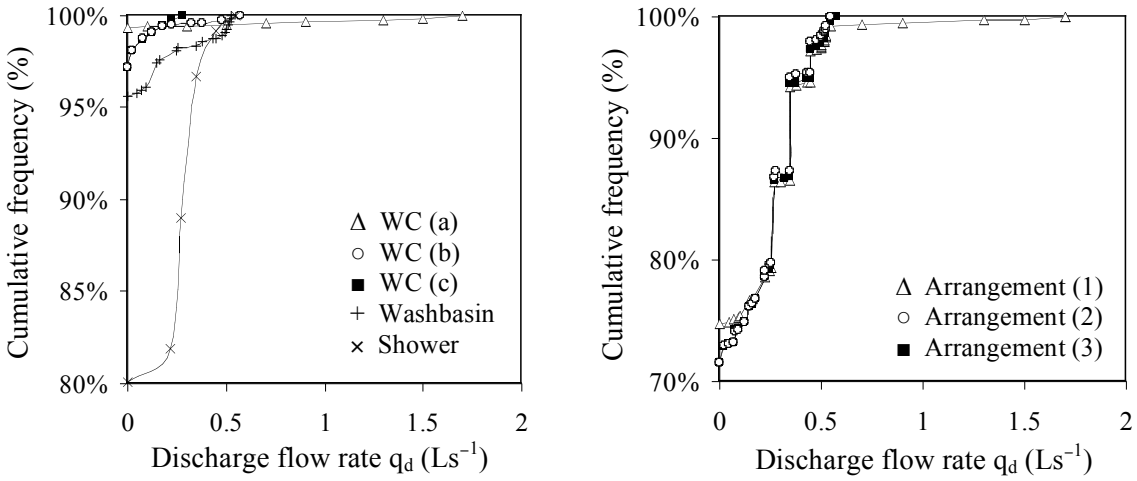
A common stack was used to collect discharges from a number of typical domestic washrooms where, a water closet (WC), a washbasin and a shower were installed in each of them. For demonstration, a WC with a 6L flushing water cistern was selected. In order to quantify the attenuation effect on stack size, the probable discharge flow rates at the stack from washrooms with the following three arrangements were evaluated:

(1) a washbasin, a shower and a WC of drainage pipe connection (a);

(2) a washbasin, a shower and a WC of drainage pipe connection (b);

(3) a washbasin, a shower and a WC of drainage pipe connection (c).

In the peak hour, Figure 2(a) shows the probable discharge flow rates at the stack due to the operation of an appliance. As expected, WC was a single appliance associated with the highest discharge flow rate, though the discharge only lasted for a short period of time when compared with an operation of a washbasin or a shower. Discharges with drainage connections (b) and (c) for WC associated similar probabilities with discharge flow rates of 0 to 0.3 Ls^{-1}; however, case (b) would have 1% probability of a discharge flow rate $q_d > 0.3$ Ls^{-1} as shown.



(a) From an appliance **(b) From a domestic washroom**

Figure 2 - Discharge flow rates at the stack

Figure 2(b) shows the discharge flow rates at the stack in the peak hour due to the three washroom arrangements. As expected, the stack underwent a certain flow rate within a small portion of time. A significant high flow rate of arrangement (1) was reported for about 1%

probability in the peak hour, as compared with the other two arrangements. Arrangements (2) and (3) were associated with similar discharge characteristics as shown in the figure.

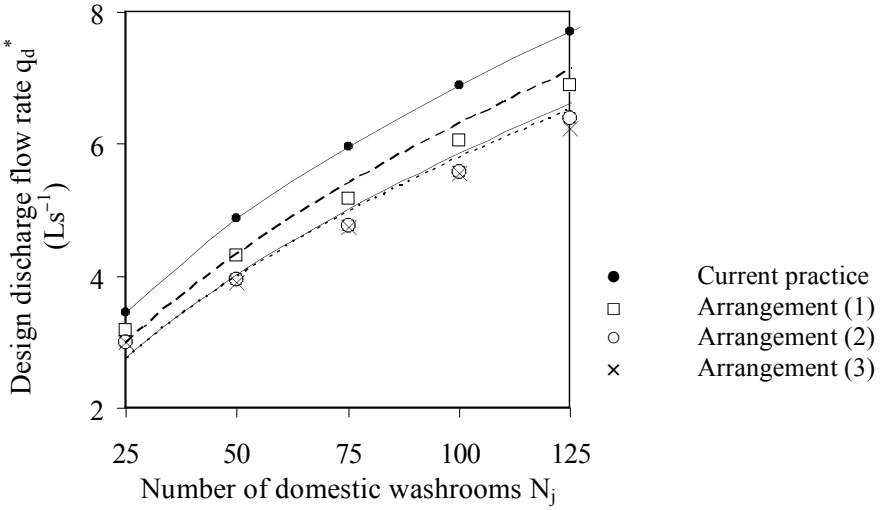


Figure 3 - Design discharge flow rates from a number of washrooms ($k_\lambda = 0.01$)

Simulation for the probable discharge flow rate at the stack in the peak hour was sampled from the discharge characteristics in Figure 2(b). For a certain number of washrooms N_j with each of the arrangements (1), (2) and (3), a total of 1×10^5 simulations were conducted in order to obtain the distribution of the stack discharge flow rate $f(q_d)$. The design discharge flow rate at the stack was determined at a limiting failure rate $k_\lambda = 0.01$ and is shown in Figure 3. Predictions using existing design guides for some buildings in Hong Kong were shown in the figure for comparison. Apparently, the assumption made for arrangement (1), i.e. no more than one appliance in the same washroom would be discharged at the same time, resulted in a lower probable maximum discharge flow rate (Plumbing services design guide, 2002). A reduction of 4.5% in the design discharge flow rate ($R = 0.9958$; $P = 2\times10^{-12}$) was found.

The attenuation effect on the probable maximum discharge flow rates due to a horizontal drainage pipe at two assigned gradients discharging into the stack, i.e. arrangements (2) and (3), was also quantified. Reductions in the design discharge flow rate of 12% and 13.4% could be obtained for arrangements (2) and (3) ($R = 0.9953$; $P \leq 2\times10^{-12}$) respectively.

5 Conclusion

The 'fixture unit' approach has been used for load estimation of drainage stacks in many high-rise residential buildings in Hong Kong, with the assumptions of simultaneous operation of all connected appliances and no attenuation effect of flow rate along a drainage pipe. Until now, the influences of drainage loads at the stack due to the attenuation effects and the simultaneous discharge patterns have not been considered in many drainage system designs and some of them might lead to problems in health, construction cost, system operation and maintenance. A new approach in determining the probable drainage loads for a stack serving a number of domestic washrooms, taking account of the attenuation effects of a horizontal drainage pipe and the probable discharge patterns in domestic washrooms, was proposed.

Probable discharge flow patterns in the stack were determined with the technique of Monte-Carlo simulations. The results showed that usage patterns of an appliance and attenuation effects of discharge flow rates along a horizontal drainage pipe at a gradient had significant effects in determining the drainage loads of a stack. It was reported that, compared with the estimated load by the fixture unit approach, there was a reduction of 4.5% in the design discharge flow rate for a washroom with no more than one appliance being discharged at the same time; and reductions in the design discharge flow rate of 12% and 13.4% could be obtained with the consideration of the attenuation effects in a 12 m horizontal drainage pipe at the gradients of 1/50 and 1/100 respectively. In order to minimize probable health, operational and maintenance problems due to an inappropriate stack size, the attenuation effects of a horizontal drainage pipe should be considered in the future drainage stack designs.

6 Acknowledgement

This work was undertaken in the Department of Building Services Engineering, The Hong Kong Polytechnic University. Funding has been received from the Research Grants Council (PolyU 5129/04E; B-Q801).

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Life Time Tests of Dry Urinals

M. Demiriz
mete.demiriz@fh-gelsenkirchen.de
Fachhochschule Gelsenkirchen University of Applied Sciences, FB3, Germany

Abstract

Three types of dry urinals were tested under real conditions. Various types of traps have been described. Build-up in the traps and drainage pipes, urine deposits and incrustations in drainage pipes of dry urinals were observed for over nine months. Tests to remove these by flushing high water volumes through the urinal itself were carried out. Water saving efficiency and some particular aspects related to the application of dry urinals were shown.

Keywords

Dry urinal, Water saving efficiency, drainage design, urinal flushing

1 Introduction

Despite the fact that dry urinals have been on the market for several decades, it was during the last few years that they have been successfully marketed in Europe. One reason for the rise in their popularity was the increasing cost of water and waste water charges. Initially there was the misconception that urinals with no water access might be unhygienic and cause obnoxious odours. Those contentions, however, were refuted through scientific research and analysis under real conditions and circumstances [1]. Urine from healthy individuals is sterile and works as a disinfectant. Through consistent daily care of the urinals with spray cleaners it is possible to keep these in top hygienic condition.

Three different types of dry urinals were tested under real conditions. Build-up in the traps and drainage pipes were observed for over nine months. Urine deposits and crust form in drainage pipes of dry urinals. It is not possible to remove these by flushing high water volumes through the urinal itself. The optimization of existing dry urinals and the new techniques developed in recent years have increased the life-span and the maintenance intervals, making their operation cost-effective.

A larger clearance has to be taken into consideration during the design and positioning of the vent pipes and the air inlet ducts because of the very intense odour in the drain lines leaving the dry urinals.

2 Types

The dry urinals differ from waterflushed urinals, and also, show variance amongst each other, mainly through the type and construction of their odor traps. At present two main variations exist on the market

a) Traps with a floating sealing liquid
b) Mechanically working traps

2.1 Traps with a floating sealing liquid

These function according to the principles of bottle or p-type traps. On the user side exits a floating sealing liquid with a lower density than water and urine. These floating sealing liquids are often pleasantly scented and have a higher viscosity and does not mix with water or urine. Thus, they form a layer on the water and urine on the user side, and prevent the obnoxious odors leaking from the urine surface. Entering the bowl urine flows through the floating sealing liquid without mixing with it. (Figur 1). In contrast to Feurich' s [2] contention, urine is neither filtered nor conditioned during this process. Organic floating sealing liquids are biodegradable, and must be topped up or refilled on regular intervals. Liquids, which are hard to break down biologically, should not be used, since under certain circumstances they will find their way into the waste water, and as a result reach waste water treatment plants or sewage-works.

Such traps are used by brands and models of Ernst, Sinaqua-Waterless, Uridan, No-Flush, Mc Dry.

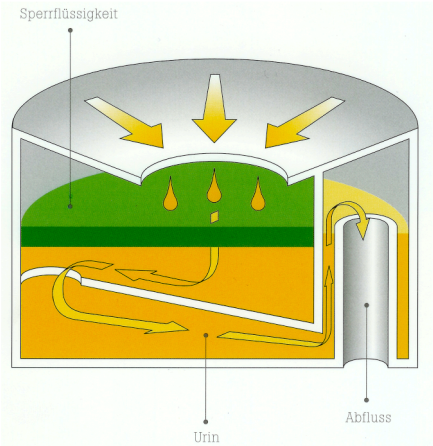

Figure 1 - Trap with a floating sealing liquid (Source: Sinaqua-Waterless)

2.2 Mechanical working Traps

Currently there are two different types of mechanical working traps on the market:

2.2.1 Trap with a buoyancy body from Urimat

This patented system (Figur 2) consists of one cylindrical plastic container (A) with overflow outlets along its circumference, a buoyancy body, and a rubber cuff with a sealing lip(D). The buoyancy body, floating in water or urine (C) is lifted upwards towards the rubber cuff and thereby seals the inlet opening. A sensor below the urinal detects the user. Subsequently an electromagnet moves the buoyancy body – before, during, and after use – downwards. As a result urine can flow from the urine collection point (B) into the trap.

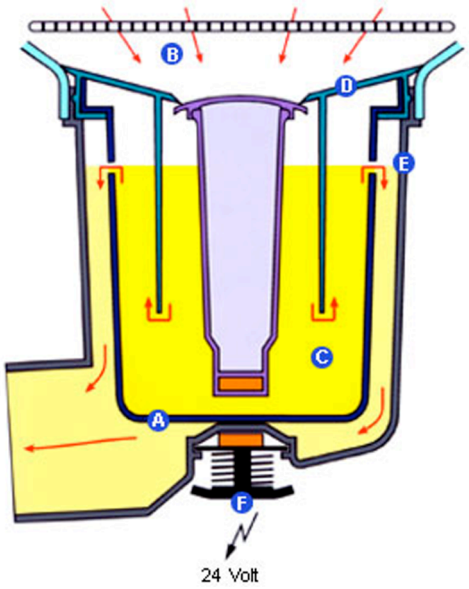

Figure 2 - Trap with a buoyancy body (Source: Urimat)

2.2.2 Trap with a duck bill

Here, a hose made from special waterproof material, serves as a trap. Its opening is round at the top, and pressed together, not unlike a pressed trouser leg, at the bottom. It lets the urine through, and immediately closes shut afterward (Figur 3 and 4). This type of trap doesn't need the floating sealing liquid or any kind of auxiliary power. Traps operating according to this principle are used by companies such as Franke, Keramag, Kuhfuss, and Sphinx.

Figure 3 - Used duck bill

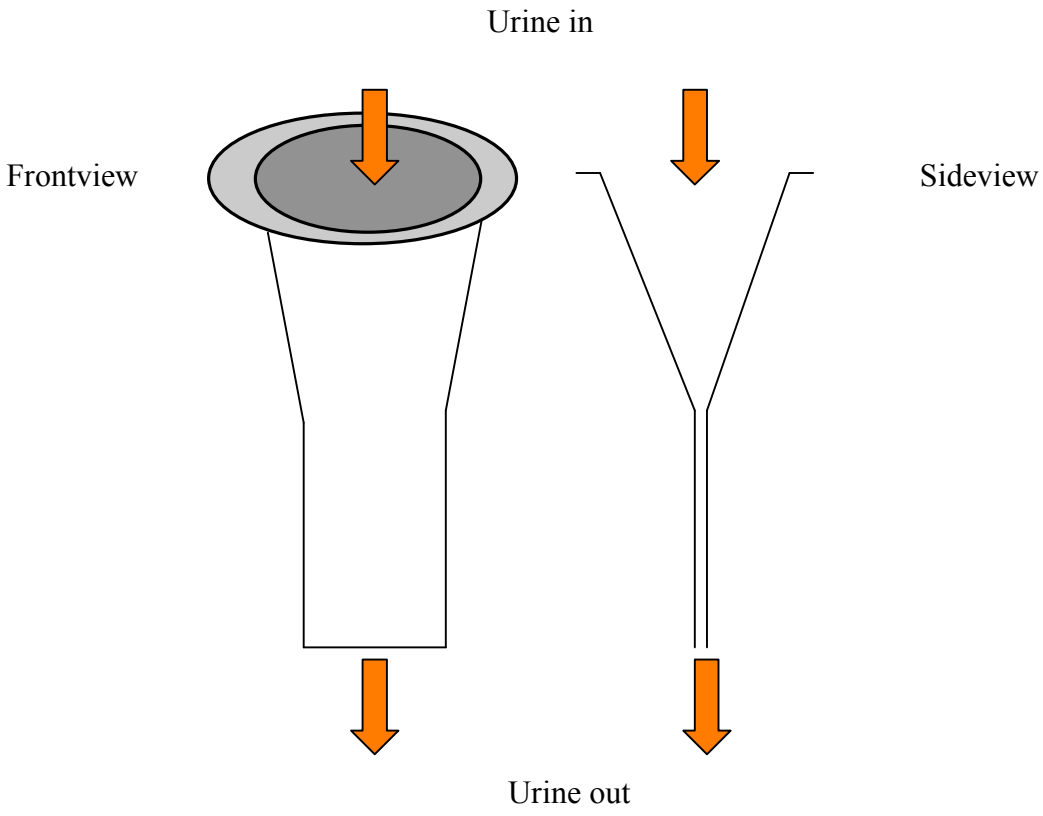

Figure 4 - Principle of the duck bill

3 Long-Term Testing

Two dry urinals each, by the companies Duravit, Sphinx and Urimat (ceramics by the Laufen Company), were tested under real life conditions for two years. For this purpose, the cafeteria toilet urinals of the Gelsenkirchen University of Applied Sciences were re-fitted. The installation was completed according to manufacturer instructions and confronted the installers with no serious difficulties (Figur 5).

Figure 5 - Tested Dry Urinals (from r.to l.): Mc Dry (Duravit), Sphinx, Urimat

The routing of the drainage line was diverted. All six urinals were connected to a 2-inch- collection line, made of glass, and joined with the individual connection line of the adjacent sink. The slope of the connection line was 1%. During the testing period it was observed that this drainline accumulated a slow but steadily growing build-up. This build-up consisted of an outer, hard layer of urine crystals, and a considerable thicker layer of sludge, which was partially penetrated by a fine hard crust, similar to puff pastry.

After nine months of use, a part of this contraption was dissembled and analyzed. The part in question was positioned behind the connection of all six urinals, but in front of the junction leading to the water drainage. This enabled observation of accumulation of all urinals in use. The thickness of the accumulation layer was 7mm thick, and 42mm wide (Figur 6). The higher this layer, the wider the adjacent flowbed became, causing slower urine flow, which in turn led to additional build-up.

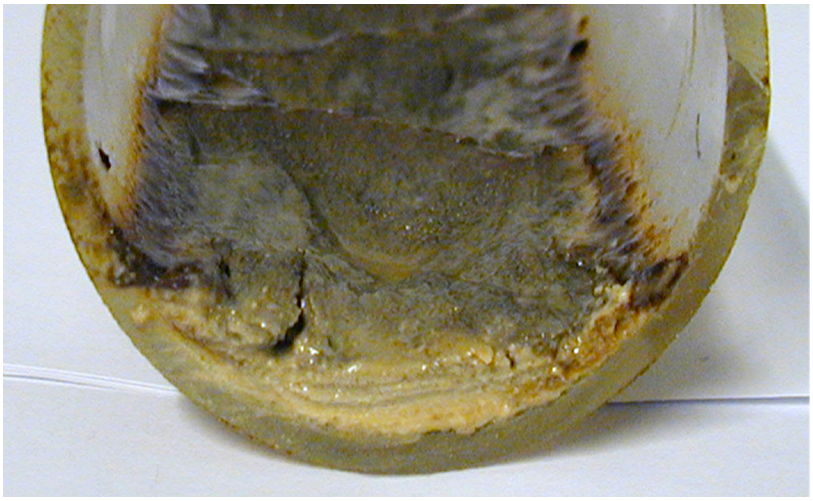

Figure 6 - Build-up in the collecting drainline after nine month of use

Both Urimat urinals were *not* maintained according to the manufacturers' specifications, so that the life span of the odor traps could be established. The manufacturer dictated a maintenance interval of 2-4 months, at which time the complete odor trap together with the buoyancy body was expected to be replaced. During the test period the odor traps gradually became dense after 8 months, and up to that point had been used 4150 times on average. Therefore, the specified maintenance interval - or even a shorter one - was deemed realistic.

The traps were clogged with hard deposits as well as sludge with organic and inorganic components. It was possible to dismantle them, and to clean them by tapping, wiping, and scraping. After that they were again fully functional. However, before they were re-installed, they had to be re-greased, since otherwise urine would have penetrated between the ceramic and the trap.

In the case of the dry urinal by Sphinx, the manufacturers' specifications concerning maintenance intervals matched the test results. At the end of the test period, the trap was taken apart, and the hose valve – acting as the odour trap – was examined for functionality. A replacement was not required, since the original one was still fully functional. There was some minor deposit at the lower edge (Figur 3). Apart from this no other anomalies were observed. Since this is a brilliant contraption, without moving parts, floating sealing liquid, or auxiliary power, only minimal breakdowns are expected.

As far as the Mc Dry model by Duravit is concerned, some congestions were noticed, mainly in the relatively small drainage openings, due to cigarette butts stuck in those openings like corks. During the monthly maintanance of the odor traps, the remainder of the floating sealing liquid had to be rinsed out together with build-up and cigarette butts.

One of the Mc Dry urinals , after an 18 month proper operation - such as cleaning and maintenance according to manufacturers' specifications – was not maintained for six months and no sealing liquid was used during this period. To document the accumulated deposits it was sawn open. It was observed that in the odor trap, a 2-6mm thick build-up had accumulated.

4 Efficiency

It is a fact that dry urinals use only a small amount of water for maintenance purposes. But to answer the question which of these systems is the most sensible in terms of efficiency, an efficiency evaluation using real data has to be conducted. Next to the cost of investment, the following aspects also play a crucial role in a proper efficiency evaluation.

- Water and waste-water charges
- Actual maintenance costs of water-flushed urinals
- Planning and construction of water connections of water-flushed urinals
- Actual maintenance intervals and costs of dry urinals
- Cleaning costs of dry-urinals
- Cleaning of drainage pipes of dry urinals
- Eventual energy costs

It is, in particular, the maintenance intervals that is the deciding factor in how efficiently the dry urinals can be operated. Complaints about the short life-span of the waterless odor traps, lead to constructive changes in the manufacturers' specifications. By enlarging the trap volume, and the orientation of the urine over-flow over the discharge pipe, the manufacturer expect to achieve 7000-8000 uses per trap. [3] Uridan urinals also have a relatively voluminous trap, so that in their case the manufacturers' specifications [4] of 5000-7000 uses can be considered realistic.

In some published efficiency calculations, the daily use of urinals is set at too high. Realistic average values show a maximum of about 50-70 uses per urinal per day. Our own measurements have shown, that by automatic urinal flushing 1.5-2 litres of water are used per flush. If this amount is used the drainage pipe stays clean, and no urine crystal build-up is formed.

5 Conclusion

- Dry urinals can be oparated hygienically, if they are maintained and cleaned according to manufacturers' specifications.
- The optimization of existing dry urinals, and new techniques in recent years have increased the life-span and the maintenance intervals, which made it possible to operate them cost-effectively.
- Despite some statements – as in Sanitarbau 2003[5] – urine deposits and forming of crusts in drainage pipes of dry urinals is still the case. It is not possible to remove these by application of high water volumes through the urinal itself.
- A very intense odour developes in the drainlines leading away from the dry urinals. A larger clearance has to be taken into consideration during the design and positioning of the vent pipes and the air inlet ducts.

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5 The Author

Mete Demiriz is working as a professor at Fachhochschule Gelsenkirchen University of Apllied Sciences in the department Utility Technologies where he is the Head of the Research and Development Lab of Sanitary Technologies. He is specialised in water saving and hygine, water and waste water hydraulics and water support of special buildings like stadions.

Evaluation of water-efficient toilet technologies to carry waste in drainlines

Bill Gauley, P.Eng. (1), John Koeller, P.E. (2)
(1) bill@veritec.ca
(2) koeller@earthlink.net
(1) President, Veritec Consulting, Inc. Mississauga, Ontario Canada
(2) President, Koeller and Company, Yorba Linda, California U.S.A.

Abstract
Anecdotal claims that water-efficient toilets are ineffective at transporting waste materials to the sewer are still relatively prevalent in the U.S. The aim of this study was to either substantiate or refute these claims by evaluating the drainline carry abilities of several different *styles* of water-efficient toilets under several different drainline conditions using a realistic test media (a combination of soybean paste and toilet paper). Testing was completed using 75mm and 100mm diameter clear plastic piping installed at various slopes ranging from zero percent to two percent. The relationship between flush volume and mass loading vs. drainline carry distance were also explored. The project concluded that all styles of water-efficient toilets tested as part of this project were capable of transporting a higher-than-average human waste loading of 200g greater than 20m in a 75mm pipe and greater than 13m in a 100mm pipe even with no supplemental flows from clothes washers, showers, etc., i.e., greater than the distance required in a typical single-family home but not necessarily greater than the distance required in commercial buildings. The study also concluded that carry distances would decrease with larger pipe diameters, flatter pipe slopes, larger mass loadings, smaller flush volumes, or the presence of 'dips or sags' in the drainline.

Keywords

Toilet; drainline; carry; slope; diameter

1 Introduction

Although suitable toilet flushing performance requirements have recently been defined, there are still those that claim that water-efficient toilets, i.e., toilets flushing with six litres of water or less, are ineffective at transporting waste from the fixture to the sewer. The concern is that low flush volumes will lead to clogging or plugging of the drainline, poor toilet performance, and potentially expensive clean-out costs.

The current North America plumbing standards mandate a drainline carry averaging no less than 12m when flushing 100 spherical polypropylene balls 19 ± 0.4mm diameter. There is some question, however, regarding the suitability of using spherical polypropylene balls to assess drainline performance.

Project Goal: to assess ability of water-efficient toilets to carry waste through drainlines under laboratory conditions and using a realistic media.

2 Methodology

This study involved physically measuring the effectiveness of several different *types* of water-efficient toilets to carry different mass loadings of a realistic test media (combination of soybean paste and toilet paper) through 75mm and 100mm diameter drainlines installed at three different slopes (0%, 1%, and 2%) with different flush volumes and different vertical drop heights from the closet flange to the horizontal drainpipe.

The following photographs show the media used in this study. The photo on the right shows 200g of media (the mass of media used in testing) and four balls of toilet paper.

Bulk Media, Toilet Paper, extruded Media

Extruded Media & Toilet Paper

A test rig was constructed such that each toilet could be bolted to a typical toilet floor flange. Clear plastic piping was used to facilitate observations. Flexible rubber-sleeve mechanical couplings were used to connect the pipe sections. A laser level was used to

establish a benchmark and ensure pipe slopes were properly adjusted. A string-line was used to ensure pipe runs were straight and true.

All toilet samples were adjusted to flush with six litres where possible (pressure-assist models could not be adjusted). Static supply line pressure for the test rig was set at 50 pounds per square inch (psi).

The test media used in this study is free to break up into smaller pieces and to either spread out as it is carried through the drainline or to 'clump up' in a ball, i.e., there is some variation in the size of the waste plug. In some cases the flushed media carried the entire 24m length of test drainline. Measurements identified in this study are based on the centre of mass of the deposited media. The length of waste plug sizes ranged from 120mm to 3600mm with an average size of 630mm and a median size of 530mm. In most cases, a second flush tended to shorten or compact the plug length slightly.

Table 1 - Variables evaluated vs. drainline carry distances:

• type of flushing system	• flush volume
• slope of the drainline,	• diameter of drainline,
• vertical drop distances	• mass of solids being flushed,
• effect of next flush[1],	• venting

Table 2 - Flushing Systems Tested

1)	Gravity - Washdown (European/Australian)
2)	Gravity – 75mm Flush Valve
3)	Gravity – Tipping Bucket
4)	Gravity – Siphon Jet in Trapway
5)	Gravity – Siphon Jet in Sump of Bowl
6)	Gravity – Rim Jet
7)	Gravity – Vacuum-Assist
8)	Pressure-Assist – 6.0-Lpf
9)	Pressure-Assist – 3.8-Lpf

3 Test Results

3.1 Effect of different flushing systems

Carry distances of each flushing system using a solids loading of 200g were compared to the *average* carry distances of all 6-L systems (Figure 6). Testing on the 75 mm pipe was completed at slopes of 0%, 0.5%, 1.0%, 1.5%, and 2.0%, and on the 100 mm pipe at slopes of 1% and 2% slopes.

[1] Refers to next naturally occurring flush, whether liquid or solids flush, not double-flushing to clear bowl.

Results indicated very little difference in carry distance between maximum and minimum drop heights (within 1% for the 75mm pipe and within 4% for the 100mm pipe). As such, data for minimum and maximum drop heights were combined when evaluating different flushing systems.

Carry distances are presented in Tables 3, 4, and 5. Test regimes where solids cleared the entire 24m length of piping were not included in the results as it was not possible to identify a final carry distance.

Table 3 - Waste Carry Distances (m), 75mm Diameter, Minimum Drop Height, 200g

Flushing Technology/Slope	0%	0.5%	1%	1.5%	2%
Pressure-Assist – 6.0-Lpf	7.5	8.8	13.6	20.1	*
Gravity – Rim Jet	7.3	9.5	11.8	16.3	*
Gravity – 75mm (3 in) Flush Valve	7.5	7.6	10.6	14.9	*
Gravity –Jet in Sump of Bowl	6.5	8.2	11.3	14.8	*
Gravity – Jet in Trapway	6.2	8.3	11.3	14.0	*
Gravity – Tipping Bucket	7.0	7.9	9.1	15.0	*
Gravity - Washdown	4.9	6.1	8.8	10.9	19.4
Gravity – Vacuum-Assist	5.2	5.8	6.8	8.1	12.7
Pressure-Assist – 3.8-Lpf	4.6	5.9	6.8	8.3	12.8
Average (not including 3.8-L model)	**6.5**	**7.8**	**10.4**	**14.3**	**-**

* media traveled entire length of drainline

Table 4 - Waste Carry Distances (m), 75mm Diameter, Maximum Drop Height, 200g

Flushing Technology/Slope	0%	0.5%	1%	1.5%	2%
Pressure-Assist – 6.0-Lpf	6.4	7.8	14.0	19.9	*
Gravity – Rim Jet	8.2	8.7	9.9	17.8	*
Gravity – 75mm (3 in) Flush Valve	7.5	8.2	14.1	17.0	*
Gravity –Jet in Sump of Bowl	6.2	7.5	10.8	12.7	*
Gravity – Jet in Trapway	5.6	8.6	11.2	16.5	*
Gravity – Tipping Bucket	5.0	7.6	10.0	12.8	*
Gravity - Washdown	4.6	6.7	8.4	13.6	*
Gravity – Vacuum-Assist	5.1	5.8	9.1	9.1	15.5
Pressure-Assist – 3.8-Lpf	3.5	5.6	6.6	12.5	16.3
Average (not including 3.8-L model)	**6.1**	**7.6**	**10.9**	**14.9**	**-**

* media traveled entire length of drainline

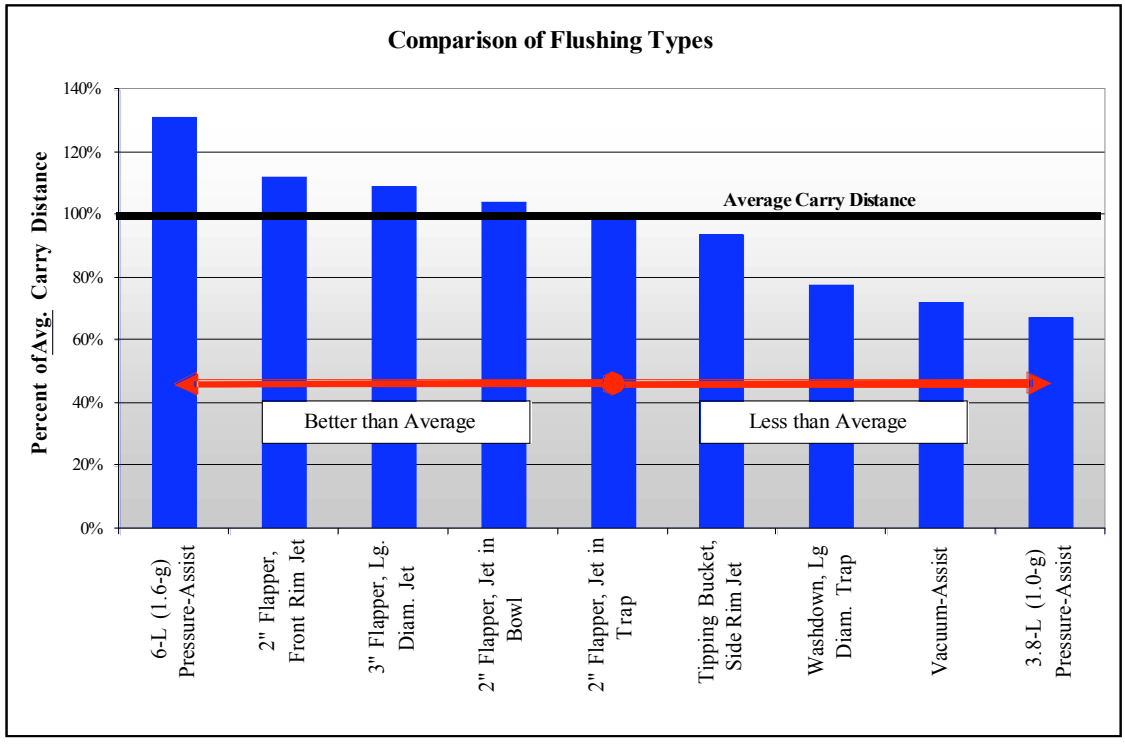
Table 5 - Waste Carry Distances (m), 100mm Diameter, Minimum Drop Height, 200g

Flushing Technology/Slope	1%	2%
Pressure-Assist – 6.0-Lpf	10.6	19.5
Gravity – Rim Jet	8.8	16.6
Gravity – 75mm (3 in) Flush Valve	9.2	15.7
Gravity –Jet in Sump of Bowl	7.8	16.3
Gravity – Jet in Trapway	8.7	11.8
Gravity – Tipping Bucket	7.3	14.2
Gravity - Washdown	6.4	10.3
Gravity – Vacuum-Assist	7.1	9.8
Pressure-Assist – 3.8-Lpf	6.7	9.2
Average (not including 3.8-L model)	**8.2**	**14.3**

The 6-L pressure-assist model had the best overall results with carry distances more than 20% further than average in the 75mm pipe and 30% further in the 100mm pipe. Results, however, indicate that there is only a modest relationship between flush rate and carry distance. For instance, the second and fourth place flushing systems are both gravity models using traditional 50mm flappers (i.e., both have a relatively slow flush rate).

In Figure 1 below, each flushing system is compared to the average of all 6-L systems to provide a relative ranking system (data for the 3.8-L pressure-assist model is not included in the average because of the flush volume difference).

Figure 1 - Comparison of Flushing Systems



3.2 Effect of toilet flush volume

Higher flush volumes equated to greater carry distances. Flush volumes between 3 and 8 litres were evaluated (larger flush volumes resulted in the media being discharged from the end of the test drainline). Pressure-assisted models were not included in this aspect of testing as their flush volumes cannot be adjusted. Test results indicate the following average relationships between carry distance and flush volume:

- Additional 2.7 m of carry per additional 1.0 litre of flush volume at 1% slope,
- Additional 4.7 m per additional 1.0 litre of flush volume at 2% slope.

3.3 Effect of Drainline Slope

Carry distance increases as pipe slope increases as follows:

- 0% slope, 75mm and 100mm piping: carry distance ~ 6m
- 1% slope, 75mm piping: carry distance ~ 10m
- 1% slope, 100mm piping: carry distance ~ 8m
- 2% slope, 75mm piping: carry distance ~ 22m
- 2% slope, 100mm piping: carry distance ~ 14m

Figure 2 and 3 illustrate approximate range in carry distances depending upon type of flush system employed.

Figure 2: Carry Distance vs. Slope - 75mm Pipe

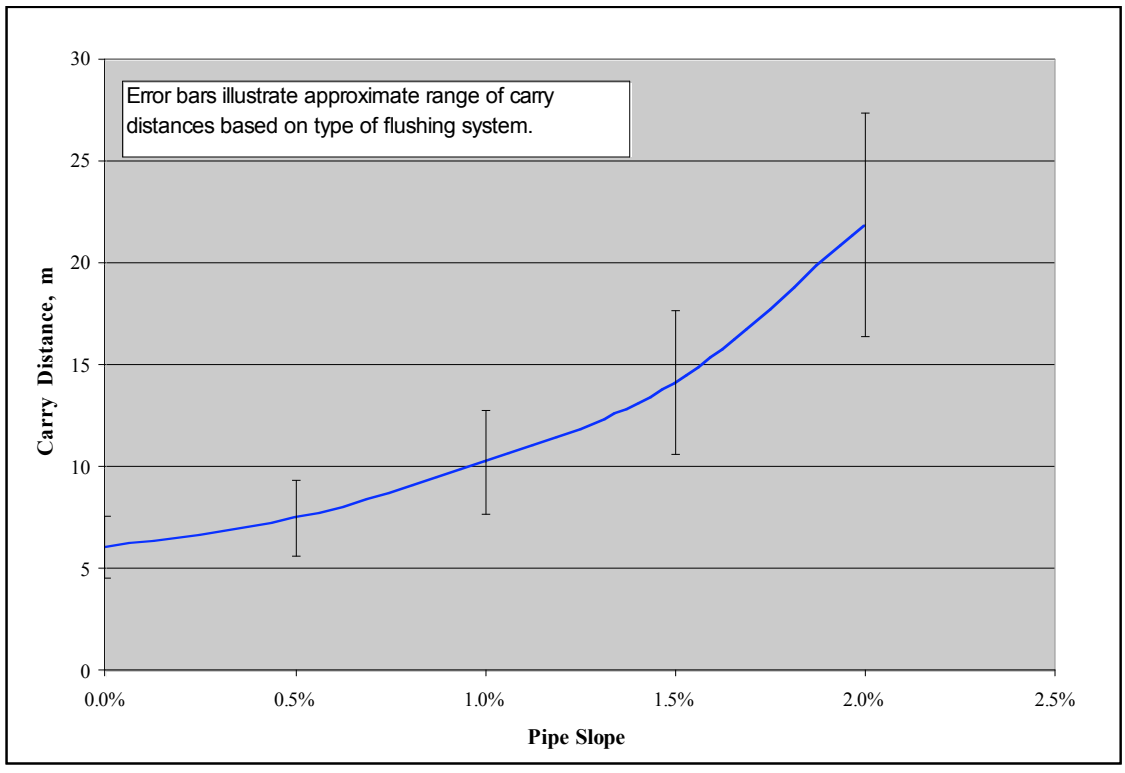
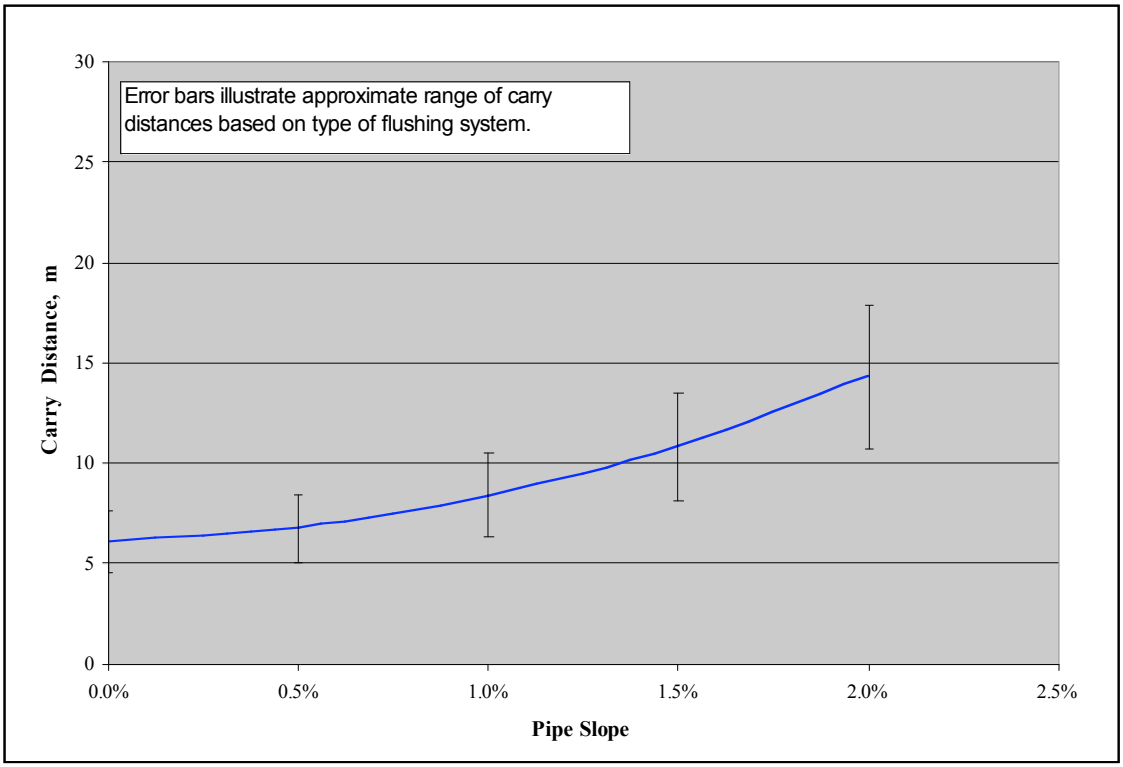


Figure 3: Carry Distance vs. Slope - 100mm Pipe



3.4 Effect of drainline diameter

Carry distance decreases as pipe diameter increases. Study data indicates that carry distance in 75mm drainlines is approximately 50% greater than that in 100mm pipes at 2 percent, and 25% greater at slopes of 1 percent.

3.5 Effect of drop height

There did not appear to be a significant correlation between the drop height between the closet flange and the horizontal drainline and the drainline carry distance, i.e., higher drop heights resulted in only *slightly* greater carry distances.

3.6 Effect of mass loading

Drainline carry distance decreases as the mass loading increases. As might be expected, increasing the mass of waste discharged into the drainline reduced the carry distance. At least within a range of 100g – 300g (typical human loading), a pipe sloped at 1 percent loses an *average* of about 1.4m of carry distance for every additional 100g of loading, whereas pipes sloped at 2 percent lose 1.6m of carry distance for every additional 100g of loading.

3.7 Effect of next flush

In real-world conditions a second flush may occur soon after an initial solids flushing or not for a day or more. In this study, however, it was not practical to wait for long periods of time between flushes. As such, the second flushes in this study followed the first (solids) flushes by only two or three minutes. The results of the second flush testing portion of this study should be taken in context and not considered to necessarily represent the effects of second flushes under different scenarios.

In the 75mm pipe, a second 'water only' flush pushed media to 170% of the original carry distance, whereas in the 100mm pipe a second 'water only' flush moved media to 159% of the original distance.

Only a limited amount of testing was completed involving second 'solids' flushes (i.e., two consecutive solids flushes). In most cases the second 'solids' flush moved the centre of mass only *slightly* further in the pipe. In some cases media from the second flush combined with that of the first flush to form an even larger *plug*.

The *second flush* results of this study tend to agree with data contained in a Swaffield/Galowin study[2] which shows a second *liquid* flush will move the centre of mass of the test media to 150% of the original carry distance, whereas a second *solids* flush will increase the carry to 125% of the original carry distance. The Swaffield/Galowin data also indicates that the centre of mass of repeated alternate solids-liquids flushing will eventually stabilize at approximately 200% of the initial carry distance.

3.8 Effect of blocking the vent

There did not appear to be a strong correlation between blocking the vent and drainline carry *under test conditions used in this study*. The results of this very limited testing should be taken in context and not considered to necessarily represent the effects of blocking the vent in complete plumbing systems.

3.9 Effect of dips and bends in the drainline

Carry distances decrease as drainline becomes less straight and true. Although this aspect of the testing program was limited (the number of possible variables is infinite), the results indicate that dips and bends in the piping will reduce carry distances.

3.10 Minimum expected carry distance ULF Toilets

Most concerns expressed by the public involve the ability of water-efficient toilets to carry solid waste to the sewer in residential installations. These concerns may be somewhat

[2] Big Drains, Small Drains, How do your wastes flow?, ASPE 1992 Convention Proceedings Technical Papers, Nov. 14-17, 1992, Washington, DC, pp 45 - 115, by Lawrence S. Galowin & John A. Swaffield

misplaced as a toilet flush would only be expected to transport waste to the building drain where the flow would be augmented with supplemental flows from showers, baths, clothes washing, etc. Rarely would a toilet flush alone be expected to transport waste to the municipal sewer. Under conditions described for this study, the test models were able to transport test media approximately 20m in a 75mm drainline at 2 percent *without any supplemental flows*. Only in very rare instances is it likely that residential drainline carry requirements would exceed this distance.

Commercial installations, however, are far more likely to have larger diameter drainlines, longer runs, and little supplemental flows. Study results indicate that there may be potential for waste remaining in, and potentially blocking, 100mm drainlines installed at 1 percent if distances exceed approximately 15m.

Table 6 summarizes the average distance achieved by the nine test fixtures. These values reflect the installation conditions outlined in this report.

Table 6 - Waste Carry Distances, metres (at 200g load)[3]

Fixture Type	Drainline Installation Characteristics			
	75mm drainline		100mm drainline	
	1% slope	2% slope	1% slope	2% slope
Pressure-Assist – 6.0-Lpf (1.6-gpf)	13.6	> 24.4	10.6	19.5
Gravity – Rim Jet	11.8	> 24.4	8.8	16.6
Gravity – 75mm (3 in) Flush Valve	10.6	> 24.4	9.2	15.7
Gravity –Jet in Sump of Bowl	11.3	> 24.4	7.8	16.3
Gravity – Jet in Trapway	11.3	> 24.4	8.7	11.8
Gravity – Tipping Bucket	9.1	> 24.4	7.3	14.2
Gravity - Washdown	8.8	19.4	6.4	10.3
Gravity – Vacuum-Assist	11.3	12.7	7.1	9.8
Pressure-Assist – 3.8-Lpf (1.0-gpf)	11.3	12.8	6.7	9.2

Figures 4 and 5 on the next page can be used to estimate approximate carry distances under various scenarios for both 75mm and 100mm drainlines. For example, the carry distance for a toilet flushing 500g of mass loading with a flush volume of 6.5 litres in a 75mm pipe would be approximately 19m. A rectangular indicator on the charts identifies the expected performance range for an average ULF toilet flushing an average human loading with a drainline slope of 2 percent.

[3] Total length of test piping was 24.4 m (80 ft).

Figure 4 - Drainline Carry in 75 mm Diameter Pipe

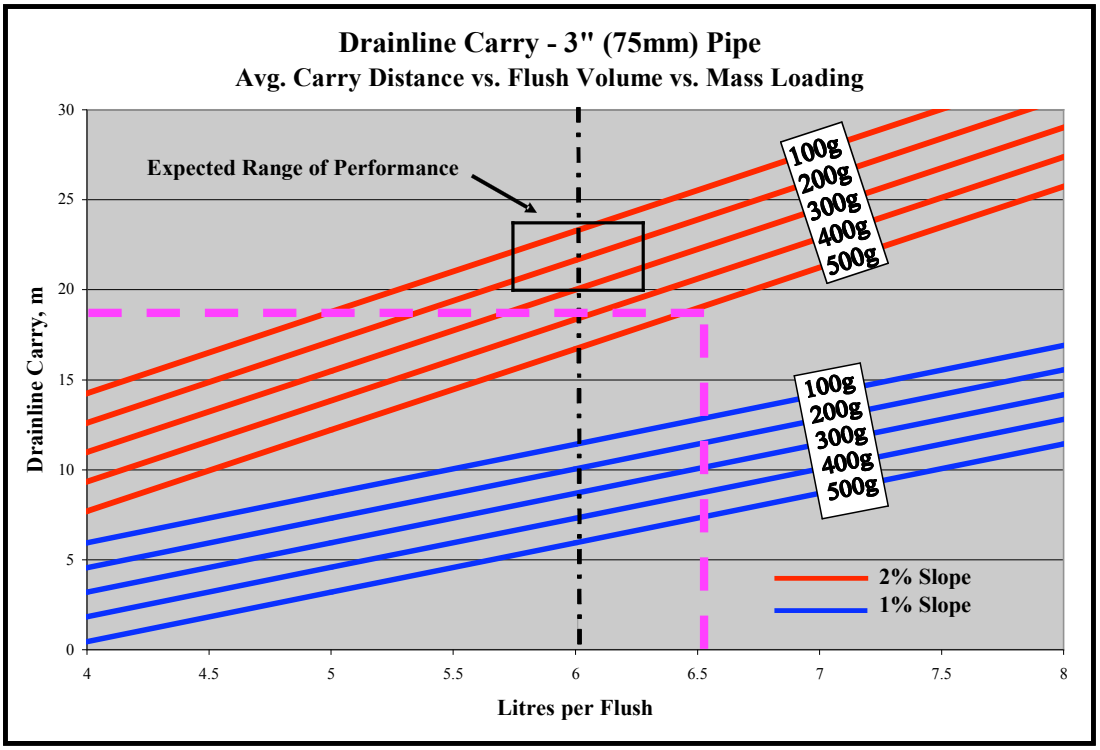
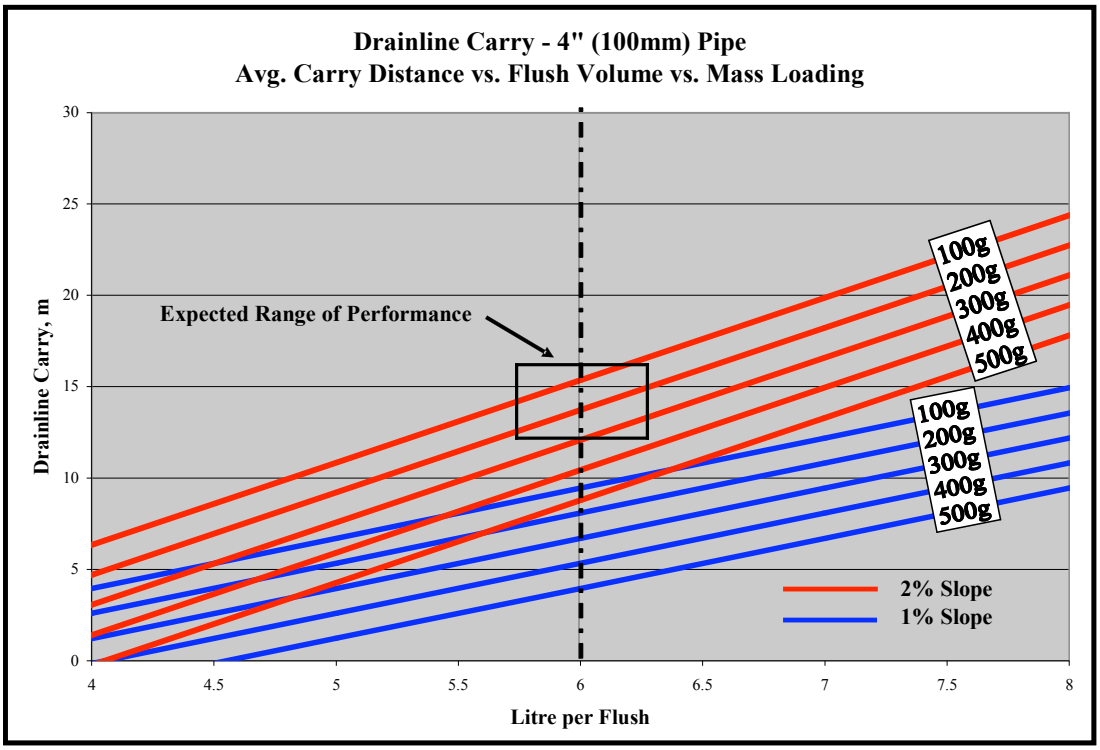


Figure 5 - Drainline Carry in 100 mm Diameter Pipe



4. Conclusions

75 mm piping installed at 2 percent slope (typical of residential installation): Under study conditions water-efficient toilets can transport 200g of test media approximately 16 – 27m, depending on type of flushing system, without supplemental flows.

100 mm piping installed at 1 percent slope (typical of commercial installation): Under study conditions water-efficient toilets can transport 200g of test media approximately 6 – 10.5m, depending on type of flushing system, without supplemental flows.

Under conditions examined in this study (clean drain pipes, straight runs, and proper slopes), all toilet models tested would be expected to meet or exceed the relatively short waste carry distance requirements typical of *household* plumbing installations even with no supplemental flows. Installations with extremely long drainage distances, e.g., shopping malls or industrial sites, however, may require evaluation on a site-by site basis, especially if no supplemental flows are available.

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Presentation of Authors

Bill Gauley, P.Eng., is a founder and principal of Veritec Consulting Inc., Mississauga, Ontario, Canada, where he is in charge of all fixture testing operations and the development of all municipal water-efficiency programs.

John Koeller, P.E. is the president of Koeller and Comapany, Yorba Linda, California. He has managed and conducted numerous scientific evaluations of water-efficient products, whose results are used widely by water agencies as the foundation for various water conservation initiatives.

Architectural Significance of Original Water Supply Systems: Sanliurfa (Turkey) As A Case

A. Temizsoy (1)
tarzu@arch.metu.edu.tr
Department of Restoration, Faculty of Architecture, M.E.T.U, Ankara, Turkey

Abstract

The original water supply systems of Anatolian cities have been destroyed as a result of implemented development plans. Today even the traces are almost lost without any measured records. As a part of preserving cultural heritage, the water supply and drainage systems of historic cities should be documented and analyzed in order to bring to light the environment-based solutions implemented in historic constructions. In this context, the city of Sanliurfa located in South-Eastern Anatolia is a good example with its well-preserved original urban water system, which supplies water for religious, commercial and public buildings, dated from 16th to 18th century. Because of the hot arid climate of the region, its original water supply system should have been planned as efficient, economic and sustainable system. In this connection, this paper tries to discover the water supply system in Sanliurfa, with a particular emphasize on architectural structures and elements, used by this system. At the end of this study, it is expected to state that Sanliurfa as an old Islamic city has a planned water system.

Keywords

Sanliurfa, urban water system, Byzantine aqueduct, Justinian dam, water collection tank, pool, fountain, cistern, pits for preserving snow

1 Introduction

Today we, as planners, architects and engineers, start to concern about careful utilization of natural sources while our decisions start to be taken on ecological grounds. Yet so many of the ancient cities survived for such long times indicate that men in history have been careful and respectfully managed the sources of ecosystem. They were successful in city site selection, which is in harmony with nature and also in city building, in terms of location, sitting, orientation and the well-informed choice of material. They also paid careful attention to water supply and distribution, which has

been essential particularly in hot arid Mediterranean climate. Because of the gap in the engineering history of cities, however, we have limited information about the water management in Mediterranean cities and their urban water supply and distribution systems.
In this context, the present study of the complex distribution network of supply yields a map of urban water system within Sanliurfa in Turkey. The city provides powerful example of water in the urban landscape and water as the importance of urban ecosystem. The abundance of water was a prime reason for selection of Sanliurfa for settlement, as it was for continued growth of the settlement. Enough water was available for ordinary domestic use, for industry, for ritual ablutions, and for the public baths that were so important an amenity of everyday life. The city had both public fountains and springs supplying flowing water of the best quality, and private cisterns in houses and public buildings to supply water of good quality. The city had wells and pits used for collecting and storing rainfall and snowfall.
First, the paper introduces the city of Sanliurfa and makes a rapid survey of topography, climate, and urban settlement, which are important natural features in the formation and development of the city. Then it presents the water sources, original water supply systems, and water system elements in Sanliurfa.

1.1 Urban settlement of Sanliurfa

Sanliurfa is located in the South-Eastern Anatolia, between longitudes 36°40 and 38°02 East and latitude 37°50 and 40° North. The altitude of the city ranges between 500-1000m, decreasing from north to south. The climate in the region is hot arid that means rainfall is concentrated in the winter months as well as there is a high temperature differences between day and night. The temperature in general is lowest in January and highest in July and August. The annual mean temperature is 18.1C° and annual mean range 37.7C°. Considering the topography, the foothills on the south and the river on the north and east are the natural boundaries. The river was called in Syriac Daisan, in Greek Scirtos and in Turkish Karakoyun. The land on the right of the river is both flat and low, while on the left stand the steep hill. (see city map)

Figure 1 - Panaroma northwards from the citadel mount.

Figure 2 - The citadel mount and columns from the Pool of Zulha

The earliest buildings of the city have been founded on the contours of the ground narrowly confined between the foothills and the riverbed and the area is still the focus of urban life. (figure 1-2) The citadel stood on the foothills on the south and surrounded

the historic city by high city walls. The walls to the north and west run alongside the valley, while to the east laid orchards and gardens in the low-lying land at the edge of the Harran plain. There were four city gates, sited at approximately the cardinal points of the compass; the West Gate, in the east Great Gate (*Bey Kapısı*), in the south the Gate of Harran, and in the northwest Gate of Samsat. Today, remains of the citadel still stand on the mount but unfortunately great part of the city walls and two city gates do not exist. The historic city still preserves its traditional form. Here we mean the organic and narrow street pattern, densely concentration of major public buildings in the city center, and the introverted courtyard houses.
Occupation of the Sanliurfa area - Edessa in Roman- begins from the 8th millennium BCE through Mittani times in the 2nd millennium and continuous from Hittates, Assyrian, Persian and early Roman periods of the 1st millennium BCE into the Imperial Roman and Byzantine era of the first millennium of our era. Settlement continues through the Arab occupation beginning in the 7th century CE through and continuous from Seljukid, Safevid, and Akkoyunlu periods of the 15th century. Turkish occupation begins from the 16th century and continues until the present.

1.2 Methodology

This study is based on the field investigation on the physical remains of urban water system. The water system is documented by using the traditional measuring techniques (hand measurement and documentation with photograph). The field survey is drawn in 1/1000 scale.

2 Water sources

Water is mainly supplied by the river Karakoyun flowing from the north along a channel to circuit the city in the east. In the past, however, it flowed from the northwest along a deep valley to enter the city in the southwest. Its water was swollen by the onrush of the winter rains and the melting snows of the mountains that caused serious disasters in the city, heavily loss in life and the destruction of the chief buildings; for example, achieve documents mention about the floods in 201, 303, 413, and 525.

Figures 3-4 - Dam first constructed by the engineers of the Byzantine Emperor Justinian in early 6th century

After the flood of 525, the central government ruled by the Byzantine Emperor Justinian made initial attempts to prevent the recurrence of such disasters. This event proved a turning point in the architectural development of Sanliurfa. The engineers of Justinian carried out important alterations to the course of the river to the north and west of the city and of the spring waters that joined it. They set up a huge wall of stones to the northwest of the city that conducted the river by an artificial channel outside the north and east walls of the city. (Figure 3-4) When the river raised to an exceptional height, the excess waters passed over the dam on the southern or right bank of the river and followed the old course of the valley bed southwards alongside the west walls. The remainder of the stream would pass under constraint into the channel devised by Justinian (Segal, 1970). Justinian's system remains to the present day.

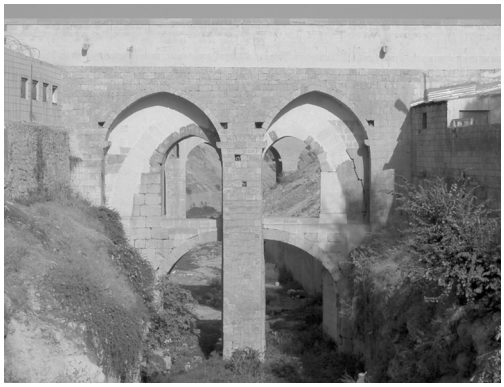


Figure 5 - Byzantine aqueduct constructed in early 6th century

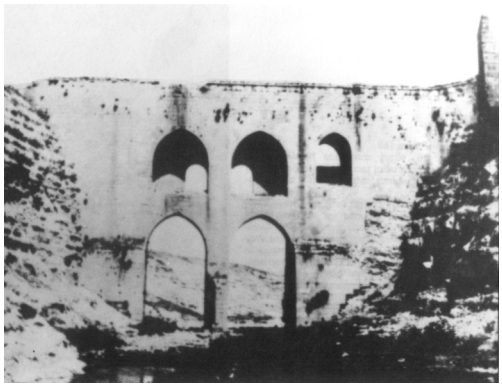


Figure 6 - Hizmali Bridge and its water collection tank on the right (dia achieves by Kurkcuoglu)

Besides the adaptation in the course of river, aqueducts were constructed on the new course of the river (figure 5). In principal, aqueducts served both as water supply canals and also bridges across valleys. The main features of the aqueducts were that they extended from distant spring-fed sources or the river in the form of tunnels through the hills and over bridges across valleys bringing water into reservoirs for onward distribution to the city. In the case of Sanliurfa, aqueducts brought water into the city from twenty-five springs lie at some distance in the high lands to the north. Until the recent past, Sanliurfa was served by a Byzantine aqueduct and two Ottoman bridges (Hizmali and Millet). Basically, these three separate features should have supplied water for the multi-compartment collection tanks constructed at the end part of these structures (figure 6). By using the hydraulics principles, engineers distributed water from the high points within the city (collection tanks) to various destinations, such as baths, fountains and domestic neighborhoods.

The second important water source is the underground springs. They followed a straight course by sluices alongside the west city walls. There was a water gate stood near the West Gate that admitted the springs to flow into the city (Segal 1970: 7, 185-187). The water supply coming from the springs feed two famous pools lying below and due north of the Citadel mount; one is called the Pool of Ibraham, and the other the Pool of Zeliha (figure 7-8). The natives of the city also call them as fish-pools because there are hundreds of fishes, which have been believed as sacred. The Pool of Ibraham is a major water source of the Sanliurfa. It has been framed with an architectural setting (the building complex of Rızvaniye) since Ottoman times. The complex is composed of two

mosques, and a madrasa. The Pool of Zeliha is the second major water source. There are no edifices near the pool. The source of the spring feed the building complex of Ibraham, which is composed of a tomb and a mosque.
After feeding the pools, the natural springs have followed originally two main routes and supplied destinations, such as baths, fountains, cisterns and domestic neighborhoods. Thus historic settlement with its public buildings and private shops had taken place according to the spring-beds. Moreover, the usual components of water elements have been systematically located. It is reasonable to continue to use outlets, but to re-supply them with long-distance lines bringing additional water from farther uphill and from the north.

Figure 7 - The pool of Ibraham and Rizvaniye Mosque dated to 1720s

Figure 8 - Source of the spring in the middle of the Pool of Zeliha

Considering the sources of the springs, it seems likely that there were four sources near the pools of Ibrahim and Zeliha; two fountains located just at the edge of the pool of Ibraham, one in the middle of the pool Zeliha and one fountain in the Tomb of Ibraham, near the Halil Ibrahim Mosque. In appearance, the fountains are caves and the water is believed as sacred. (Figure 9)

3 Urban water supply systems

The water was supplied by three main water pipe lines in the city of Sanliurfa. Below the general features of these systems is given.

3.1 Water pipeline – 1

The first water pipeline supplies water for baths, fountains, wells and the houses, located in the northern districts of the city. Once the aqueducts reached the city, water was collected in the water tanks (WT 1-2). Then it was distributed through pipes and channels to another water tank (WT 3), just adjusted to the Kadioglu mosque by using Hydraulic principles. The water tank (WT3) distributes water through two main branches;
(i) The first branch of the water line supplies water to the Great Mosque, street fountains adjusted to Eyyubi Madrasa, Nimetullah Mosque, kiosks of Seyh Ebubekir and Firuz Bey, and Seyh Saffet Street Fountain
(ii) The second branch of the water line supplies water to the Yusuf Paşa Mosque, Vezir Bath, and Huseyin Pasa Mosque

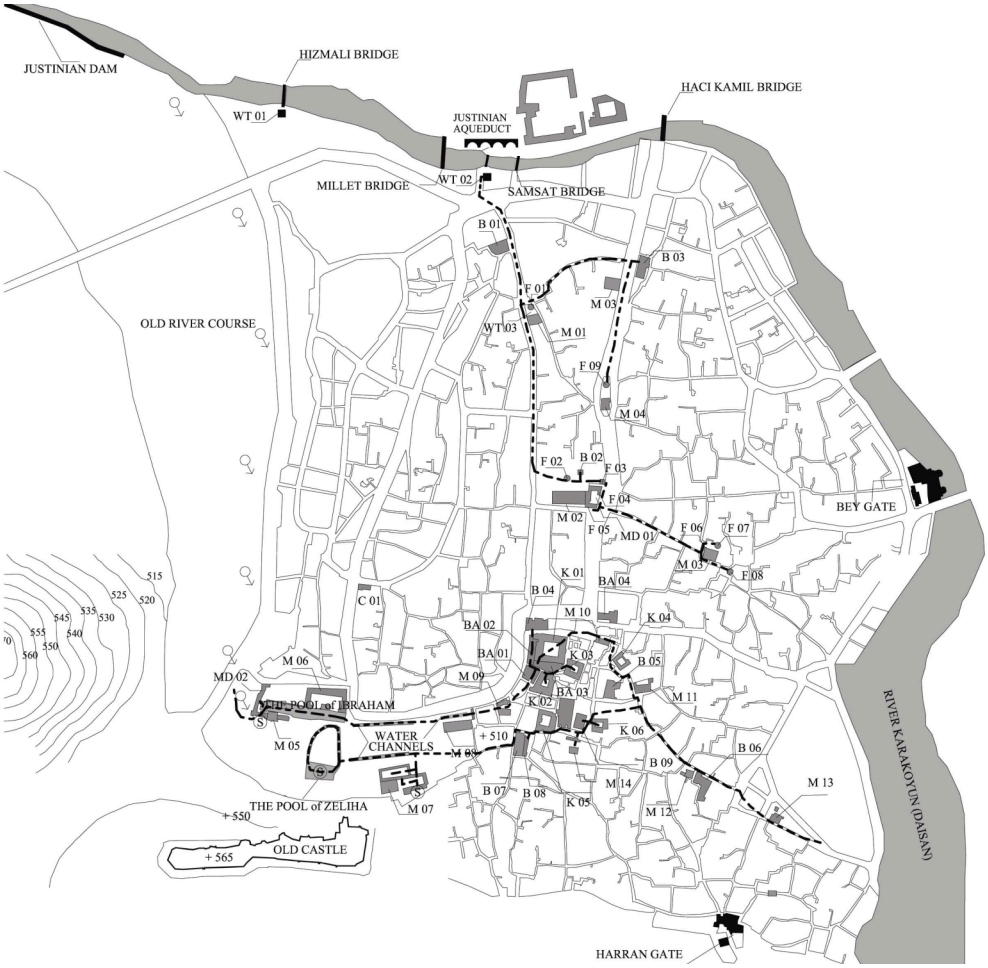


Figure 9 - Site features of the city of Sanliurfa and its water distribution pipeline

Water Pipeline 1: B01-Serce Bath, F01-Mencekzade Street Fountain, M01-Kadioglu Mosque, M02-Great Mosque, F02-Fountain of Great Mosque, B02-Bath of Great Mosque, MD01-Eyyubi Madrasa, F03- Seyh Ebubekir Fountain/kiosk, F04-Yildiz Meydani Street Fountain, F05- Firuz Bey Street Fountain, F06- Firuz Bey Fountain/kiosk, F07-Fountain of Nimetullah Mosque, F08- Seyh Saffet Street Fountain, M03- Yusuf Pasa Mosque, B03- Vezir Bath, M04- Huseyin Pasa Mosque, F09-Fountain of Huseyin Pasa Mosque

Water Pipeline 2: M05- Halil-ul Rahman Mosque, M06- Rizvaniye Mosque, The Pool of Abraham & Water Channels, M08- Hasan Padisah Mosque, M09- Narinci Mosque, BA01- Pamukcu Bazaar & Water Mill, BA02- Sipahi Bazaar, B04- Arasta Bath, BA03-Bedesten, K02- Fountain of Mencek Khan, K03- Fountain of Haci Kamil Khan, K01-Stream of spring water in the courtyard of Gumruk Khan, M10- Fountain of Pazar Mosque & Water Mill, K04- Kumluhayat Khan, B05- Velibey Bath, M11- Tabakhane Mosque, M12-Hizanoglu Mosque, B06-Cincikli Bath and Water Mill, M13- Cakeri Mosque, three Water Mills (Mazi, Dabakhane, Sultanlik) on the same water line

Water Pipeline 3: The Pool of Zeliha & Water Channels, M07- Mevlidi Halil Mosque, B07- Sultan Bath, B08- Kececi Bath, K05- Barutcu Khan, M14- Omeriye Mosque, B09-Saban Bath, Connected to the second water pipeline near the Tabakhane Mosque

3.2 Water pipeline – 2

The second water pipeline supplies water for the baths, fountains and cisterns located in the commercial center of the city. Once the natural spring feed the Pool of Ibraham, it flows through the open channels that are directed to the Hasan Padisah Mosque. Then the stream from the springs runs along the courtyard of the mosque. It is the last time to the flow of the spring on the ground level because the spring starts to flow through the underground tunnels. The second water pipeline supplies water for several important religious, commercial and public buildings in the commercial center; such as Gumruk khan, Mencek Khan, Haci Kamil Khan, Arasta Bath, Velibey Bath, Cincikli Bath, Narinci Mosque, Pazar Mosque, Tabakhane Mosque, Hizanoglu Mosque and Cakeri Mosque. Its water was also used for small industrial activities in the commercial center in the past. For example, it was used for dying cloths or cleaning the leathers. The water is also used for irrigating the orchards and gardens on the neighborhoods of commercial center. Finally, the spring leaves the city in the eastern wall.

Figures 10-12: Water mill (left), open water channels from the (middle), stream from the springs of water flowing through the courtyard in the Hasan Padisah Mosque (right)

3.3 Water supply pipeline – 3

The third water supply pipeline is mostly an underground tunnel system originally fed by piping from a small natural spring. The spring is first feeding the Pool of Zeliha. Then it supplies water for Sultan Bath, Kececi Bath, Saban Bath and Saban Khan, and Omeriye Mosque. Finally it connects to the second water pipeline near the Tabakhane Mosque.

4 Water System Elements

The elements of the urban water system are aqueducts tapping distant springs, water collection tank structures, open channels, distribution pipelines to baths, fountains, on-site wells and cisterns, pits for preserving snow.

4.1 Public Baths

Today, we know of six major public bathing facilities within the city, which are supplied by the same water piping lines. They were constructed in the Ottoman period and dated from 16th to 17th century: Vezir Bath, Saban Bath, Arasta Bath, Sultan Bath, Veli Bey Bath and Cincikli Bath. For economy, they are located as close as possible to the main waterlines. They are still representing the general characteristics of their period. Because of the bathing activities, they have hot and cold water supply systems, heating system and waste water system, forming the overall service systems of the structure and using the same water and/or heating sources. (Temizsoy, 2004)
There are also single-room baths, located in the courtyard of mosques. This type of small baths was founded for the charity and they were free for poors. In Sanliurfa, they were taken place according to the spring-beds. We can give the small baths located in the courtyards of Hasan Padisah Mosque, Hizanoglu Mosque, Great Mosque as examples. In plan, they have single room, less than 2m wide and 2m long.
Different from bathing activities, there are special baths used for the production of felt by the crafts. Felt is a material made from goat wool and it was usually used for the floor covering in the past. The Kececi Bath is a good example for this type, which is adjusted to the Sultan Bath. It has a rectangular plan and having two rooms; one is used by the crafts for resting and the other is used for the production of felt.

4.2 Open Channels

The pools and the open channels in the courtyards are used to purify air and create comfortable resting places.

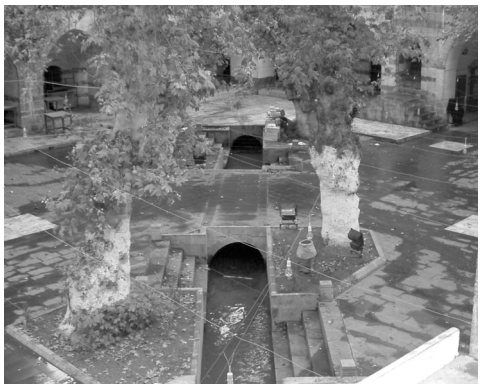


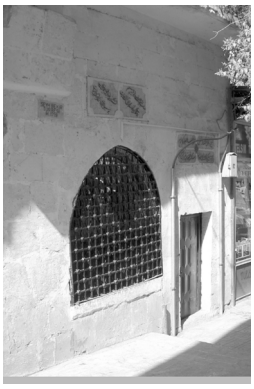
Figure 13 - Stream from the springs of water flowing through the courtyard in Gumruk Khan

Figure 14 - Pool and the water channels in the courtyard of the Mevlidi Halil Mosque

4.3 Fountains

There are three types of fountains in Sanliurfa; street fountains, kiosks type fountains and fountains as a separate structures. In general, street fountains attached to the walls supply drinking water for the houses and shops. The mosques have fountains usually located in the middle of courtyard, which are used for ritual ablutions and as drinking

water because of its good quality of water. There are also kiosks (*sebil*s) built for the dispensing of free drinking water as an act of piety.



Figures 15-17 - Firuz Bey street fountain (left); Seyh Ebubekir fountain/ kiosk (middle); Fountain of Great Mosque (right)

4.4 House Form and The Use of Water:

For most domestic tasks, the cistern under each courtyard was the normal source of water. The rainwater that fell on the roofs of houses was collected by the floor slope to the wells and stored in cisterns. If the rainfall is collected during the winter, it was enough to supply all family needs for several months.

Figures 18-20 -Well of Job at makam Nebi Eyüb (left) and two wells located in the courtyards of traditional houses

Locating the cistern in the courtyard also meant that this was a logical place for the basin for washing hands, faces, and dishes. It seems likely that there was an efficient grouping of water-use features of the houses. Since the cisterns were cleaned out annually, the water in them was essentially clean and could be used for cooking, domestic cleaning, watering animals, and plants. However, most families preferred the taste of spring water for drinking.

Small pools located in the center of courtyard are the second prominent element in the houses. They are mostly square, sometimes circular and polygonal in shape. In general, there is also a planting section in the courtyard near and around the pool. Considering the hot arid climate, the pool in corporation with greenery and trees help to create a

good microclimate in the courtyard and decreases the uncomfortable effects of summer heats.

4.5 Pits for preserving snow

During the winter, the snow was collected and stored in the caves, located in the foothills on the southwest of the city. The pits carved on the floor were used for preserving snow for summer use. The process is simple; the pit was filled with snow and then snow was pressed to produce ice. Finally, the opening of the pit, which was approximately 6-10m wide was closed until summer. The pits in Sanliurfa were approximately 8-15 m high and somewhat between 4-6 m wide.

5 Conclusion

Since the urban water systems of Sanliurfa have functioned properly for hundreds of years under hard environmental conditions, they deserve more comprehensive and extensive studies. There is necessity to better understand their original characteristics, capacity, and sustainability properties for their repair and maintenance. This paper would be evaluated, as an attempt to understand the ancient principles of the urban water system in Sanliurfa. The study indicates some important results. First of all, there is continuity in the usage of water engineering techniques in centuries; for example, the Ottomans used the Byzantine's water system with its dam, aqueduct, water collection tanks, and water channels by repairs and maintenance. Secondly, Ottomans constructed several important religious, public and commercial buildings on the natural course of springs. Considering the hot arid climate, it is functional and reasonable to formation and development of city center through the springs in order to create necessary human comfort, the effective and economic usage of water.

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7 Presentation of Authors

Arzu Temizsoy is a Ph.D. student at Middle East Technical University, in the Department of Restoration. She is working as Research Assistant at Department of Architecture. She is specialised in the conservation of Ottoman city khans located in South Eastern Anatolia.

Potable water slow sand filtering application from a two centuries basis

Dr. Lawrence Galowin, Consultant
larrygales@earthlink.net

Abstract

Slow Sand Filter (SSF) provides a simple means of potable water treatment that qualifies to the minimum potable water specifications of World Health Organization (WHO). World wide potable water unavailability noted stresses desperate need to prevent major death rates particularly in underdeveloped nations by alleviating serious lack of potable water. Successful SSF technique applications by philanthropic organizations and national aid agencies do not achieve vast implementations for "world needs to prevent deaths due to the water crisis" (Pure Water for the World). The new project introduces the "Quencher[1]" and comprehensive programmatic plans that included new design and materials advances in application to low cost devices. The comprehensive scope included establishment of all functions/operations, demonstrated implementation procedures, and implementation results established of reliable performance data banks which interested organizations can apply internationally for worldwide expanded SSF implementations. Clarifying water by SSF active mode occurs in a thin upper sand layer called **'Schmutzedecke'** (German for "dirty skin") that forms on the sand bed. The function is provided from biologically active microorganisms in a 'mat' that break down organic matter while suspended inorganic matter is removed by straining. A basic sand fill rests on gravel (or other support porous media base) that fills a container. **Schmutzdecke** contains biologically active media described in SSF information of the method realized from almost two centuries historical experiences but lacking descriptive functions.

Keywords

Potable water, slow sand filters (SSF), world water needs, water filtration methods

[1] EPGW - The Entrepreneurial Partnership of Greater Washington (EPGW) is an IRS qualified 501 C3 that focuses on the development of creative solutions to problems of humanity; developer of Quencher new SSF model.

1 Introduction

A recent United Nations statement on the worldwide "silent humanitarian crisis" lack of potable water in undeveloped nations (1) indicates calamitous tragedies of deaths and illnesses that potable water could almost eliminate extents of tragic events. UNESCO and UNICEF warnings of a major environmental problem points to the vast extent of lack of potable water which cite "… a death every six seconds … 2.3 billion suffer… almost 5,000 children die from water borne diseases … and that "50% of the world's wetlands have disappeared, and in the past century, water withdrawal has increased almost tenfold" when coupled with population growth results in human catastrophe. 'Pure Water for the World' indicated of crises in the world today—wars, famine, AIDS, landmines— all pale in comparison to the water crisis.

The historical two century records of Slow Sand Filters developments provided a basis for the new project approaches and extension of methods for implementation. Several characteristics for water filtering methods are indicated:

	Slow Sand Filter	**Rapid Sand Filter**	**Diatomaceous earth filter (Diatomite filter)**
Filtration rate (GPM/ft^2)	0.015-0.15	2-3	1-2
Pros	Reliable. Minimum operation and maintenance requirements. Usually does not require chemical pretreatment.	Relatively small and compact.	Small size Efficiency. Ease of operation. Relatively low cost. Produces high clarity water. Usually does not require chemical pretreatment.
Cons	Large land area required. Need to manually clean filters.	Requires chemical pretreatment. Doesn't remove pathogens as well as slow sand filters.	Sludge disposal problems. High head loss. Potential decreased reliability. High maintenance and repair costs.
Filter Media	Sand.	Sand. Or sand and anthracite coal. Or sand and anthracite coal and garnet.	Diatomaceous earth.
Gravity or Pressure?	Gravity.	Gravity.	Pressure, gravity, or vacuum.
Filtration Mechanism	Biological action, straining, and adsorption.	Primarily adsorption. Also some straining.	Primarily straining.
Cleaning Method	Manually removing the top 2 inches of sand.	Backwashing.	Backwashing.
Common Applications	Small groundwater systems.	Most commonly used type of filter for surface water treatment.	Beverage and food industries and swimming pools. Smaller systems.

Various philanthropic organizations and national aid agencies have applied SSF in projects for users in needy locales. From references on methods, realization techniques, and provision of construction essentials and/or newer operations conceptual and practical implementations were foreseen. Limited performance data appears with data detailed documentation. The new project plan for implementations included development of comprehensive detailed records for worldwide availability. Specific detailed results were foreseen as means to achieve needy regions' programmatic expansions to eliminate deaths and disease by broadened SSF usages.

2 Historical Brief

Water treatment history dates back to approximately the thirteenth century B.C. in Egypt. Two centuries ago slow sand filtration introduction as built by John Gibb's in 1804 in Scotland, was the first filter used for treating potable water in large quantities. Slow sand filters spread rapidly with the first in the United States built in Richmond, VA, in 1832. A set of slow sand filters adapted from English designs was built in 1870 in Poughkeepsie, NY. A few decades afterwards the first U.S. rapid sand filters were installed that is linked to the discovery of coagulation. Addition of certain chemicals (coagulants) to turbid water causes material to be made to clump together and quickly settle out so that clear water from rapid filtration could be produced from turbid, polluted streams.

3 Prototype "Quencher"

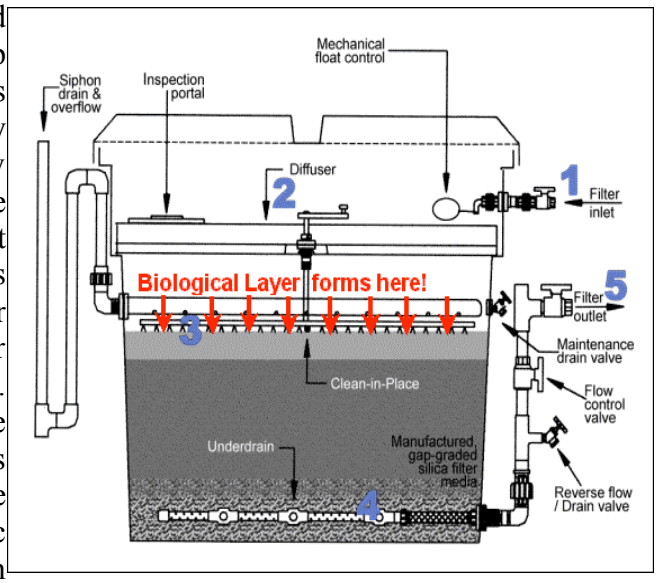
The project core "EPGW's Slow Sand Filtering (SSF)" activities undertook developments for delivery and demonstration applications of the prototype Quencher (QPT), plastic pilot models'[2] illustrated. Those efforts provided for basic units to establish test validity and reliability for potable water, verified site applications test data and developments for resources for worldwide public utilization. Validation demonstrations with actual data records of performance assure confidence to diverse localities from an accessible worldwide applicable public resource. Actual test results provide assurance for implementations with confidence and offer all major instructions and procedures, replenishment requirements, local training, and sustained utilization through maintenance. Initial voluntary staffs and preliminary networks were established, or already in place, including an industrial supplier and Rotarians participative assistance.

[2] Led by Brian Cunningham of EECG - descriptive materials herein were excerpted from EECG descriptions and for planned efforts in response to proposal announcement by the World Bank

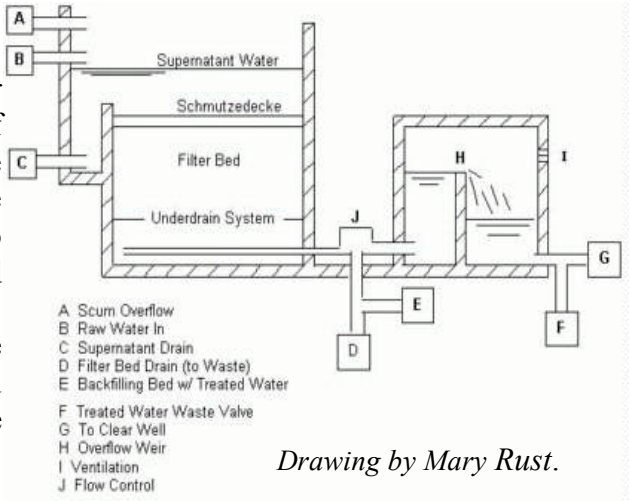
Project details included developments for operational characteristics, usage instructions, local site placements and implementations by cooperative support actions, establishment of assured valid data, and provisions for a world-wide accessibility resource data bank. Initial development included a modified fabrication design of preformed lightweight materials (e.g., plastic pilot model - “Quencher”), research on performance parameters for identified primary needs in establishing site functions/operations, and achievement of implementations with cooperative interested organizations at several sites.

4 SSF Specifics

A layer of dirt, debris, and microorganisms builds up on the top of the sand. This layer is known as **schmutzdecke** (German for "dirty skin") where the process biologically breaks down organic particles in the water, and effectively straining out even very small inorganic particles from water. SSF clarifying water active mode occurs in the thin upper sand layer that forms in early time. There, biologically active microorganisms in the ‘mat’ breaks down organic matter while remainder suspended inorganic matter is removed by the sand on gravel base (or other support porous media base) through adsorption and straining. From the porous sand water is drained through the bottom and a riser for discharge by a valve as noted in illustrations.



Maintenance of a slow sand filter consists of clearing top layer of schmutzdecke without which the filter does not produce potable water. After filter cleaning up to two weeks operation may be required while allowing the schmutzdecke layer to rebuild. New sand must be added after many repeated operations. The figures indicate the basics of the units.



Drawing by Mary Rust.

The SSF significance for supply and availability of potable water quality has substantially improved health of impoverished populations in specific locales of underdeveloped nations. References indicate successes from national agencies and philanthropic efforts but with limited realizations for expanded and widespread needs.

Repeated demonstrated SSF means for potable water alleviation in undeveloped regions has been shown possible. Other agency awards and organizations for introduction, applications and assistance with aspects of implementations are reported (2). The units are relatively inexpensive, require minimal operational maintenance, and process simplicity. Water applications percolate untreated influent through the filter and no hazardous chlorine byproducts in delivery (from gelatinous upper layer). Little cloudiness of suspended organic and inorganic matter occurs so there is no need for chemical requirements. The simplicity with no power makes the slow sand filter appropriate for undeveloped regions implementation (performance indicated from Metaficient Internet page).

Water Quality Parameter	Removal Capacity
Turbidity	< 1.0 NTU
Colforms	1-3 log units
Enteric Viruses	2- 4 log units
Gardia Cysts	2-4 log units
.Cryptosporidium Oocysts	> log units
Dissolved Organic Carbon	< 15 – 25 %
Biodegradable Dissolved Organic Carbon	< 50 %
Trihalomethane Precursors	< 20 – 30 %
Heavy Metals Zn, Cu, Cd, Pb	> 95 – 99 %
Fe, Mn	> 67 %
As	< 47 %

Other elements of importance are: sludge handling problems are minimal; operator supervision is not necessary; systems can make use of locally available materials and labor. Turbidity exceeding 20 nephelometric turbidity units (ntu) may require an inflow roughing filter that reduces turbidity by 50 to 80 percent and considerably reduces maintenance on slow sand filters. Removal of microorganisms decreases with colder water since biological activity declines with temperature. SSF filters work at low flow rate ranges of 0.015 to 0.16 gpm/ft^2 so that particles tend to settle in the very top layers. Purification mechanism process depends on sticky mat formations on the sand surface composed of a wide variety of debris where particles are trapped and organic matter is biologically degraded. The materials include tiny organisms e.g., bacteria, algae and various other single and multiple cell organisms. The matrix lives off whatever is passing in the water stream. Pore size of the bed is unimportant since bacteria passing through can't touch anything without being stuck and consumed thereby providing for removal of constituents smaller than the space between sand particles.

Reliance on this upper cake filtration for biological straining takes on the dominant role in filtration. After some time the biological layer begins to plug up and flow becomes substantially reduced so that renewal is required by surface scraping. Principal actions of matrix biofilms that account for the governing mechanisms and performance factors for the quality function are unknown. Lack of detailed research studies of those micro-biological processes from treatment in the top most layers have not been presented with explanatory details for credible evidence.

5 SSF Information Sources

Slow sand filtration utilization is straightforward since it does not require pretreatment, extensive operator responsibilities, energy sources, advanced technology trained personnel. Despite successful applications of this simple technique the apparent lack of in-depth understanding for functions and principles governing the (probably) complex bio-chemo-physical phenomena have not hindered applications. Without parametric information on governing factors developed of understanding detailed advantageous designs cannot be achieved. It is necessary to understand interactions between solids and biological materials in order to develop optimizations for capacity sizing, weight ratios and area surface requirements, or materials distribution with height to diameter ratio for maximum performance.

The Engineers Without Borders (EWB) project activities include Workshops with special emphasis on developing world needs and investigations of operations with variants of large and small filter types (3). Also, in their active research support financial aid is granted for particular proposal actions that correspond to their needs. The organization Centre for Affordable Water and Sanitation Technology - CAWST – (4) provides intensive training that facilitates programs. Pamphlets present detailed information for setting up SSF concrete container units and other required operational aspects. The CAWST projects are particularly recognized by Friends Who Care Charities Ltd (5) which emphasizes projects in Guatemala, Honduras and Mexico. In their reference internet listings more than thirty involved multinational organizations are indicated that assist in undeveloped world activities for potable water and sanitation improvements. Recently, an experimental plan was described for determination of recovery time of family sized biosand filter following a cleaning cycle to establish optimal pathogen removals (6).

The National Drinking Water Clearinghouse (7, 8) provides many source materials in published “Tech briefs” that includes specifics on SSF applications primarily for utilization and operation of small community type water supply systems. A sample information page is presented in the Appendix. Other reference resource for small community applications is found in American Water Works Association (AWWA) publications.

Insight for controlling mechanisms that governs fundamental aspects appears in an hypothesis that cleaning is a result of immobility of biological forms in the water within the “schmutzdecke” and sand. The control indication stems from a fluid dynamics perspective that is based on extremely low Reynolds dependency that primarily governs extraction processes as a result from immobility of hazardous forms (10). Isolation of detrimental forms in the inhibiting passageways is explained as the removal phenomena in the matrix mat and sand interstices. The consideration points to extremely low Reynolds numbers (ratio of inertia to viscous “forces” from fluid dynamics) in flows through interstices of SSF matrix and sand bed passageways. Since bioforms have negligible momentum there can be no real transport so that viscous force considerations have no influence. Consequently, the achieved removals result from apparent lack of inertia coupling for movement or transport in the upper layers. Since removal of micro-biological materials/forms are the desired end effect the limitations indicated from fluid

considerations suggest an evaluative approach in understanding of the entrapment phenomena.

A recent study directed to horticultural applications presents detailed test information derived from measurements applied for biological aspects related to chemical variables of concern for water conditions/impurities. The investigation focus was on suppression of the microbial community, consisting of bacterial and fungal bacterial constituents in applications with SSF (11). The report details indicate experimental controls and several refined measurement methods applied in the study. Reinforcement of the controlling factors that govern biological extraction activity occurrences in top matrix of sand was again confirmed. Stepwise sampling extractions of measured quantities down the sectional lengths of the test cylinders sand bed height were reported. Many references were indicated to other specialized microorganism studies that applied advanced micro-biological measurement detection techniques.

6 Scope of "Quencher" project

The project development for Quencher individual small size SSF unit applications to family type usages for undeveloped sector needs was undertaken from standpoint of successful utilizations with reported successes and experiences. The project investigation plan consolidated total comprehensive requirements described in the proposal summary. The initial tapered cylindrical tank plastic pilot model (manufactured "Quencher" plastic model) differs from flat rectangular concrete sided units. The design and delivery of such units provides significant advantages in reduced endeavors at on-site implementations. Light weight tapered containers facilitate shipping by stack packaging which eases on-site efforts for initiation of function in reduced time. Personnel efforts benefit from eliminating burdensome local construction requirements by lightweight materials and handling ease followed by sand filling setting and operational implementation. Materials and energy requirements are reduced for resource requirements as compared to mainstream cement based construction.

Planned studies initially at pre-selected sites for implementations of all aspects included comprehensive demonstrations of all functions associated for operations, and development of data on performance parameters with results from cooperative interested organizations. The establishment of reliable performance data banks for providing worldwide accessibility assures confidence for other implementation projects (initially with Rotarians field efforts). Principal site directed effort plans included a locally dependable "Water Doctor[3]" with trusty local status to undertake supervisory responsibility and control/teaching, and to implement prepared procedures for sampling data assembly of water quality measurements with prearranged water test laboratories. Maintenance efforts records for sustained operations and performance renewal of production of acceptable water output following cleaning (by re-establishment of matrix mat microorganisms') would be part of the record system.

[3] "Water Doctor" – Local person of assured local status, sufficient capability (literacy and trustworthiness) paid a monthly stipend. Submittal via Internet EPGW's required reports; verified visits (up to 20 sites) at least once/week for reporting conditions of clients. QPT Reports availability from field evaluations of QPT results to date.

SSF utilization avoids undesirable chemical compound formations associated with chlorine treatment so other health hazards are avoided. Since a key advantage that results from no chemicals, or electricity, implementations in isolated areas makes site installations practical. The preformed cylinders supplied make implementations with other locally available material (sand, stones) have an obvious advantage at facility sites being developed; otherwise, locally available materials can be readily transported. Maintenance by community members can also create livelihood options. Uncovered slow sand filters may require covering to prevent undesirable insect lure to the inlet water supply and would be determined on an as needed basis. For available heavily silt laden waters of high turbidity it may be necessary to reduce turbidity levels. Such installations can add a simple inclined "stepped barrier tray" that permits clearer overflow of lessened solids water (left at barriers) at entry to the SSF container inlet.

7 Quencher project aspects

Quencher evaluations from process water analyses were to demonstrate consistent achievement in accord with minimum safe water standard recommendations (WHO). Data specific documentation for assured replication with varied resource water sources at multiple sites would then result from rigorous field trials as an inherent aspect. EPGW organized field test establishment, a rigorous testing protocol, overseen implementation by reliable locals, data development in public reports could achieve substantial relief of potable water shortages to many locales.

Comprehensive published Manuals by the Centre for Affordable Water and Sanitation Technology (CAWST) provide extended implementation topics (4). The information and directions relate to only the "Biosand Concrete Filter" application and instructions for concrete containers but provides no guidance for selection of alternative fabrication methods. Although concrete usage is historically well known there is no implementation guide for other fabrication methods. Concrete in remote and needy sectors of the world may introduce implementation difficulties.

At local level materials reductions eliminate shipments of raw construction materials and overcome other needs or shortages, as well as local energy power production. Cost benefit analyses and studies of efficacy potentials for water projects are required essential to assist and guide in undeveloped nations decisions. The simplified prefabricated molded cylindrical plastic tapered design provides particular advantages in regions with little or no power availability for fabrication or materials of concrete containers. Shipping costs are reduced since stacks of tapered cylindrical containers are space-wise efficient. The cylindrical unit advantageously reduces local dependency requirements, trims implementation costs and reduces labor time for implementation. Hence many more installations would result from this effort.

8 Proposal descriptions - "Quencher pilot tests" (QPT)

The effective EPGW support infrastructure activities were established and organized to implement utilization of 'Quencher' initial achievements by volunteers. Participant members represented experience of hundreds of related man-years roles in technical,

management, marketing and distribution experience. Inclusive pilot model planning was based on low cost production, distribution methods planning and implementations at field sites. Aspects of response to proposal request indicated broad aspects of considerations from the several elements of concern.

8.1 Benefits to a *sustainable environment*

From SSF advanced techniques for global practical achievements for potable water availability provided for:

- ***Energy efficiency at the community level*:** conserve wood burning and/or electric energy to boil water for other needs; reduce time and efforts spent to fetch water.
- ***Environmental education & awareness**:* disseminate water crisis information and successful achievement of a need for water conservation and sanitation.
- ***Protecting environmental health:*** improve water quality and sanitation benefits that improve quality of life.
- ***Sustainable uses of natural resources:*** sustainable uses of water promote economic developments in underdeveloped and developing countries - leads to improving education, population health, and promotes conservation of species.

8.2 Overall Cohesive Integration

The comprehensive program provided a realistic implementation plan for detailed achievements for implementations in undeveloped world sectors. The scope provided noticeable cost and performance benefits and an effective model for distribution of results to other active national and philanthropic organizations that establish potable water relief efforts, as well as for recovery from natural (tsunami) disaster events. Those all-inclusive combinations for outcomes necessary in worldwide applications ***have not previously been cohesively integrated into an overall approach***; foreseen impacts are:

1. Wide publication of Quencher basic design; solicited feedback/comments, i.e. field interviews, prior SSF programs, internet;
2. Partner arranged with SpecialMade/RubberMaid Division (Quencher manufacturer) - advanced design prototypes production;
3. Personnel recruitment selections for QPT realization for effective field forces; development of established leadership and functions by local “Water Doctor,”
4. Devices testing at selected sites facilities, e.g., US and foreign correspondent local laboratories for test analyses in “before and after” water quality studies;
5. Partner with Rotarians' Pure Water for the World; distribute/install 120 prototypes at sites;
6. Collect and analyze data; evaluate QPT's outcomes;
7. Recommend Quencher's local modifications (as necessary), implement communications links, broaden experiences input, training methods, full-scale operations;
8. Publish QPT's results through various media channels, especially the internet.

8.3 Sustainability

Stress on locally adapted approaches with low costs for product's affordability to alleviate world's neediest, i.e., children, elders and disabled, is essential to global solutions for ensuring projects' ***sustainability***. Local support infrastructures are essential components including participation of nearby academic centers/universities. Expanding communication and education through indigenous local "Water Doctors" assures broader user acceptance in local practices. Innovations for relief of the diverse world water crisis are of importance in undeveloped parts of the world. Applications require multiple differentiators' projects that assure potable water availability.

Success requires participants with organizational links for unsurpassed distribution and implementation force offering services for humanitarian causes (approximately 1.2 million Rotarians - a primary partner - in more than 166 countries). Participation of public and private partnerships finance model with growth models can offer venture opportunities. Provision of openly published performance details from confirmed reliable test results of QPT's availability abets successes for agencies, assistance programs, and governments to publicly sponsored assistance.

8.4 Scalability

Quencher design offers global "***scalability***" adaptable as unique solution for local water problems. Following confirmed test results EPGW plans full-scale operation, striving to achieve the U.N. target for alleviation by half the proportion of people lacking sustainable access to safe water by 2015. EPGW's model provides for Quencher's sustainability based upon public and private partnership from financial assistance sources (anticipated proposals, e.g., USAID, WHO, UNESCO, and UN) for multiple sites in poor nations. Private sector's opportunities growth by involved participation is essential for necessary support to the non-profit's function. EPGW considers the Purchasing Power Parity, and objective to make Quencher widely available and affordable to the neediest—children, the elders, the disabled, and the poor. Those create potentials for societal contributions and venture profit incentives. QPT's confirmations will demonstrate Quencher as the global solution to the disparate water crises and could solve one of the biggest problems our planet faces - quenching billions of people's thirst.

8.5 Systematic approaches

SSF integrated ***systematic approaches*** will provide outcomes that result in:

(a) Significant improved water quality - Quencher's removal rates of sediments, cysts, worms, bacteria, and other water pathogens, some inorganic compounds, and metals in contaminated water comparable to SSF literature prior experiments' conclusion for 93 % of all fecal coli-form removed and 100% of Giardia, worms and parasites, and 99.89% of Cryptosporidia filtered);

(b) Successfully established QPT's support infrastructures for implementation, operation, and further expansion. Partnering extensions accomplished with the Rotarians. Extended associated activities through developed local academic centers'; broadened local "Water Doctors" implementations. Initiate local adaptation and customization planning for Quencher's design. Implementation of indigenous

economically efficient construction required for local utilization and by encouraging communication and education for Quencher's maintenance and quality control.

(c) Management implementations of SSF demonstrated tested solutions for sustainable support infrastructures with significant health benefits from reduction of water-borne illness.

8.6 Replicability

QPT's published "***replicability***" of performance details, testing methods and results transfer will assure agencies, assistance programs, and governments to reproduce reliable demonstrated resources, i.e. replication, reproduction, widespread applications, etc. The model of organization, product, and support infrastructures could be readily duplicated; the published information of experience, guidance, and participation would greatly accelerate that process. Guidance for implementation derived with validated methods provides opportunities for successful endeavors and avoids improvident undertakings. Production and delivery of readily transportable low cost molded containment units rapidly alters prospects for significant eliminations of potable water scarcity for many sectors of the world's populations. Other applications would benefit disaster relief in emergency situations, e.g., 'tsunami' disasters in Asia that brought aid requests for such immediately useful devices to assist recovery by relief of potable water shortages.

9 Serviceable requirements

Information descriptions point to topmost layers as of primary importance for the function and renewal recommendations indicate cleaning and replenishment is necessary over time in order to maintain water quality. Top layers require renewal cleaning by removal after periods of usage for continuity that requires draining and workers scrape away the top biological layer. Renewal of the layer is required after that for biological layer to re-establish itself. For larger community size water supply installations added scraping monthly labor expense may occur. Reference sources developed for applications and educational materials would become readily available to organizers of efforts for needy regions of the world (long term period servicing activities are insufficiently documented). Assistance to undeveloped regions requires long-term outlook for practical practices for sustained water supply and not just demonstration of SSF devices functionality.

10 Conclusions

Potable water project plans introduced newer concepts for SSF low cost techniques and implementations. Provision for demonstrations and assured data basis to undeveloped and poor sectors of the world provides assurance and confidence from innovative ideas. Illustrated "Quencher" approaches with implementation plans were developed. Organizations concerned with water needs require new comprehensive long-lasting initiatives for implementation plans. Process applications with new materials offer cost savings methods that are essential to achieve realistic relief of water shortages. Particular availability with intensive local interactions from simplified procedures, and investments in kind eliminates inhibiting conditions so that broader utilizations become

practical. Developed nations and involved agencies can readily achieve the broader goals only from an integrated cohesive program that assures realistic attainments for major life saving steps within the next two decades.

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12 APPENDIX (Following Page)

Dr. Lawrence Galowin has had extensive experiences at National Institute of Standards and Technology (NIST) leading plumbing research and direction. In voluntary consultant activity he contributed assistance to the experienced individuals undertaking efforts that could bring potable water relief to worldwide needy sites. The SSF device technical requirements were part of his contributions for inclusion in the project.

Slow Sand Filtration

TABLE 1 Typical Treatment Performance of Conventional Slow Sand Filters

Water Quality Paramenter	Removal Capacity
Turbidity	<1.0 NTU
Coliforms	1-3 log units
Enteric Viruses	2-4 log units
Giardia Cysts	2-4+log units
Cryptosporidium Oocysts	>4 log units
Dissolved Organic Carbon	<15-25%
Biodegradable Dissolved Organic Carbon	<50%
Trihalomethane Precursors	<20-30%
Heavy Metals	
Zn, Cu, Cd, Pb	>95-99%
Fe, Mn	>67%
As	<47%

Source: Adapted from Collins, M.R. 1998.

Slow sand filters also provide excellent treated-water quality. (See Table 1.) Slow sand filters consistently demonstrate their effectiveness in removing suspended particles with effluent turbidities below 1.0 nephelometric turbidity units (NTU), achieving 90 to 99 + percent reductions in bacteria and viruses, and providing virtually complete *Giardia lamblia* cyst and *Cryptosporidium* oocyst removal.

Limitations

Slow sand filters do have certain limitations. They require a large land area, large quantities of filter media, and manual labor for cleaning.

Water with high turbidity levels can quickly clog the fine sand in these filters. Water is applied to slow sand filters without any pretreatment when it has turbidity levels lower than 10 NTU.

When slow sand filters are used with surface waters that have widely varying turbidity levels, infiltration galleries or rough filters—such as up-flow gravel filters—may be used to reduce turbidity.

Waters with a very low nutrient content may impair turbidity removal since some nutrients must be present that promote biological ecosystem growth within the filter bed.

Slow sand filters do not completely remove all organic chemicals, dissolved inorganic substances, such as heavy metals, or trihalomethane (THM) precursors—chemical compounds that may form THMs when mixed with chlorine. Also, waters with very fine clays are not easily treated using slow sand filters.

A granular activated carbon (GAC) sandwich filter is a modified slow sand filter that removes organic material. This filter uses a base sand layer that is approximately 1 foot deep, an intermediate GAC layer approximately 0.5 feet, and a top sand layer approximately 1.5 feet deep. This modified slow sand filter effectively removes pesticides, total organic carbon, and THM precursors.

Slow sand filters are less effective at removing microorganisms from cold water because as temperatures decrease, the biological activity within the filter bed declines.

Process Description

Slow sand filters require a very low application or filtration rate (0.015 to 0.15 gallons per minute per square foot of bed area, depending on the gradation of the filter medium and the quality of the raw water). The removal action includes a biological process in addition to physical and chemical ones.

A sticky mat of biological matter, called a "schmutzdecke," forms on the sand surface, where particles are trapped and organic matter is biologically degraded. Slow sand filters rely on this cake filtration at the surface of the filter for particulate straining. As the surface cake develops during the filtration cycle, the cake assumes the dominant role in filtration rather than the granular media.

Pilot testing is always necessary when designing slow sand filters. Currently, engineers are not able to predict the performance of a slow sand filter with a specific quality of raw water. Operation of a small pilot filter, preferably over several seasons of the year, will insure adequate performance of the full-scale plant.

Remember, after the designer sets the parameters—such as the plant filtration rate, bed depth, and sand size—there is little a plant operator can do to improve the performance of a slow sand

After the Tsunami: water supply and sanitation, from emergency response to rehabilitation.

Dr. M. Gormley
Drainage Research Group
The School of the Built Environment
Heriot Watt University
Edinburgh EH14 4AS
m.gormley@sbe.hw.ac.uk

Abstract

The Tsunami which struck South East Asia and parts of Africa in December 2004 was particularly indiscriminate in its destruction. The concentration of internally displaced people (IDP) in public buildings without adequate facilities was a particular cause for concern. A clean water supply and effective sanitation (WATSAN) are recognised as essential if disease outbreak is to be avoided in refugee camps and places of temporary habitation for the IDP. The Sphere project's field manual '*Humanitarian Charter for Minimum Standards in Disaster Response*', provides a basis for the design of emergency interventions which need to combine a respect for the dignity of those people affected with realistic engineering solutions, whilst at the same time planning for the future. This paper examines the interventions implemented by an international humanitarian organisation, GOAL, for water supply and sanitation in the affected area of the district of Ampara, Sri Lanka in the immediate aftermath of the Tsunami, looking at the overall disaster response decision making process and its implications for future development.

Keywords

Emergency relief engineering, Water and Sanitation

Abbreviations

IDP	Internally displace people
GOAL	International humanitarian aid agency
NGO	Non Governmental Organisation
UNHCR	United Nations High Commissioner for Refugees
WATSAN	Water and Sanitiation

1. Introduction

The media coverage of the disaster and its aftermath ensured a massive financial response from the international community, leading to an influx of international humanitarian aid to assist with the emergency. The scale of the devastation and the geographical spread of the affected area stretched local services to breaking point, leaving many areas with acute shortages of essential services. Water and sanitation are critical determinants for survival in the initial stages of a disaster. People affected by disasters are generally much more susceptible to illness and death from disease, which are related to a large extent to inadequate sanitation, inadequate water supplies and poor hygiene. The most significant of these diseases are diarrhoeal diseases and infectious diseases transmitted by the faeco-oral route. Other water and sanitation related diseases include those carried by vectors associated with solid waste and water.

The main aim of water supply and sanitation programmes in disasters is to reduce the transmission of faeco-oral diseases and exposure to disease-bearing vectors through the promotion of good hygiene practices, the provision of safe drinking water and the reduction of environmental health risks. The term sanitation [1], refers to excreta disposal, vector control, solid waste disposal and drainage. Simply providing sufficient water and sanitation facilities will not, on its own, ensure their optimal use or impact on public health. In order to achieve the maximum benefit from a response, it is imperative to ensure that disaster-affected people have the necessary information, knowledge and understanding to prevent water- and sanitation-related disease, and to mobilise their involvement in the design and maintenance of those facilities.

This paper outlines the response of one international relief organization, GOAL, with whom the author served several weeks on the eastern coast of Sri Lanka in January 2005. The assessment, planning, implementation and review of an intervention programme is considered in the light of internationally recognized standards for disaster relief response.

2. A devastated Area

The area of devastation in South East Asia was extensive, however this paper will deal with only one small section of coastline on the East coast of Sri Lanka. The area, some 10km long, in which thousands were killed and 30,000 people were left homeless. Most of those killed worked, or lived, in well constructed buildings in an urban setting. The power of the waves was no respecter of construction quality and very little remained of the first 300m from the coastline. Behind this area was a second, less devastated area, where the damage was similar to that of a major flood, with debris washed in by the waves. In the hours following the disaster local people mobilised to provide temporary shelter for the dispossessed in nearby schools, community centres, Mosques and Temples.

3. The emergency relief team

3.1 The Background

This initial work by local people, water board, municipal council employees and local NGOs was an amazing show of co-ordinated response at a time when many were in grief at their own personal loss as a result of the Tsunami. Their efforts put in place initial emergency water supplies and sanitation to alleviate some of the strain on services in public buildings used to house internally displaced people (IDP).

The district administration centre in the town of Ampara became the centre for the co-ordination of the relief response for one of the many districts affected. International assistance arrived within days to offer expert advice and assistance for the relief effort. The arrival of many independent international relief organisations, mandated to help by the overwhelming response from donors at home, poses a range of difficulties for the host administration in itself, non least than trying to assure that an overlap of assistance doesn't occur. The response by the local authorities in Ampara, assisted by the UNHCR, was impressive and served also to link with central government, charged with an overview of the national relief effort.

The centrality of local people to such an operation is vital, particularly when it is borne in mind that decisions made soon after a disaster can affect people's lives for years after international relief agencies have gone away. The principle of local involvement is recognised in many development fields as an important way to ensure sustainable solutions are arrived at. Much of the thinking on this topic is due to Robert Chambers [2] who advocated that development workers make themselves redundant by ensuring local involvement in decision making and an eventual handover of responsibilities, 'handing over the stick' as he put it.

The international relief team has a vital role to play in the design, implementation and running of emergency relief operations. With skills and experience of similar disaster situations, the relief NGOs can quickly assess situations and avert further devastation due to disease outbreak by implementing pre-determined emergency plans.

3.2 The Organisation

GOAL is an international humanitarian agency dedicated to the alleviation of the suffering of the poorest of the poor. It was founded by its current Chief Executive, John O'Shea in 1977 and operates out of Dublin, Ireland. GOAL works towards ensuring that the most vulnerable in our world and those affected by humanitarian crises have access to the fundamental needs and rights of life, i.e. food, water, shelter, medical attention and primary education. It is non-denominational, non-governmental and non-political. GOAL has responded to nearly every major natural and man-made disaster in the past 28 years and is currently operational in 15 countries in the developing world. It also implements

rehabilitation and long-term development programmes and works with local partner organizations that have similar objectives. While GOAL's priority is to bring life-saving assistance to people affected by emergencies, through the provision of food, healthcare and other basic requirements, it also prioritises programmes which care for street children and people affected by HIV/AIDS.

3.3 The Team

A temporary advance team is usually sent to assess the needs of the area and co-ordinate with local authorities and other NGOs. The initial team assembled by GOAL in Ampara comprised the following responsibilities.

Table 1 - The emergency relief team

Job Title	Duties
Team leader	Overall Co-ordinator
Accountant	Financial control
Logistics x2	Setup supply lines Infrastructure
Medical assessor	Assess if full medical team required
Engineer - WATSAN	WATSAN evaluation using Sphere Guidelines
Engineer - Civils	Assess civil/ building works required/ plan reconstruction
Environmental Health Officer	Vector control in IDP camps
Non food items Distribution	Co-ordinate distribution of non food items, hygiene packs etc.
Livliehoods specialist	Assess possibilities of rehabilitating local income streams.
Psychosocial counsellor	Assessment of mental trauma and implement counteracting measures.

While these are varied jobs, the team works together to assure that the overall aims are being met. Much of the initial work involves setting up structures for administration and supplies and assessing the needs of the people, in conjunction with local stakeholders. This paper will necessarily consider the WATSAN function of the emergency team, however there is quite a lot of overlap between the functions, which contributes to the team effort.

4. Sphere: an emergency engineers handbook

The Sphere Project is a programme of the Steering Committee for Humanitarian Response (SCHR). The project was launched in 1997 to develop a set of universal minimum standards in core areas of humanitarian assistance. The aim of the project is to improve the quality of assistance provided to people affected by disasters, and to enhance the accountability of the humanitarian system in disaster response.
Figure 1. shows an overview of the elements to be taken into account in the design, installation and operation of WATSAN programmes in disaster zones.

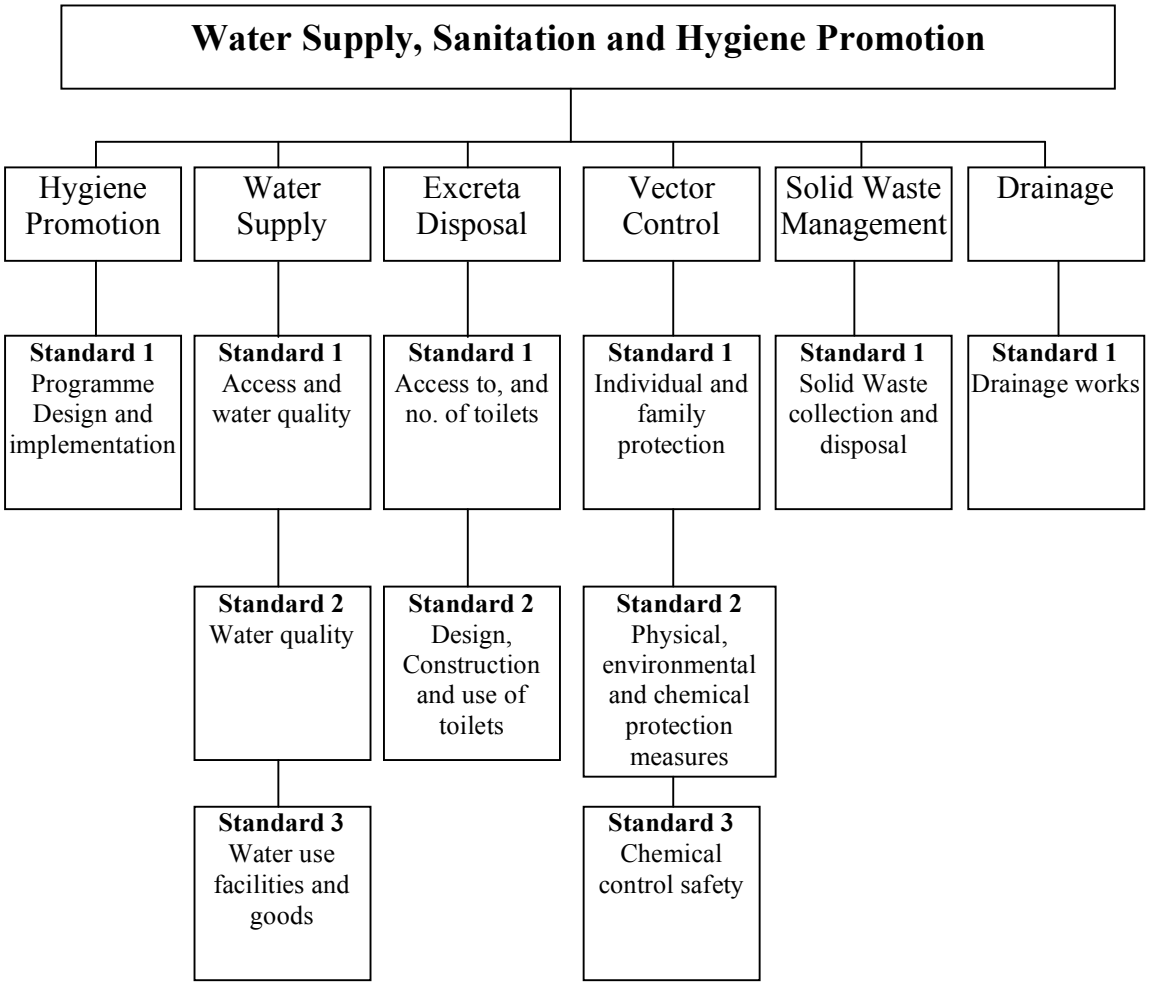

Figure 2 - Overview of WATSAN Sphere guidelines

Particular advice is given on the number of toilets recommended and the quantities of water required to maintain vector control. These details are given in Tables 2 and 3 below.

Table 2. - Planning guidelines for minimum numbers of toilets at public places in disaster situations

Institution	Short term	Long term
Market Areas	1toilet to 50 stalls	1 toilet to 20 stalls
Hospitals/medical centres	1 toilet to 20 beds or 50 out-patients	1 toilet to 10 beds or 20 out-patients
Feeding centres	1 toilet to 50 adults 1 toilet to 20 children	1 toilet to 20 adults 1 toilet to 10 children
Reception/ transit centres	1 toilet per 50 people 3:1 female to male	
Schools	1 toilet to 30 girls 1 toilet to 50 boys	1 toilet to 30girls 1 toilet to 60 boys
Offices		1 toilet to 20 staff

Source: Sphere manual adapted from Harvey, Baghri and Reed (2002)

Table 3 - Planning guidelines for minimum water quantities for institutions

Health Centres and hospitals	5 litres/ out-patient40 -60 litres/in-patient/day Additional quantities needed for laundry equipment, flushing toilets etc.
Cholera centres	60 litres/patient/day 15 litres/carer/day
Therapeutic feeding centres	30 litres/in-patient/day 15 litres/carer/day
Schools	3 litres/pupil/day for drinking and hand washing (use for toilets not included)
Mosques	2-5 litres/person/day for washing and drinking
Public toilets	1-2 litres/user/day for hand washing 2-8 litres/cubicle/day for toilet cleaning
All flushing toilets	20-40 litres/user/day for conventional toilets connected to a sewer 3-5 litres/user/day for pour flush toilets
Anal washing	1-2 litres /person/ day

Source: Adapted from Sphere manual

The planning guidelines included in these tables are ideal figures and depending on the situation, may not be obtainable. However they present an aim to try to achieve which makes planning easier.

5. Assessment

5.1 General

The Tsunami event was swift and fierce but once the wave had subsided it was over, and while there was fear that another one would occur in the days and weeks following the disaster, no such event occurred. In many ways this made the initial clean up operation easier, since all structures at more than 1km from the sea were left intact and supplies were easily obtained. This is in marked contrast to many emergency situations around the world where supply lines are severed and people are forced to move great distances due to armed conflict, or famine, or both. What occurred in the immediate aftermath of the Tsunami was swift intervention from local NGOs and government departments. The local water board worked round the clock to establish emergency water supplies to the many places of refuge hastily established in the hours following the Tsunami.

5.2 Establishing facts

At a meeting with the local authority GOAL were allocated WATSAN responsibility for 15 IDP camps. The day to day running of the camps was carried out by local officials who were consulted before any intervention was implemented. The results of the initial assessment of the WATSAN for the 15 camps is shown in Table 4. It can be seen that many of the places had an under – provision of sanitation, however the situation isn't as bad as it appears. People were, in the main, only using the camps at night, during daytime they were staying with relatives and friends, nearby. A lot of people were able to use toilets outside the designated areas which took the pressure off the already stretched systems.

Table 4 - Summary of assessment of IDP camps – one week on

No.	IDP Camp name	Population	Water supply			Sanitation		
			Tank (litres)	Frequency of fill	Mains water	Total No.	Total No. Operational	O&M Plan
1	School	1650	1000	1/day	Yes	10	10	No
2	School	1315	2000	2/day	Yes	8	4	No
3	Mosque	685	1000	1/day	Yes	8	8(filling fast)	No
4	Community Centre	438	1000	1/day	No	4	2	No
5	School	179	1000	1/day	Yes	5	5	No
6	Public Hall	4830	1500	2/day	No	7	5	No
7	School	2400	1500	2/day	Yes	4	4	No
8	School	3150	1000	2/day	Yes	2	2	No
9	Public Hall	1400	1000	2/day	Yes	10	4	No
10	Mosque	965	1000	2/day	Yes	8	8	No
11	College	1985	1000	2/day	Yes	7	3	No
12	School	3117	1500	2/day	Yes	12	0	No
13	Community Centre	1735	2000	2/day	Yes	2	2	No
14	Mosque	1646	1000	1/day	No	4	4	No
15	School	1600	1000	2/day	No	13	13	No

The most commonly used toilet was the pour flush type. These were either connected in a block of four to a septic tank, or individually connected to a single septic tank/pit beneath.

The assessment summary shown in Table 4 was made one week on from the disaster, a time when systems were beginning to fill up and there was the potential for disease to take hold. The provision of water looks inadequate as well, however most places had sporadic mains water supplies that people were prepared to wash with but not drink. There was a local perception that the 'chlorine water' was not safe, due to the piping system. Most people depended on wells for their drinking water but these had been salinated by the wave. Water was delivered to the sites in Water Board and donated bowsers.

Hand in hand with the engineering assessment went an assessment of the general hygiene of the camps. After a week in crowded conditions this was beginning to pose a serious problem and a potential lethal hazard to the health of the population. The final column of Table 4 refers to an Operation and Maintenance Plan (O&M plan) for the camps. Following the work of installing new latrines and toilets in these crowded conditions there was a need for a plan to deal with cleaning the sanitation areas and dealing with solid waste material. None of the camps were operating a co-ordinated O&M plan at this stage, however cleaning and maintenance were being carried out on an *ad-hoc* basis.

5.3. Intervention Planning

At the centre of an intervention there must be a method for assessing its effectiveness. The model shown in Figure 2 shows the approach taken.

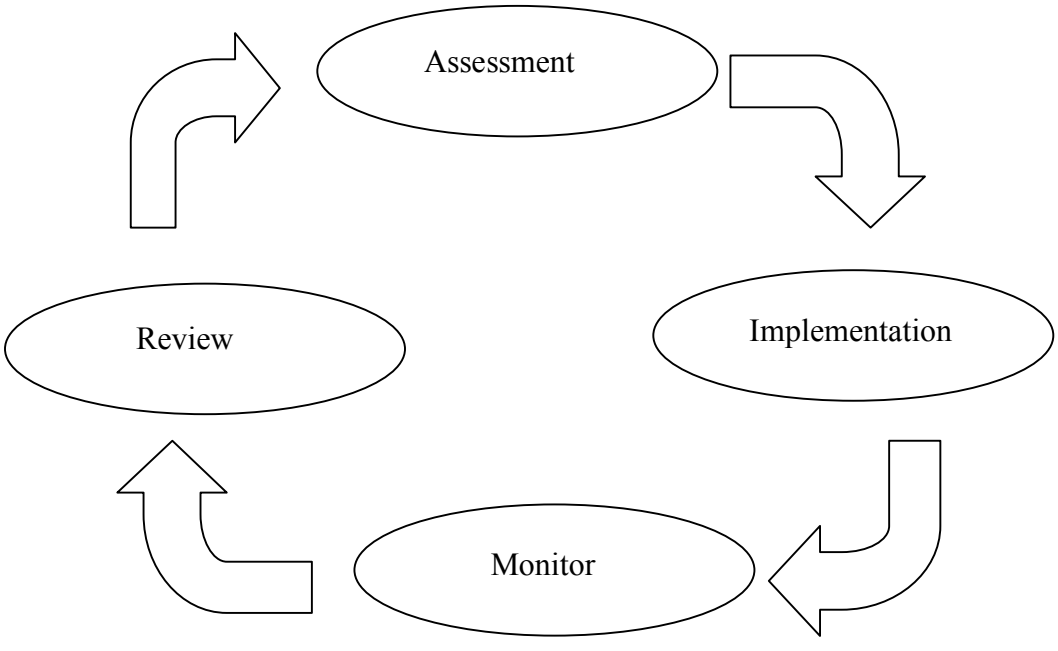

Figure 2 - Project planning and implementation cycle

In the absence of an overall plan for reconstruction and resettlement it was considered prudent to assume that people would remain in the IDP camps for at least 8 more weeks while alternative arrangements were made.

The overall scheme was designed as follows

Water supply

Short term	Increase frequency of water filling tanks Extra water tankers and drivers to contribute to Water Boards work
Medium term	Well refurbishment, clear debris and pump out salinated water.
Long term	Refurbish mains water system

Sanitation

Short term	Keep existing systems working Construct additional latrines Initiate septic tank cleaning service with local authority Hire O&M staff at each camp
Medium term	Provide adequate on plot sanitation for temporary dwellings when people move out of IDP camps.
Long term	The area is built up and growing and would benefit from a public sewerage system with treatment plant (Government responsibility)

Water supply

The short term aims of the water supply plan were relatively easy to implement. The water tankers were hired and seconded to the Water Board. The rehabilitation of the wells was a different matter. In east Sri Lanka there is a short monsoon season in January. This raises the water table temporarily and poses a real problem for well pumping. It is possible to pump out salinated water from wells but if the ground water is too high then there is a danger of the well collapsing as the walls buckle.

Sanitation

The objective was to keep existing systems - permanent toilets, septic tanks, temporary structures – working. Many permanent latrines were not being used because there was a perception that the septic tank was blocked when in fact it was the pipe between the latrine and the septic tank that was blocked. Rumours also abounded that the Tsunami had permanently altered the water table causing foul water to back up into toilet cubicles.

Site investigations showed that this was not the case. Over-use had blocked the collection pipe from the pour flush latrines to the septic tanks. Levels in the septic tanks were rising fast but there was still enough capacity to allow time for an alternative to be found. Simple daily cleaning with a toilet brush and water was found to restore all of the affected systems and provided time in which to deal with the space issue. While the septic tanks were found to have some remaining capacity, they were filling up at a rate of 150litres per day net (allowing for seepage).

Plates 1 and 2 show the situation before and after cleaning in the worst camp (No.12 in Table 4 above) with over 3000 people and no effective sanitation.

Plate 1. Pourflush toilet unusable Potential hazard for disease.

Plate 2 Toilet following implementation of O& M plan

The key to avoiding this situation occurring on a regular basis was to hire O&M personnel in the camps, provide protective clothing and cleaning materials. These personnel would also do a much needed monitoring task. It was also considered necessary to work with the municipality to create a septic tank cleaning service.

Semi-permanent latrines were built in some of the most crowded places. The latrines were fitted with removable covers to allow for cleaning with a sludge pump. Designs are available for different situations from sources such as the Sphere Manual [1] and Oxfam Technical Manual [3]The method used to procure these buildings was to try to find contractors staying in the camps and offer them the opportunity to do the work. This proved effective and was a good way to get funds directly to those affected. The structures were built using corrugated zinc sheets instead of plastic as it was considered that this could be reused when the need for the extra sanitation subsided.

Plates 3 and 4 and 5 show the type of structure that were built in two days.

Plate 3 Well ring used as latrine Plate 4 Squat Plates Plate 5 The Structure

The septic tank cleaning service was more difficult to initiate and required the approval of a dumping site by the local authority. This service was deemed critical since it was not only the sanitation systems of the camps that were put under strain by this event, but because people were using the facilities of family and friends outside the camps, their systems were being overused as well. This raises the broader issue of the wider effects of such a disaster on people not directly affected - secondary effects.

General waste

The general waste removal service had been suspended following the Tsunami as vehicles and drivers were diverted to the clean-up operation along the sea front. This, again, posed a potential hazard for the wider population and not just those directly affected. A new service was initiated for the camps to ensure that waste wasn't allowed to accumulate and so prevent disease. This was expanded and assimilated into the municipal council's service with the assistance of GOAL, by way of vehicle provision.

The implementation of these simple services ensured that the threatened disease outbreak, and spread, due to lack of sanitation did not occur. Overall the key to ensuring that situations were under control depended on good information from people on site, the O&M staff hired provided an excellent line of communication and an effective monitor on site at all times.

6. Six months on

Some of the elements of the longer term plans shown above are necessarily for review by central government and their discussion are outside the scope of this paper. Six months on and the camps have all reverted to their original functions, schools, Mosques, community centres. Following on from the initial assessment, and in the light of stress put on buildings by the presence of so many people, it was decided to refurbish all the schools used as camps. The assessment showed that the sanitation provision was inadequate, even for a school. Temporary shelters are still being built and on-site sanitation provided.

7. Conclusions

The work of the emergency relief team is difficult, yet rewarding. The disciplines used by such professionals are well tuned, through years of commitment to those caught up in disasters, and are ever increasingly in demand as emergency follows emergency. The Sphere standards provide a very good starting point from which to design and implement emergency plans and are the result of many years of collaboration between experts in the field. On a practical level, on the ground, there is a need for cooperation with local people and authorities in order to ensure that programmes are equitable and sustainable. The purpose of the WATSAN intervention is to ensure that disease does not take hold and spread throughout places where people are living in crowded conditions. It is testimony to the local people, local authorities and the international relief team that no such outbreak was recorded in Ampara. As the reconstruction work continues, with a different set of issues and problems to overcome, it is hoped that the plans instigated in the days and weeks following the disaster will not hinder the long road back to something close to normality for those who suffered as a result of the Tsunami.

8. Acknowledgements

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9. Author

Dr. Michael Gormley is a Research Associate and has been a member of the Drainage Research Group since 2000. He specializes in air pressure transient analysis and solid transport in building drainage systems. As well as emergency relief work with GOAL, he has worked as a development engineer in Africa and is also an Associate Lecturer in International Development with the Open University in Scotland.

A Flushing Water Consumption Model for Residential Buildings in Hong Kong

K. W. Mui and L. T. Wong
behorace@polyu.edu.hk
beltw@polyu.edu.hk
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China.

Abstract

Domestic water closet (WC) flushing consumes a considerable amount of the total water supply in a typical apartment; however, there is a lack of concern about the consumption of flushing water due to occupant load patterns in cities having a high population density, e.g. Hong Kong. Indeed, flushing water consumption is of primary importance in designing a plumbing and drainage system for buildings. This paper proposes a mathematical model of flushing water consumption for residential developments. Density functions of the model parameters, including the installed cistern capacity and usage patterns of water closets, occupant load and its diurnal variations, were determined from a recent survey for water consumption in some residential buildings in Hong Kong. In particular, numerical values of the parameters were sampled from the density functions using the Monte Carlo technique in order to determine the probable flushing water consumption for a residential development. The model accuracy was verified by the measured flushing water consumption in a residential building. The results showed that occupant load and its variations had significant influence on domestic flushing water consumption and that confirmed the highlight of the proposed model. The model would be a useful source of reference in determining domestic flushing water consumption for residential building developments with appropriate model parameters selected.

Keywords

Occupant load, Water consumption, Residential building, Water closet

1. Introduction

Toilet flushing has been identified as one of the key issues of sustainable water system designs for buildings as it is the single activity contributing to the highest water consumption. The water required for toilet flushing is at least 30% of the public water consumption for domestic

buildings (Butler, 1991; Friedler *et al.*, 1996). In Hong Kong, seawater has been used for flushing more than 70% toilets; it is intended to extend the seawater flushing mains to cover 90% of areas (Kam, 1997; Hong Kong Information Services Department, 2002). Modelling for the probable flushing water consumption is therefore essential to proper planning and development of flushing water systems.

Traditionally, flushing water consumption was determined by the 'per capita' approach (Plumbing services design guide, 2002; Webster, 1972). Since water consumption is closely related to climate, culture, economy, individual demands, occupant attributes and appliance characteristics, flushing water consumption among countries varies wildly. It was reported that the total in-home water consumption and wastewater flow to building drainage systems varied from 29% to 48%. The daily domestic flushing water consumption found in some European countries was 31 to 45 L $ps.^{-1}day^{-1}$; and in USA, it was 36 to 76 L $ps.^{-1}day^{-1}$ (Lazarova *et al.*, 2003; Plumbing services design guide, 2002).

This paper proposes a simple stochastic model of daily domestic flushing water consumption. The model parameters, including the installed cistern capacity of water closets, variations of occupants' demands, occupant load and its diurnal variations, were determined from a recent study on domestic WC usage patterns of five residential estates in Hong Kong (Wong and Mui, 2004). With appropriate parameters selected, the model will be useful for effective planning on water resources for cities of similar high densities.

2. Model formulation

Flushing water consumption depends on the capacity of the WC cisterns installed V_w (L), variations of occupants' demands, occupant load and its variations (Wong and Mui, 2005). The daily flushing water consumption V_{cd} (L day^{-1}) is determined by the sum of hourly consumptions i in a day as follows, where V_w is the cistern capacity (9L cistern is typically used in Hong Kong), N_F ($ps.^{-1}h^{-1}$) is the number of flushes per capita per hour, ϕ is the occupant load variation factor expressed as a percentage of the maximum occupant load N_p (ps.),

$$V_{cd} = \sum_i V_w N_F N_p \phi_i \quad \ldots (1)$$

The consumption would be significantly influenced by the occupant load of the buildings N_p (ps.) which can be determined by the floor area A_f (m^2) and the occupant-area ratio O_a (ps. m^{-2}) (Wong, 2003),

$$N_p = O_a A_f \quad \ldots (2)$$

Frequency distributions of N_F, N_p and ϕ of residential developments were studied (Friedler *et al.* 1996; Webster 1972; Wong and Mui, 2004). A recent survey on 597 randomly invited households in Hong Kong showed that the average number of flushes per capita per hour was 0.48, and the maximum number of flushes per capita per hour was 1.09, higher than the value (0.75) used in current practice (Wong and Mui, 2004; Plumbing services design guide, 2002). It was noted that in some local residential buildings, a water closet was serving a population of 8 instead of 4 that is assumed in current practice (Laws of Hong Kong, 1997; Plumbing services design guide, 2002). Table 1 shows the typical values of O_a, N_F and ϕ for two surveyed buildings,

A from the public sector and B from the private sector. A large variation was found, as indicated by the fluctuation intensity φ defined by the standard deviation σ divided by the mean μ, i.e. $\varphi = \sigma/\mu$.

Table 1 - Model parameters

Parameter		Mean, μ	Fluctuation intensity, φ	Maximum, ϖ
No. of flushes per capita per hour, N_F ($ps.^{-1}h^{-1}$)		0.480	0.26	1.09
No. of users served by a WC, N_p		3.950	1.40	7.20
Occupant-area ratio, O_a ($ps.\ m^{-2}$)	Building A	0.084	0.38	0.16
	Building B	0.078	0.40	0.15
Occupant load variation factor, ϕ	Building A	0.785	0.16	1.00
	Building B	0.640	0.55	0.90

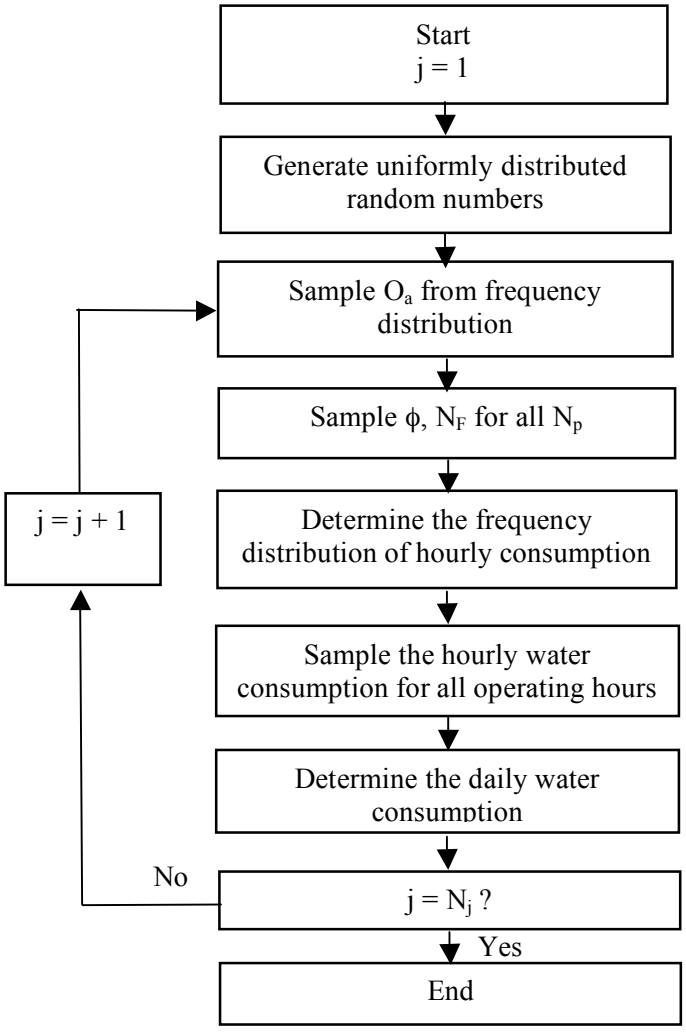

Figure 1 - Monte Carlo simulation for the flushing water consumption

3. Result and discussion

Figure 1 shows a stochastic model using the Monte Carlo sampling technique for daily flushing water consumption in residential buildings (Wong and Mui, 2005). Each simulation j was repeated with different random number streams for sampling the parameters N_F, N_p and ϕ. The hourly water consumptions of the development were then calculated and used to compute the frequency distribution of hourly flushing water consumption. The daily water consumption was determined for the total operating hours i from the sampled hourly consumptions with Equation (1). By repeating the simulations, the daily water consumption was determined from all the simulations with the average values, the standard deviations and the histograms against the development area. The simulation were repeated for j times and the convergent criteria for the output parameters λ_j, i.e. N_F, N_p and ϕ, are given by ξ, an error term of each output parameter,

$$\xi = \frac{\lambda_j - \lambda_{j-1}}{\lambda_j} \leq 0.005 \qquad \ldots (4)$$

A typical residential building 'A1' in Hong Kong was used for the simulations of probable flushing water consumption. It had 40 floors, 20 apartments per floor, a total area of 42000 m^2 and a total of 800 WC installed. Its design occupant load was 3500 persons. The input parameters were determined from a survey of this building. The occupancy ratios ϕ in 88 apartments from 10 am to 5 pm of a day were recorded; the mean and standard deviation of ϕ were $\mu = 0.785$ and $\sigma = 0.125$ respectively.

In this study, the actual flushing water consumption was measured at the flushing water pump room of building 'A1'. The operation time, water pressure and flow rate of the flushing water supply pump were also recorded. The predicted and measured daily water consumptions of 'A1' at confidence levels p = 0.5, 0.9, 0.95 and 0.99 are shown in Figure 2. The model yields a good prediction of flushing water consumption for the building.

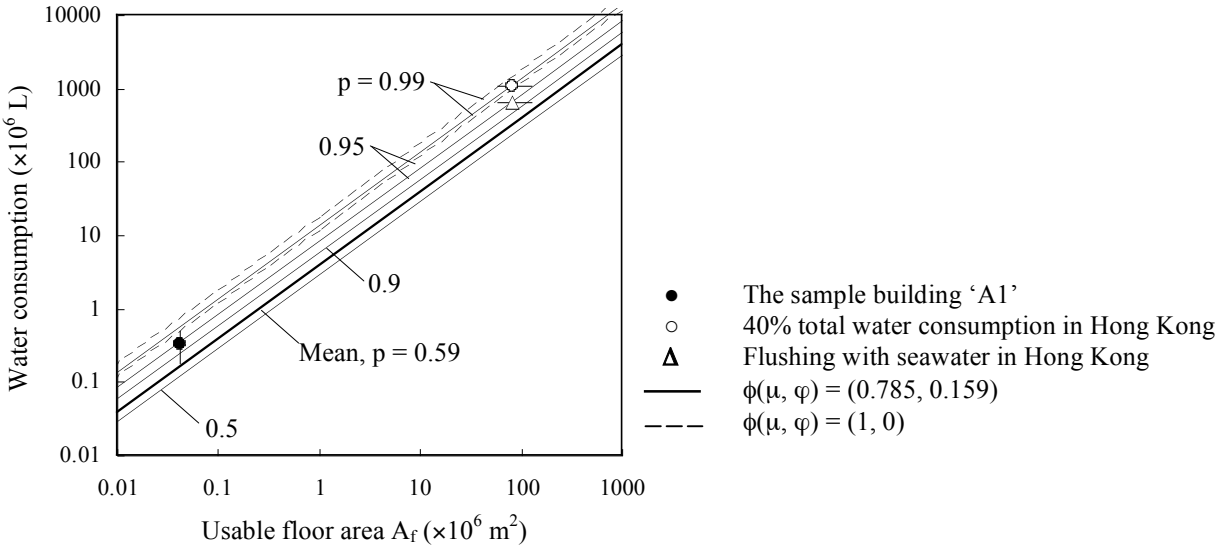

Figure 2 - Daily flushing water consumption

The applicability of the model was further justified with the Hong Kong water consumption records. A crude estimation of the daily flushing water consumption in Hong Kong was made by taking 30-40% of the total daily water consumption recorded from 1999 to 2001 at $\phi = 1$ and is shown in the figure (Hong Kong Information Services Department, 2002). The daily seawater consumption for flushing in Hong Kong is shown as well. Since these figures included water consumption for the industrial (although this was not the significant portion) and the commercial sectors, and the probable water leakage of up to 40% in the supply pipelines were not excluded (Kam, 1997), the actual flushing water consumption for flushing purpose by the end users might be less than the values shown. Figure 2 shows the flushing water consumption for seawater consumption and 40% of the total water consumption at confidence levels 0.89 and 0.96 respectively. The indicative figures yield a reasonable estimation made with the proposed flushing water consumption model.

Occupant load influences

This model was used to study the influences on domestic flushing water consumption due to occupant load and its variations in a residential development of a floor area 42000 m^2. Figure 3 shows the predicted daily flushing water consumption for the development at occupant-area ratios O_a from 0.01 to 1 ps. m^{-2}, corresponding to the occupant load factors from 1 to 100 m^2 $ps.^{-1}$. It was noted that a design occupant load factor of 9 m^2 $ps.^{-1}$ (O_a = 0.111 ps. m^{-2}) was used for some building designs in Hong Kong.

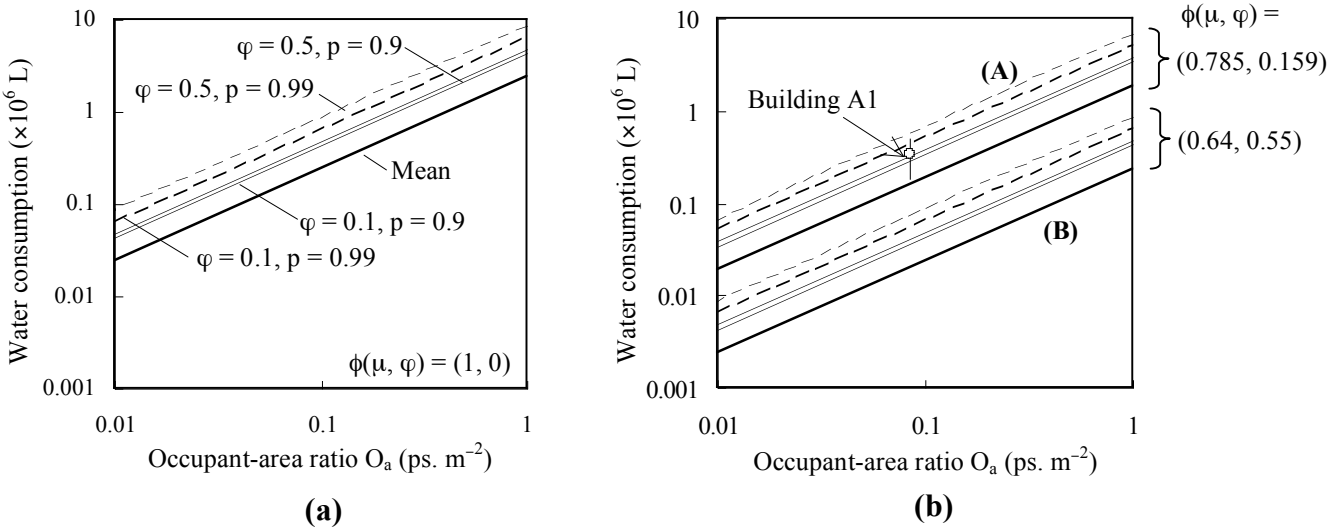

Figure 3 - Predicted daily flushing water consumption

As shown in Figure 3(a), maximum water consumption would hypothetically occur when all occupants are present in the building at $\phi(\mu, \varphi) = (1, 0)$. The influence due to the fluctuation intensity of the occupant-area ratio at $\varphi = 0.1$ to 0.5 would be significant at certain confidence levels, e.g. p = 0.9 and 0.99. In the figure, the confidence level p would be interpreted as the

probability that the flushing water consumption is less than the specified value under the specified conditions of O_a and ϕ.

Figure 3(b) shows the predicted flushing water consumption for buildings having occupant load conditions similar to buildings A, a residential building in the public sector, and B, a residential building in the private sector. These conditions were surveyed from a typical public building for A and from a typical private building for B. A higher consumption was predicted for A as more occupants were expected in it.

4. Conclusion

This paper presented a mathematical model of flushing water consumption for residential developments. In particular, the model parameters for Hong Kong were determined from a recent survey on water closet usage patterns in some residential buildings. This model took account of the diurnal variations of occupant load and flushes, and the cistern volume of the water closet. With the Monte Carlo simulations, the model could determine the domestic flushing water consumption to illustrate the effects of occupant load variations and occupancy ratio. Numerical values of the consumption at certain confidence levels were generated for typical residential buildings in both the private and public sectors at various occupant load conditions. The results showed that the occupant load had significant influence on the water consumption. A higher water consumption was predicted for a higher occupant load variation factor, and also for a residential building in the public sector probably due to the higher number of occupants present in this kind of building than in a private one. It is proposed that the probable flushing water consumption at various occupant load patterns should be determined and the occupant load conditions of residential buildings should be considered in future domestic flushing water system designs. The model would be a useful source of reference in determining the domestic flushing water consumption for residential building developments, with appropriate model parameters selected.

5 Acknowledgement

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Design and maintenance of safety shower installations

Ing. O.W.W. Nuijten (1)
o.nuijten@isso.nl
ISSO, Sanitary and Gas installations, The Netherlands, Rotterdam

Ir. J. van Wolferen (2)
hans.vanwolferen@mep.tno.nl
TNO-MEP, The Netherlands, Apeldoorn

Ing. J.A.G.M Wittens (3)
jwittens@avans.nl
Avans Hogeschool, The Netherlands, Den Bosch

Abstract

The law and regulations in various countries make demands on the application of safety or emergency showers and eye/facewash equipment. Large companies or industries often have their own guidelines. In The Netherlands, the regulations and requirements for these showers are described very globally. For almost every project, the designer has to find answers to a lot of questions. Probably the situation in other countries is comparable to that of The Netherlands. The designer, in his search for answers, has to cope with questions like:

- What type of safety shower do I have to use in certain situations?
- Where can I find guidelines and standards?
- Can I use the American, DIN or other standards?
- What microbiological water quality is needed?
- What water temperature is required?
- How can I connect these to the (potable) water system?
- What are the design flow rates and design pressures?
- How can I heat the required flow rate to the required temperature during the required flushing time?
- What about maintenance and testing?

That is why Uneto-VNI and TVVL took the initiative for a preliminary study. The results of this study have to lead to more detailed regulations and technical guidelines for

design and maintenance of watersupplysystems for emergency shower, drench hoses and eye/facewash equipment.

The literature study was carried out by Hans Van Wolferen (2) and the results and recommendations were published in a technical TVVL-report, ST-11 [1].

In 2004 and 2005, Hans Wittens (3) carried out a complete investigation on the recommendations in ST-11 with the purpose to advise about detailed regulations and technical guidelines that are acceptable to the government of the Netherlands and other parties involved. That resulted in technical TVVL-report ST-16 [2].

Keywords

Emergency shower, safety shower, eye/face wash, drench hose, potable water, tepid water, Legionella, process water, flushing, flow rate, simultaneously, flow pressure, duration of use, maintenance, testing, employees, victim, burns, medical expert, chemical, microbiological..

1 Introduction

The investigation has three phases:

1. Phase of preliminary investigation:
   - Study of technical report ST-11 [1]

2. Phase of analysis:
   - Interviews with various experts in the field of legislation on this matter
   - Formulating of thesises (questions)
   - Presenting these thesises to a large forum of experts and discuss these.

3. Phase of recommendations
   - Working out proposals for guidelines

2 The research

2.1 The organization of the research

2.1.1 Preliminary study

The literature study (ST-11) has provided a clear image of rules, guidelines and standards that are valid for the above mentioned equipment and installations in the USA (ANSI), Germany (DIN) and The Netherlands (Legislation and guidelines on working conditions and potable water supply).

In this phase, experts were interviewed based on the results of literature study ST-11 .[1]. Out of these interviews a table with a survey was developped. (see par. 2.2.1).

2.1.2 Phase of analysis

Questions of investigation
From the missing answers out of the preliminary study, questions of investigation were formulated:

1.	Are the Dutch ARBO-policy instructions (concerning working conditions) sufficient for watersupply installations that are feeding plumbed emergency equipment?
2.	Which requirements have to be met with the waterquality in watersupply installations that are feeding plumbed emergency equipment and under which condiotions is it allowed to use process water for this purpose?
3.	Which guidelines can be recommended for the: - watertemperature, - design flowrate, - flow pressure - time of use - testing and maintenance - prevention of Legionella risk?
4.	Which factors of simultaneity have to be used for the sizing of watersupply lines that are feeding combined installations for sanitary purpose, fire-hose spools and safetyshowers.

Interviews
Interviews were held with experts of:

- Dutch Ministry of Social Affairs and Employment (SZW) and their department of Labour / Factory Inspection (AI)
- Netherlands Ministry of Housing, Spatial Planning and Environment (VROM)
- KIWA, Certification Institute
- RIVM, National Institute for Public Health and Environment

From the results of the interviews a list of items was developed.

Thesises
Thesises were formulated arising from the results of the interviews with the experts.
Those thesises were presented to a *forum of experts* of the most important parties involved in this matter.
That's what made it possible to reach consensus and give a solid basis to the recommendations for uniform guidelines in The Netherlands. The forum of experts

could not agree upon all propositions. The persons present, advised to give the medical experts the last word on these subjects.

2.1.3 Phase of recommendations

In this phase recommendations were given for Dutch guidelines (VEWIN [4], ISSO 55 [5]) and policy instructions for Legionella prevention (ARBO) concerning design and maintenance of potable water installations for plumbed emergency equipment.

2.2 Results

2.2.1 Preliminary study

The results from literaturestudy ST-11..[1] and comparison between German [8], American [9] and Dutch legislation, standards and guidelines are summarized in tables 1 to 10.

Table 1 – Microbiological and chemical waterquality

Type of safetyshower	DIN	ANSI	NL-Leg. or Std's
Emergencyshower (body)	potable(1)	potable	potable (2)
Eyewash	potable(1)	potable	potable (2)
Facewash	potable(1)	potable	potable (2)
Hand held drench hose	potable(1)	potable	potable (2)

(1) Potable water or water with equal quality for this purpose (This does not need to comply with hall the microbiological requirements of potable water)
(2) Connected to (public) waterdistributionsystem

Table 2 – Water temperature

Type of safetyshower	DIN	ANSI	NL-Leg. or Std's
	[°C]	[°C]	[°C]
Emergencyshower (body)	-	>15	-
Eyewash	-	>15	-
Facewash	-	>15	-
Hand held drench hose	-	>15	-

Table 3 – Measures against freezing

Type of safetyshower	DIN	ANSI	NL-Leg. or Std's
Emergencyshower (body)	-	yes	-
Eyewash	-	yes	-
Facewash	-	yes	-
Hand held drench hose	-	yes	-

Table 4 – Minimum flowrate

Type of safetyshower	DIN	ANSI	NL-Leg. or Std's
	[l/min]	[l/min]	[l/min]
Emergencyshower (body)			
- all types		76	80
- for laboraties	30	-	-
- industry&outside single showerhead	30	-	-
- industry&outside multiple showerh.	100	-	-
Eyewash	12	3	-
Facewash	24	11,4	-
Hand held drench hose	10	-	-

Table 5 – Minimum operating time			
Type of safetyshower	**DIN**	**ANSI**	**NL-Leg. or Std's**
	[min.]	**[min.]**	**[min.]**
Emergencyshower (body) - all types - for laboraties - industry & outside	 - 30	15	-
Eyewash	-	15	-
Facewash	-	15	-
Hand held drench hose	-	15	-

Table 6 – Minimum pressure			
Type of safetyshower	**DIN**	**ANSI**	**NL-Leg. or Std's**
	[kPa]	**[kPa]**	**[kPa]**
Emergencyshower (body)	100	200	-
Eyewash	100	-	-
Facewash	100	-	-
Hand held drench hose	100	-	-

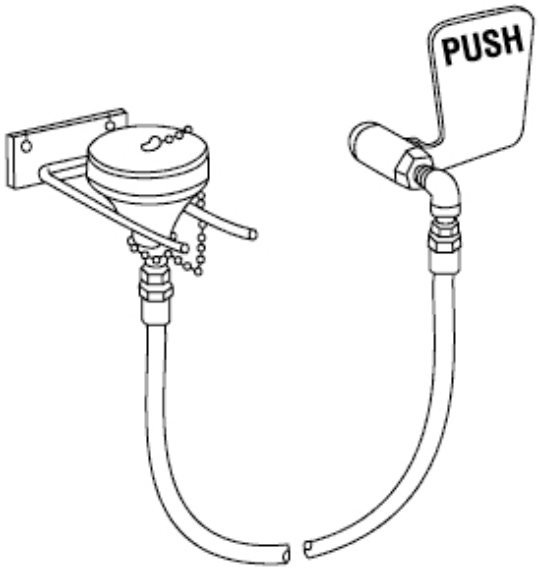
Table 7 – Testing of functioning			
Type of safetyshower	**DIN**	**ANSI**	**NL-Leg. or Std's**
Emergencyshower (body)	-	weekly	-
Eyewash	-	weekly	-
Facewash	-	weekly	-
Hand held drench hose	-	weekly	-

Table 8 – Maintenance of watersupply			
Type of safetyshower	**DIN**	**ANSI**	**NL-Leg. or Std's**
Emergencyshower (body)	-	annually	- annually(3)
Eyewash	-	annually	- annually(3)
Facewash	-	annually	- annually(3)
Hand held drench hose	-	annually	- annually(3)
(3) According Dutch regulations for potable water installations [5]			

Table 9 – Connection to watersupplylines			
Type of safetyshower	**DIN**	**ANSI**	**NL-Leg. or Std's**
Emergencyshower (body)	-	yes(4)	-
Eyewash	-		-
Facewash	-		-
Hand held drench hose	-		-
(4): Valves for maintenance are not allowed to be closed unauthorized..			

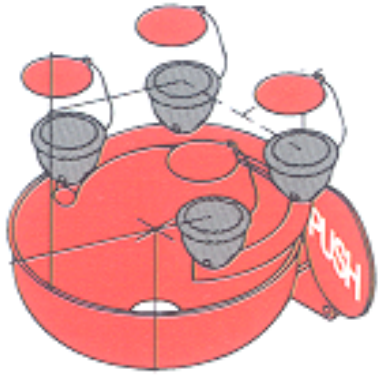
Table 10 – Sizing of watersupplylines			
Type of safetyshower	**DIN**	**ANSI**	**NL-Leg. or Std's**
Emergencyshower (body)		yes(5)	
Eyewash		yes(5)	
Facewash		yes(5)	
Hand held drench hose		yes(5)	
(5) At combination of more showers the flowrate must be sufficient for simultaneous use.			

Emergency shower



Handheld drench hose

Eyewash



Facewash

Figure 1 – Examples of plumbed safety equipment

2.2.2 Analysis

Microbiological and chemical waterquality
In general, one agrees upon the demand that for emergency showers potable water is needed or water of equal quality. But what is "equal quality" in this case?
In the Netherlands potable water delivered to users has to comply to very strict demands on the (microbiological and chemical) quality.

Medical experts state that in water for use with emergency showers:

- the concentration of van Pseudomonas aeruginosa at 22 ºC < 100 cfu/ml (geometric year mean value).
- Ill-making micro-organismes of faecale origin are not allowed under any circumstance.
- Acanth-amoebe = 0 cfu/ml.

In water dissolved pipeline material or other small particles are normally no problem for emergency showers. That is why it is basically allowed to use "dead" turbid water for this purpose. For eye-- and face wash, turbid water is not wanted.

Table 11 shows the recommended minimum quality of water for emergency showers and eye-/facewash and the frequency of analysis.

Table 11 – Recommended minimum biological and chemical waterquality for use with safetyshowers (RIVM, ir. Ans Versteegh)

Parameter	Maximum value	Analyse-frequency per year
Pseudomonas Aeruginosa	100 cfu/100 ml	2
Acanthamoebe	0 cfu/100 ml	2
Nitrite	0,1 mg/l	2
Ammonium	0,2 mg/l	2
Bacteriës Coli	0 cfu/100 ml	4
Colonynumber 22 ^{o}C	100 cfu/ml	2
pH	7,0<pH<9,5	2
Oxigen	>2 mg/l	2
Smell	No change	2
Troublinggrade	< 4 FTE	2

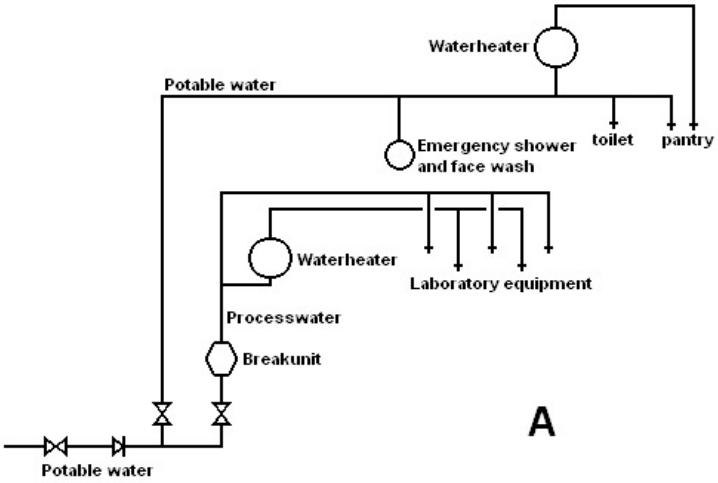
Legionella:
Legionella can grow in the waterinstallation. When an emergency shower or eye/facewash is used in case of an accident, it is a matter of very incidental exposure. A good advice is to analyse the water at the showerhead after use.

Use of process water in laboratoria:
In laboratories, one often sees a (limited) potable water installation for sanitary purpose and a process water installation for the equipment in the laboraty. This laboratory installation can be fed with potable water. In the connection there must be a break unit.with a pump or an equal backflowprevention device. After this break the potable water has become process water, as defined in NL (see figure 2A)

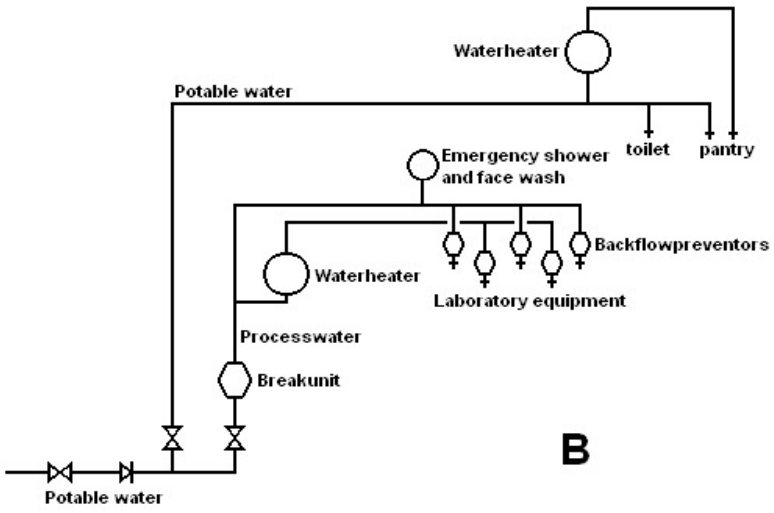
The forum of experts concluded that it is required to frequently analyse the water according a certain simplified measurement program, if the emergency shower equipment is connected to a process water installation.

Backflow prevention:
When emergency showers are connected to the process water installation in a laboraty, it is possible that the supplied water gets polluted as a result of backflow from the connected laboraty equipment

The forum of experts concluded that the emergy showers must be connected to the potable water system if there is a chance of microbiological contamination (see figure 2A).
This is also preferred if there is a chance of chemical contamination, but an alternative can be the mounting of individual backflow preventors at each wateroutlet, combined with regular testing and maintenance of these devices (see figure 2B).



Emergency-equipment connected to potable water



Emergency-equipment connected to process water

Figure 2 – Process water installations with emergency showers

Watertemperature

The watertemperature is important to prevent undercooling, damage or acceleration of chemical reactions. When the water suplied has to be cooled or heated it can have considerable effect on the installation (and costs).

Too cold:

- For emergyshowers a watertemperature of < 15 °C in the first tens of seconds is no problem. But after a longer time undercooling can occur.
- For an eyewash flushing with water < 20 °C is so unpleasant that the victim cannot hold on the flushing long.
- Water with temperatures < 5 °C can even cause a temperatureshock.

Too warm:

In some cases, a too high temperatures can occur. For emergency showers 20-25 °C is ideal.

- Temperatures > 38 °C are harmful.
- For eye-/facewash the maximum is 30 °C.
- ANSI Z 358 [8] says that when chemical reactions can be accelerated, a medical expert has to be consulted to advise about the temperature limit.

The forum of experts indicates that the temperature that are given by the medical experts requirements have to be used in the guidelines. Information is asked from prof. Boeckx (burnwound specialist, of hospital AZM in Maastricht). Based on consultation of literature and college,s he advises as follows:

- *Emergency shower for all burn wounds (also chemical): > 15 °C*
- *Facewash: > 15°C*
- *Eyewash: > 25°C*

Minimum flowrate

Rules in the Netherlands:

- The only rule in the Netherlands is that the minimum flowrate of an emergency shower has to be 80 l/min.

Rules in Germany and the USA:

- The German standard DIN 12 899 and American standard ANSI Z 358 are different. (see table 4).
- The German standard mentiones a minimum flowrate of 30 l/min for an emergency shower in a laboratory.
- For eyewash and facewashequipment the demands are also quite different (see table 4)

Duration of use

- ANSI mentions a possible duration of use of 15 minutes.
- DIN does not mentione a duration of use in laboraties, but it mentions 30 minutes for emergencyshowers that are placed outside (industry)
- The Dutch Brandwonden Stichting from Beverwijk (David Mackie) mentions a time of at least 10 minuten for cooling fire burns.
- For cooling of chemical burns a time of 60 minutes is mentioned.

Flow pressure

Flow rates are related to a certain flow pressures at the showerhead. ANSI prescribes a minimum flow pressure of 200 kPa, and DIN 100 kPa.
ANSI mentiones also a maximum pressure of 550 kPa above which one has to take care for a too strong waterstream that can injure the victim.

The forum of experts advises a minimum flow pressure of 100 kPa. At higher pressures than 300 kPa the pressure has to b e reduced on indication of the manufacturer, to maintain the proper spraypattern and to prevent a to strong waterstream.

Testing and maintenance

The literaturestudy ST-11 says that maintenance and testfrequency of emergencyshowers depend on the conditions at their location. Dirt, soot and chemicals can affect and cover operating devices and sprayheads. showerheads. .

- Under such dirty circumstances weekly or monthly inspection is required.
- In a clean outside location once per month or three month will do.
- In a laboraty with clean air and other inside locations once per three month or once per year is okay.

The maintenance frequency has to be determined after an Analysis of the circumstances.

- The functional testing of an emergency shower consists of a short flushing action.
- Maintenance has to be according manufacturers instructions.

Legionella risk

There is a distinction between the following risks:

1. infection of the victim and helper by using the emergency shower or eye/facewash
2. infection of the maintenance personnel while testing the equipment.
3. contamination of the potable water supply lines, that are feeding sanitary showers and other spray forming wateroutlets.

Ad 1.

Because there is only a very incidental exposure at a possible infected waterspray the chance of infection of the victim and helper is small.

- Dutch guidelines tell: “The use of the emergencysystem always prevails above infection or contamination with Legionella”.
- The victim and his physician can be informed about the possible effects of Legionella, so they can recognize infection before it is too late.

Ad 2.
When emergencyshowers are frequently tested the duration of exposure is longer.
In this case:

- the watersupply installation has to be kept free of Legionella

or

- the maintenance personnel has to take protective measures so they cannot inhale aerosoles.

Figure 3 – Legionella-safe testing of emergency shower

Ad 3.
Contamination of the watersupplysystem due to emergency showers can be prevented with the measures shown in figure 4, in case of roomtemperatures < 25 ^{o}C.

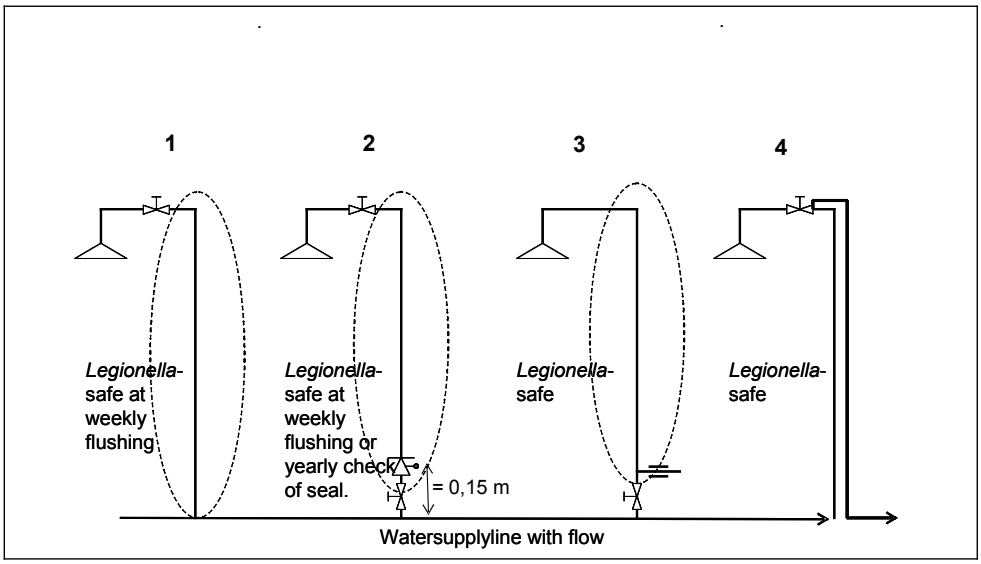


Figure 4 – Four ways to connect emergency showers "Legionellasafe" to watersupplylines

Sizing (capacity) of watersupplylines:
During the use of an emergency shower, the flow in the rest of the potable water system is maintained. Sometimes there are circumstances that even a firehose spool has to be used simultaneaously.
For the calculation of the design flowrate of a potable water system with plumbed emergy equipment, the following formulas are applied in The Netherlands:

If $q_{mmd} \leq q_{lim}$ then $q_{mmc} = q_e + f * q_{mmd}$
If $q_{mmd} > q_{lim}$ then $q_{mmc} = q_{mmd}$

In which:

q_{mmc} =	maximum moment flowrate of combined potable water and emergency installation.	[l/s]
q_{mmd} =	maximum moment flowrate of the potable water installation.	[l/s]
q_{lim} =	limited flowrate = $q_e / (1 - f)$	[l/s]
q_e =	maximum moment flowrate of emergencyinstallation	[l/s]
f =	Factor of simultaneity for q_{mmc} and q_{mmd}	[-]

In Dutch guidelines there is given that factor $f = 0,7$. That is rather large.
For example if q_{mmc} is only for sanitary use than this flowrate will only be reached very occasionally.
A lower value of factor f may be justified depending on circumstances.
Other values could be used based on an analysis of the use of the waterinstallation, for example $f = 0,25$, $f = 0,50$ or $f = 0,75$.

If more plumbed emergency equipment is connected to the watersupplyline in the building, then simultaneous use of the differenent showers, eyewash and firehose spools has to be taken into account.
The following can be of influence on the simultaneity of different and/or more emergency-equipments:
- possibility of more victims at the same time;
- possibility of fire in the building and fire burn wounds at the same time;
- the amount of emergency equipments;
- the lay out, purpose and size of the building.

The forum of experts advises that a risk analysis has to be made under the responsibility of the customer.
The results of this risk analysis has to give information about the location/type/sizes of emergency-equipments and their simultaneous use. The results have to be included in the specifications of the building installations.

3 Conclusions and recommendations

In this paragraph the results of the investigation are presented with a summary of the answers to the four questions of investigation and proposed guidelines for design and maintenance of safety shower installations in The Netherlands.

3.1 Answers and proposed guidelines

1.	Are the Dutch ARBO-policy instructions (concerning working conditions) sufficient for watersupply installations that are feeding plumbed emergency equipment?
	Answer: No Motivation: ▪ ARBO-policy instruction 4.4-5 prescribes that an emergency shower installation has to be connected to a potable water installation.This instruction does not mention the possibility to use process water of equal quality for this purpose. ▪ In the ARBO-policy instruction no requirements are prescribed for the watertemperatures and duration of use. ▪ The ARBO-policy instruction does not make a distinction between design flowrates of emergency showers depending on sorts of danger. ▪ The ARBO-policy instruction does mention the possibity of simulteneous use of emergency-equipment.

2.	Which requirements have to be met with the chemical and biological quality in watersupply installations that are feeding plumbed emergency equipment and under which condiotions is it allowed to use process water for this purpose?
	Answer: ▪ When connected to a (public) potable watersupply system there are no extra requirements. ▪ When connected to a process water installation there are extra requirements. Proposed guidelinesL: ▪ It is preferred that plumbed emergency equipment is connected to a potable water system that complies with Dutch legislation.. ▪ Eye- and facewash must be connected to a potable water line in which there is regular flow to keep the water fresh. ▪ In microbiological laboraties the emergency equipment shall NOT be connected to the processwater installation. ▪ In chemical laboraties it is advised not to connect emergency equipment to the process water installation. ▪ When connected to a process water installation the quality should be monitored by a simplified measuring programm (table 11). ▪ When connected to a process water installation in a chemical laboratory, the wateroutlets to the laboraty equipment shoud be equipped with indiviual backflowpreventors (fig. 2B). The functioning of these devices should be checked annualy. ▪ Emergengy equipment, connected to process water, must have a warning *"Non- potable water"* ▪ An (extra) measure can be to analyse the water on Legionella after use of the equipment by a victim and helper.

Continuation of answers and proposed guidelines

3.	Which guidelines can be given for the: ▪ watertemperature ▪ design flowrate ▪ flow pressure ▪ time of use ▪ testing and maintenance ▪ prevention of Legionella?
	Answer: ▪ The guidelines concerning watertemperature, design flowrates, flowpressure and duration of use in The Netherlands are given in table 12. ▪ For prevention of Legionella contamination of the watersupply system use ISSO-publication 55.1 [6] or 55.2. [7] (see also fig. 4).

4.	Which factors of simultaneity have to used for the sizing of watersupply lines that are feeding combined installations for sanitary, fire-hose spools and safetyshowers.
	Answer: ▪ At first a riskanalysis about the quantity, place, and simultaneity of the emergency equipment has to be made under the responsibility of the customer. ▪ For understanding about simultaneity and the sizing of the watersupplylines see also par. 2.2.2, subject Sizing (capacity) of watersupplylines: Proposed guidelines: ▪ In chemical laboraties (also in schools) an emergency shower and eyewash have to be installed and it must be possible to use these simultaneously. ▪ Calculate the flowrate in combined installations according the general formula.with a factor for simultaneity. ▪ In combined installations with normal sanitary use.a standard value $f = 0{,}25$ can be used for the watersupplyline at the watermeter. ▪ In other situations, for example with continuous flows, and in other downflow linesections, the factor *f* has to be determined by an analysis.

Table 12 – Proposed guidelines for minimum flowrates, temperatures, duration of use and flowpressure

	q [l/min]	θ_{min} [°C]	t_{use} [min]	p_{min} [kPa]	Remarks
Eye wash	12	25	10	100	2 heads at 6 l/min.
Face wash	24	15	10	100	4 heads at 6 l/min.
Emergency shower **I**	30	15	10	100	For fire burns in for example a kitchen in a restaurant
	30	15	20	100	For chemical burns at small stores of chemical goods or (school) laboratories
Emergency shower **II**	80	15	20	100	For chemical burns at large stores of chemical goods and chemical industry.

- *The selection of a 30 or 80 l/min shower must be the result of a riskanalysis.*
- *The flowrate and spraypattern and sprayvelocity have to be in compliance with the flowpressure specified by the manufacturer.*
- *For reasons of Legionellaprevention the maximum temperature can be limited to max. 25 °C.*
- *For prevention of eyedamage the max. temperature at an eye wash = 30 °C.*
- *For prevention of skindamage the max. temperature at a shower and face wash = 35 °C.*

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5 Presentation of Author

Oscar Nuijten is currently working as a project coordinator with ISSO (knowledge centre for building services) in Rotterdam, The Netherlands), where he is responsible for the realisation of technical publications in the field of sanitary and gas installations.

First ten years of practical experiences with use of water hydraulics diode for elimination of water hammer

E. Petrešin(1), M. Nekrep Perc(2)
(1) eugen.petresin@uni-mb.si
(2) matjaz.nekrep@uni-mb.si
(1) Faculty for Civil Engineering, University of Maribor
(2) Faculty for Civil Engineering, University of Maribor

Abstract

In our work we are explaining experiences, advantages and problems in using water hammer damper is water hammer prevention element in water distribution systems in last ten years. The results are testifying that water hammer damper is one of the most efficient instruments for prevention against water hammer.

In addition we are presenting suggestion for solving problems with noise and water hammer in high-rise buildings drainage systems with use of water hammer damper named also water hammer damper.

Keywords

High-rise buildings, drainage, water hammer damper

1. Preface

Water hammer damper prevents water distribution systems again water hammer and another types of oscillations. With significant reductions of oscillations we eliminate damage on tube systems, pump stations, etc. Water hammer damper is also equipped with recurring flap and vacuum and pressure valve, which is also used as safety valve. In case of horizontal pumps water hammer damper is mounted directly on pump. The size of pump defines the size of hydraulics diode. In case submersible pumps water hammer damper is mounted in utility building over the well. It acts considerable faster then the pressure boiler. The volume of water hammer damper is about 50 times smaller than the volume of appreciate pressure boiler.

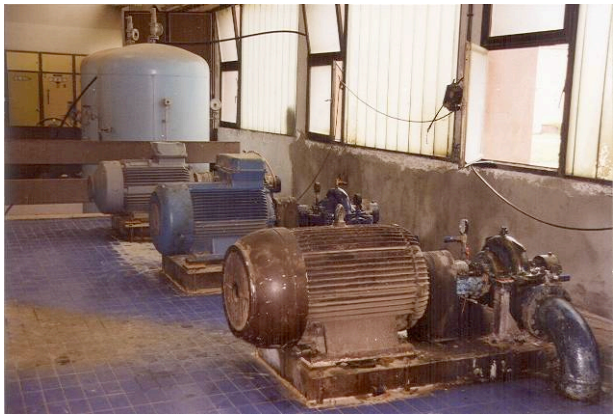

Figure1 - Solution with pressure boilers (Pump station Tuzla BiH)

Figure2 – New solution with water hammer damper (Pump station Tuzla BiH)

Comparison table water hammer damper versus pressure boiler

- **Advantageous effect on quality of water (there is no water stagnation)**
- **Easier and cheaper technical documentation**
- **Much cheaper (works without pressure station)**
- **Mechanical device (works without electrical energy)**
- **Easy mounting on pump**
- **Low operation and maintain cost**
- **Change of working pressure or water flow doesn't require change of hydraulics diode**
- **Minimal energy loses in the unit**

2. Dangerous phenomena caused by water hammer

Occurrence of vacuum in pipe lines is caused by:

- pumps breakdown
- uncontrolled valve closing
- pipeline breakdown
- by mistake of control stuff
- etc

Figure 3 - Damage caused by water hammer; pump station in Italy

If pressure remains higher than atmospherically pressure such an unpredictable events doesn't cause any damage.

Figure 4 - Damage caused by water hammer; pump station in Italy

In case of vacuum in the pipe line, outside pressure pipe line could not resist such a pressure difference, water column could be broken and when it is again established pipe lines could be damaged.

In most cases pipa lines are not damaged immediately, but materials are under repeated stress and became fatigued. Pipe lines are flattened and become untied during the time.

Figure 5 - Damage caused by water hammer; pump station in Italy

Water could be polluted and we have higher water loses. Cavitation causes pipe lines damages.

Also the momentary rise of pressure causes damage in the pipe lines and joints.

3. Discussion about water hammer prevention methods

In water distribution system we have to take measures against water hammer. Measures are needed all kind of water distribution systems.

For prevention against too low or too high pressure in pipe lines following measurements are used:

- longer time of closing valves
- over dimensioning of pipe line
- deformable sections of pipe line
- oval section tube
- parallel pipe lines
- air valves
- *"by pass"*
- hydraulics diode

5. Description of water hammer damper

Water hammer damper prevents water distribution systems again water hammer and another types of oscillations. Water hammer damper is also equipped with recurring flap and vacuum and pressure valve, which is also used as safety valve.

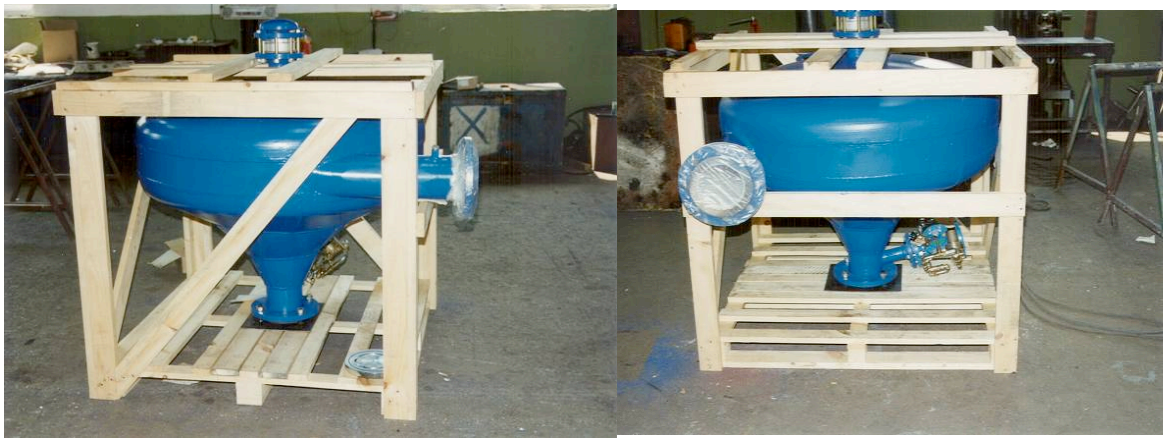

Figure 6 – Water hammer damper prepared for transportation

In case of horizontal pumps water hammer damper is mounted directly on pump. The size of pump defines the size of hydraulics diode. In case submersible pumps water hammer damper is mounted in utility building over the well.
Main characteristic of water hammer damper unit is that it is completely mechanical unit consequently it doesn't need any energy source to be functional. It uses only its unique shape to reduce velocity of fluid.

Figure 7 – Recurring flap

It acts fast and need less volume than other common solutions. Also building for pump station is reduced considerable. Quality of water is improved due absence of water stagnation. Pressure losses are negligible. It works under low operation and maintain cost. Technical documentation for build in is easy and low cost.

6. Practical applications of water hammer damper during past ten years

We have many successful application of hydraulic diode in water distribution systems in our country and abroad. There are forty eight pump stations in Slovenia, Croatia, Sweden, Serbia and Montenegro and Bosnia and Herzegovina equipped with water hammer damper.

Figure 8 – Application in the Pump station Ptuj

We have chosen pump station in our neighborhood which could be easily controlled and in case of any problems we are able to act immediately.

Figure 9 – Small pump station building is needed

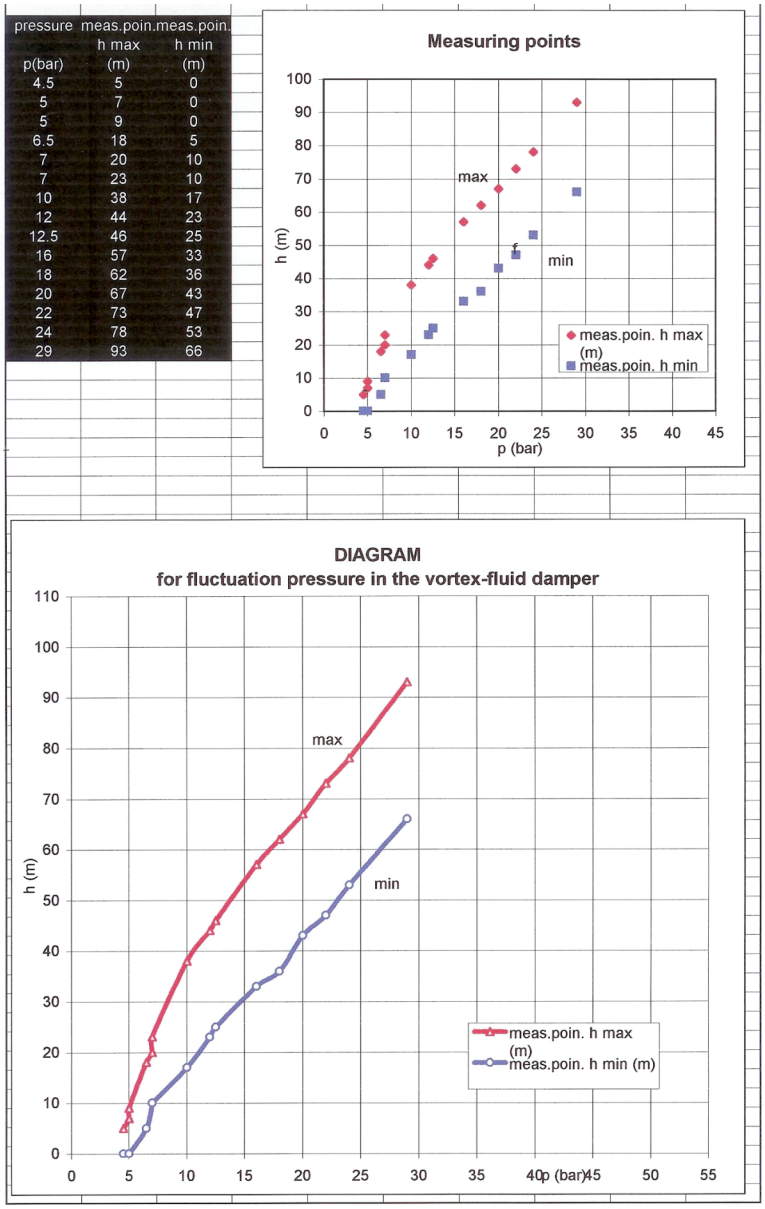

Figure 10 – Fluctuation pressure

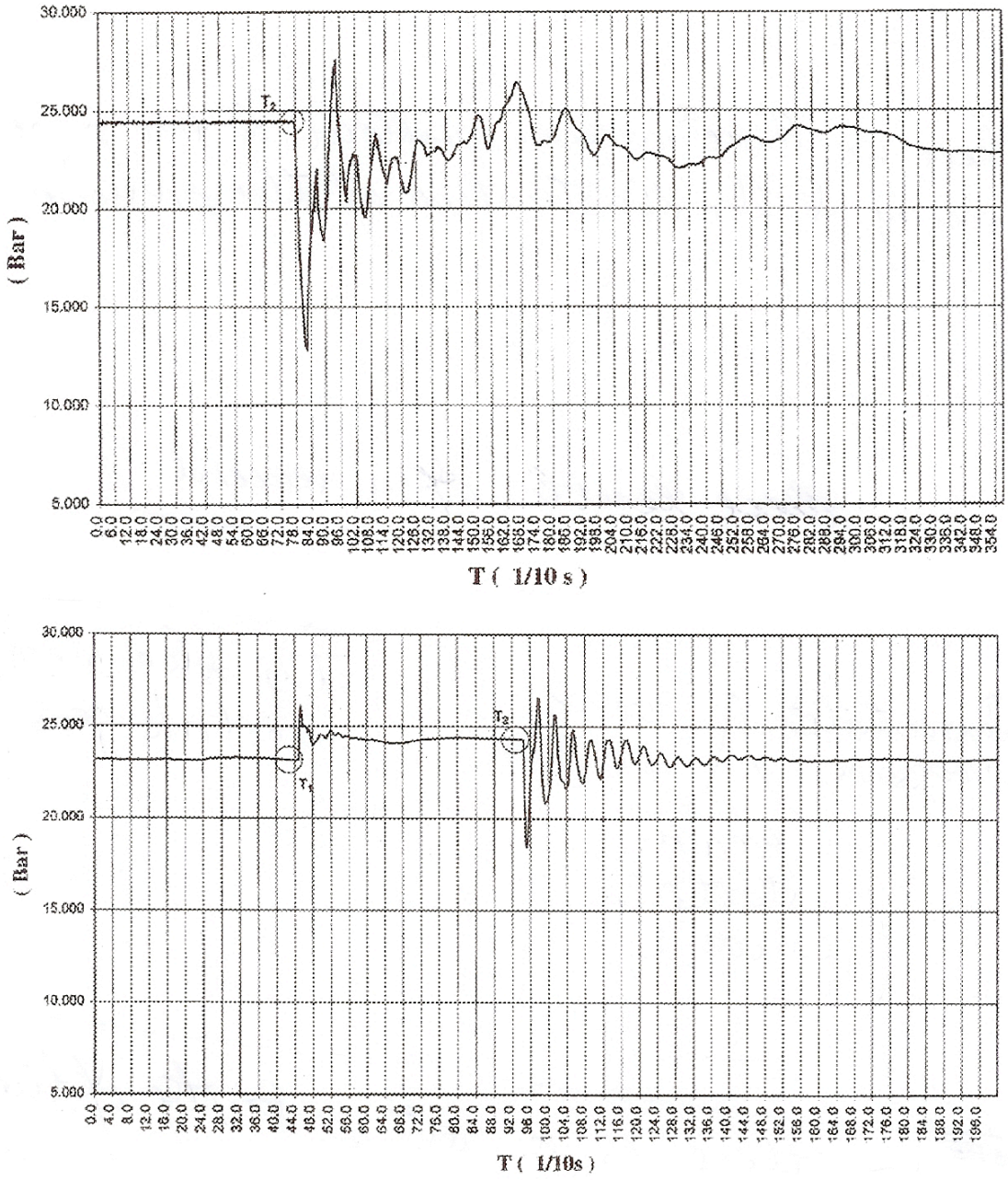

Figure 11 – Pressure cauldron without and with hydraulic hammer damper

After ten years of experiences we could say that the new solution for water hammer prevention is here.

7. Suggestion for solving problems with noise and water hammer in high-rise buildings drainage systems with use of hydraulics diode

Water hammer damper with its speed reduction capabilities and other qualities (low cost and complete mechanical unit) is very unique and suitable solution as noise and water hammer effect reduction element in high rise buildings.
Our solution forced waste water to helical flow near the pipe wall. In the center we have free air flow. It enables the easiest possible transition from horizontal to the vertical flow.

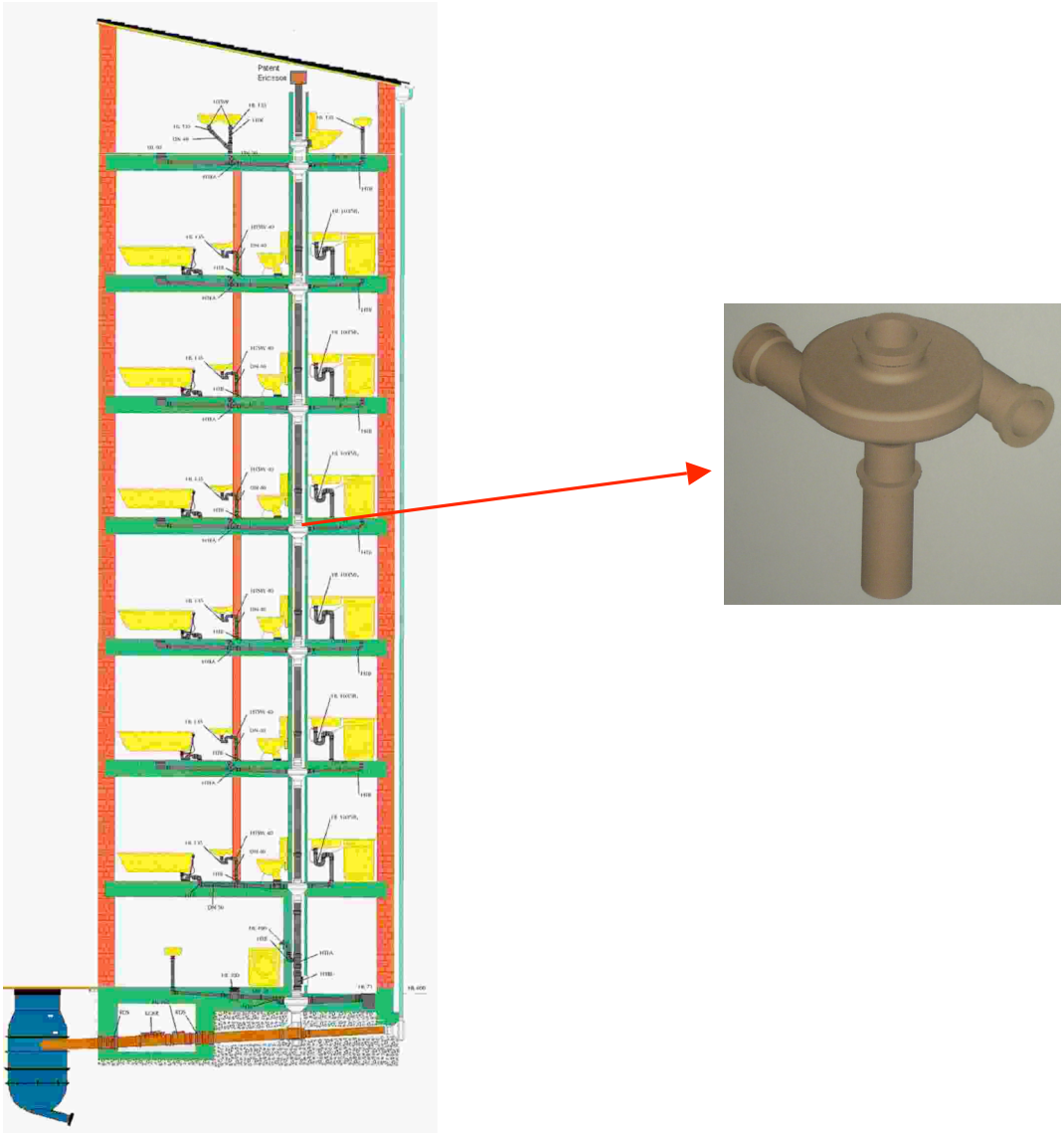

Figure 11 - High-rise buildings drainage systems with our solution

8. Conclusion

In past ten years water hammer damper proved itself as very useful solution for prevention against water hammer with many qualities. The results are testifying that water hammer damper is one of the most efficient instrument for prevention against water hammer.
In addition we propose the use of water hammer damper as a noise and water hammer prevention in the high-rise buildings drainage. We propose detailed analyses and measurements in the experimental high rise buildings.

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10. Presentation of Authors

Dr. Eugen Petrešin is Professor at Faculty for Civil Engineering, University of Maribor and Head of The chair for hydraulics.

Matjaž Nekrep Perc is Teaching Assistant at Faculty for Civil Engineering and postgraduate student of Informatics sciences

An original tool to investigate drinking water distribution system

O. Correc (1), F. Derrien (2), Y. Diab (3)
(1) olivier.correc@cstb.fr
(2) derrien@cstb.fr
(3) ydiab@univ-mlv.fr

(1) (2) CSTB, 84 Avenue J. Jaurès, 77447 Marne la Vallée Cedex 02
(3) LGUEH, 5 Bd Descartes, 77454 Marne la Vallée Cedex 02

Abstract

The corrosion cost in private plumbing is probably of equal or greater magnitude compared to public systems [1]. In particular, a typical complete replacement of water supply installation costs about 6000 dollars [2]. Moreover materials dissolution leads to bad water quality and risks for consumer's health. Therefore, a best attention is necessary to decrease economic and sanitary impacts linked to corrosion problems.
This paper provides a methodology to investigate and estimate the degradation risk of these installations according to their technical characteristics. The theory of possibilities is used to take into account uncertainty of theoretical knowledge and measures on the site [3]. Our study aims to build a computer tool to inform building managers on possible degradations before their apparition.

Keywords

Sanitary water, building, degradation risks.

1 Introduction

Drinking water systems inside buildings suffer from two main degradations: corrosion and scaling phenomena. They can be induced by design errors, bad implementation or poorly adapted maintenance but also by water and materials quality [4], [5].

These degradations lead to bad water quality and risk for consumer's health. Indeed, dissolution of metallic components may modify parameters of water quality and deposition of corrosion product may increase development of bacteria. Moreover

corrosion cost is very important, it was estimated to $16 milliards in the USA in 2004 [6].

In this context, a best management of these installations is wished but there is no general method to investigate a water installation. It can be explained because of the multiplicity of involved parameters and also because parameters values at which degradation phenomena is initiated are not so well known.

Therefore the first part of this paper attempts to develop a risk analysis methodology in order to provide a fast and simple tool to help to organize policy maintenance for building managers. The second one deals with computer implementation of the process created in the first part and an example is given to illustrate the application of proposed tool on a concrete case.

2 Assessment method of degradation risk

In order to build our assessment methodology, characteristic parameters which launch degradations phenomena are shown by means of three methods used in the functioning safety in the industrial world. The first one, functional analysis, allows to describe water installation structure and to understand its functioning. The second one, Failure Mode and Effect Analysis identifies and indexes all possible failure modes. And finally, the Fault Tree method searches event sequences which can lead to a degradation. These three methods are not the topic of this paper, for more information see [7].

The method developed in this study consists of founding the possibility of appearance for three degradation qualitative risks (low, average and high) according to characteristic parameters of the studied water distribution system. Low risk means that installation hasn't to undergo modifications whereas average risk points out that some modifications should be made and a monitoring of key parameters has to be done. On the opposite, high risk indicates that water installation functioning must be reviewed.

Fives stages build the methodology and lead to several risk maps, one map for each degradation type (selective corrosion, differential aeration corrosion, galvanic corrosion for galvanized steel [8] and erosion corrosion, pitting corrosion for copper [9]). These stages aim to take into account and to represent uncertainty of theoretical knowledge, inaccuracy of site information and interaction between parameters with the intention to obtain the knowledge of possibility level for each qualitative degradation (low, average and high).

One part of these stages will be described in the following sections. The figure below illustrates general assessment method with different stages A, B, C, D and E. In this paper only stages A, B and C are developed.

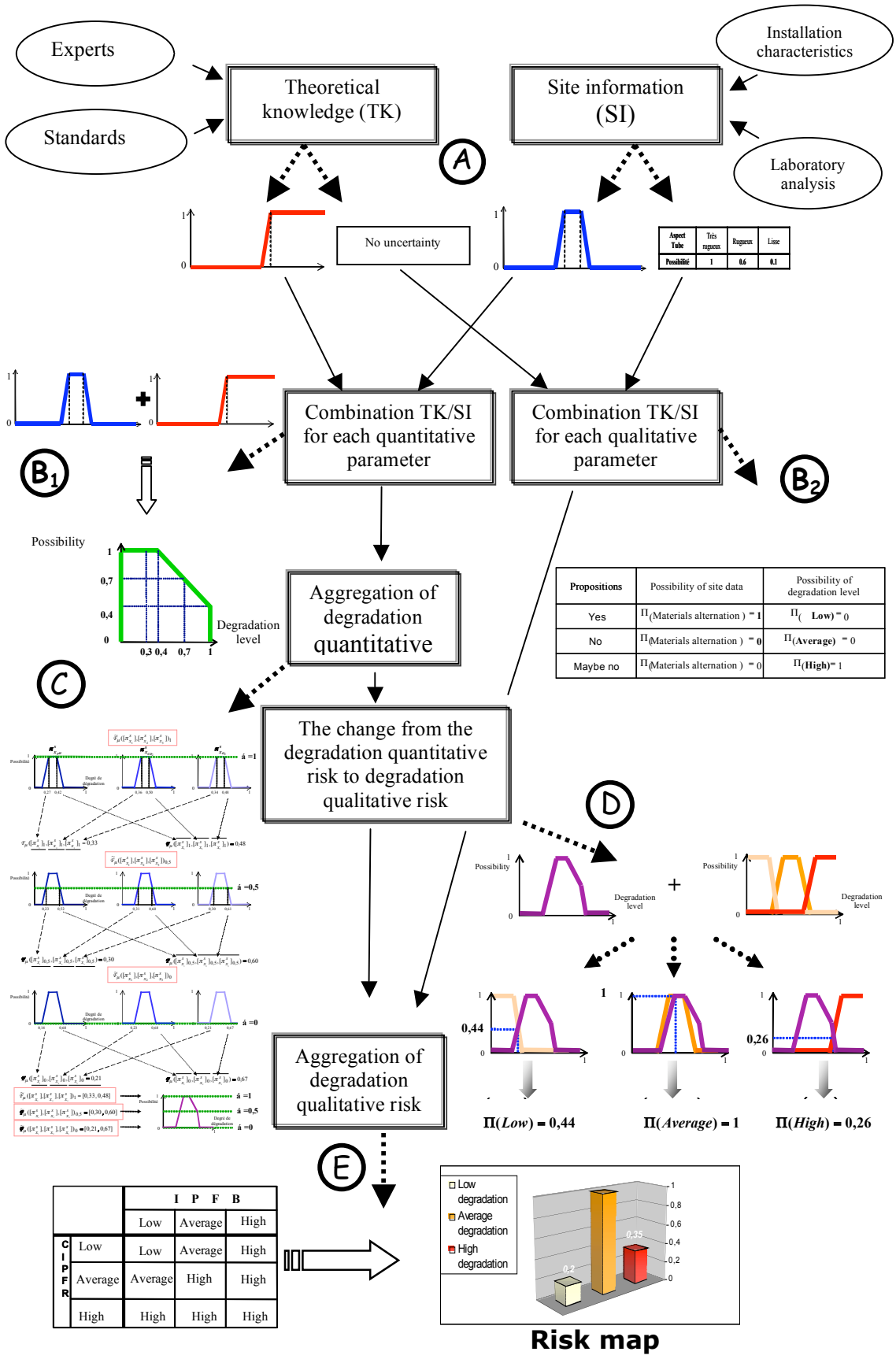

Figure 1 - Five stages of assessment method

2.1 Representation of knowledge uncertainty: Stage A

Representation of knowledge uncertainty is devoted to model uncertainty of theoretical knowledge and site information for each parameter involved in the degradation. Theoretical knowledge attempts to quantify theoretical importance of degradation according to the parameter value, whereas site information measures parameter value on site. Two parameters type exist, but the purpose of this paper is to focus on quantitative parameters, for more information on qualitative parameter see [7].

These uncertainties are taken into account by means of building two functions:

-**Constraint function** represents degradation theoretical risk as a function of parameter value. It is built with expert knowledge, European standards, technical book or state of the art. An example is given on figure 2 : model uncertainty for chloride concentration of water, important parameter in degradation of galvanised steel.

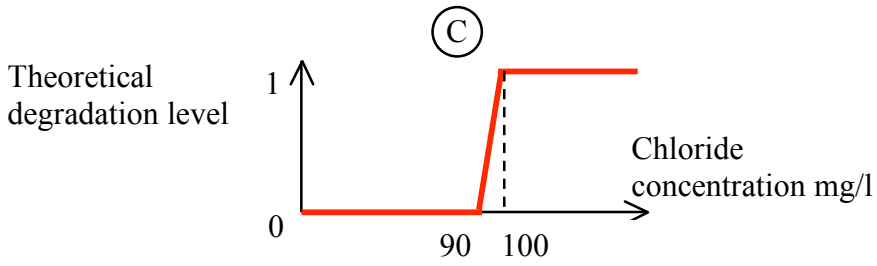

Figure 2 - Constraint function for chloride concentration

Possility theory allows us the construction of figure 2. It indicates that values of chloride higher than 100 mg/l mean maximum of degradation, on the opposite values of chloride lower than 90 mg/l lead to no degradation. Whereas from 90 to 100, theoretical degradation level increases linearly with chloride concentration. Finally, this figure is better than binary representation where accuracy value is a bound between good or wrong state of functioning.

-**Uncertainty function** expresses possibility level to obtain measured value on site. It is represented with possibility distribution on whole definition field of parameter. Figure 3 illustrates measure of 85 mg/l on the site.

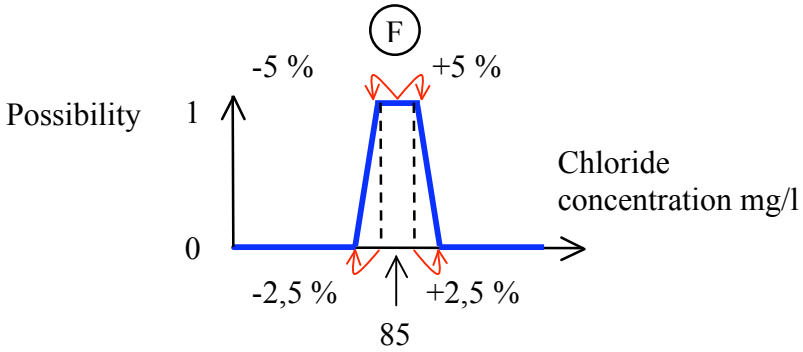

Figure 3 - Uncertainty function for chloride concentration

Therefore it is totally possible that real value takes place between 85 ± 5% whereas it is impossible that real value is situated higher than 85 + 5% + 2,5% and lower than 85 - 5% - 2,5%.

2.2 Combination between theoretical knowledge and site information for each quantitative parameter: Stage B_1

Combination between theoretical knowledge and site information for each quantitative parameter allows to determine appearance possibility for each degradation level. This compatibility derives from Zadeh's studies [10]. Considering chloride parameter, its constraint function C is superposed on its uncertainty function F. Each chloride value correlates with one degradation level and with one possibility level such as figure 4.

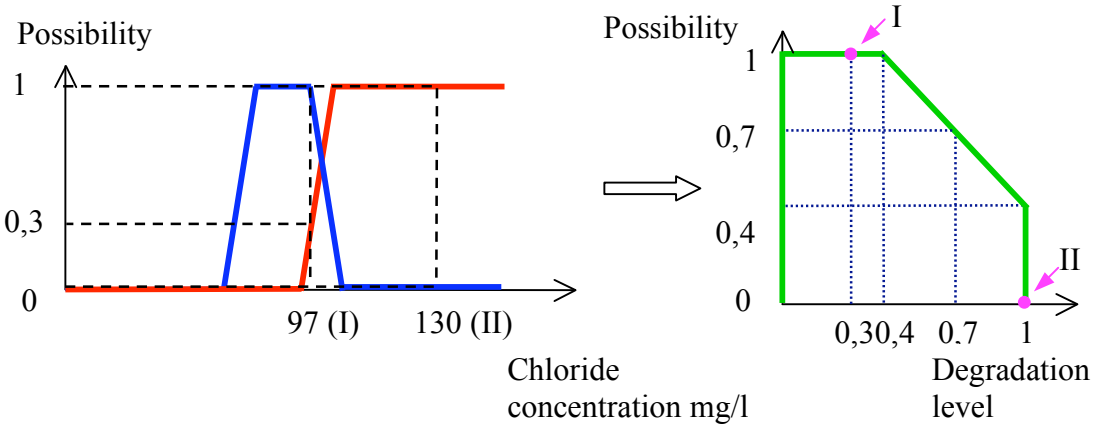

Figure 4 - Compatibility between Function C and F

For instance, the value 97 mg/l correlates with 0,3 of degradation level and 1 of possibility level, this point noted (I) is represented on the right in figure 4. All values of definition field of chloride concentration are studied and all couples of point are transferred on green diagram. This curve shows level possibility according to degradation level for one parameter.

2.3 Aggregation of degradation quantitative risk: Stage C

So as to gather several quantitative degradation risks issued from stage B1 in one quantitative degradation and to take into account interactions between parameters, two aggregation operators are used: averaging operator and fuzzy integrals.

-**Averaging operators** M_α have the property to be compensative, that is, low values can be compensated by high values, so that the result of combination will be medium.

$$M_\alpha(a_1,\ldots,a_m)=\left(\sum_{j=1}^{m}\omega_j a_j^\alpha\right)^{1/\alpha}$$,with

α balancing factor

ϖ parameters weights

-**Fuzzy integrals** and especially Choquet integral C_μ allows to model a positive synergy (complementary), a negative synergy (redundant) or to model without interaction (independent) between parameters. It can be possible by means of fuzzy measure μ which defines weights on individual parameter by means of the coefficient $\mu(\{x_i\})$, but also on any group A of parameters by means of g(A).

$$C_\mu(a_1,\ldots,a_m) = \sum_{i=1}^{m} a_i \cdot \mu(X_i - X_{i+1})$$

Quantitative degradation risks are not precise values but a possibility distribution on [0,1] expressing to what degree each degradation level is possible (figure 4). So we cannot use the approach directly in the case of possibility distribution, we have to employ the extension principle. The extension principle is a natural way for expending crisp concepts to fuzzy ones [11].

A practical computation of this approach is based on α-cuts. It is well known that each fuzzy set can be uniquely represented by the family of all its α-cuts. From a practical point of view, each α-cut A_α of a fuzzy set A represents a crisp approximation of A at the level $\alpha \in [0,1]$.

The figure 5 below shows an aggregation example for three parameters and α=1.

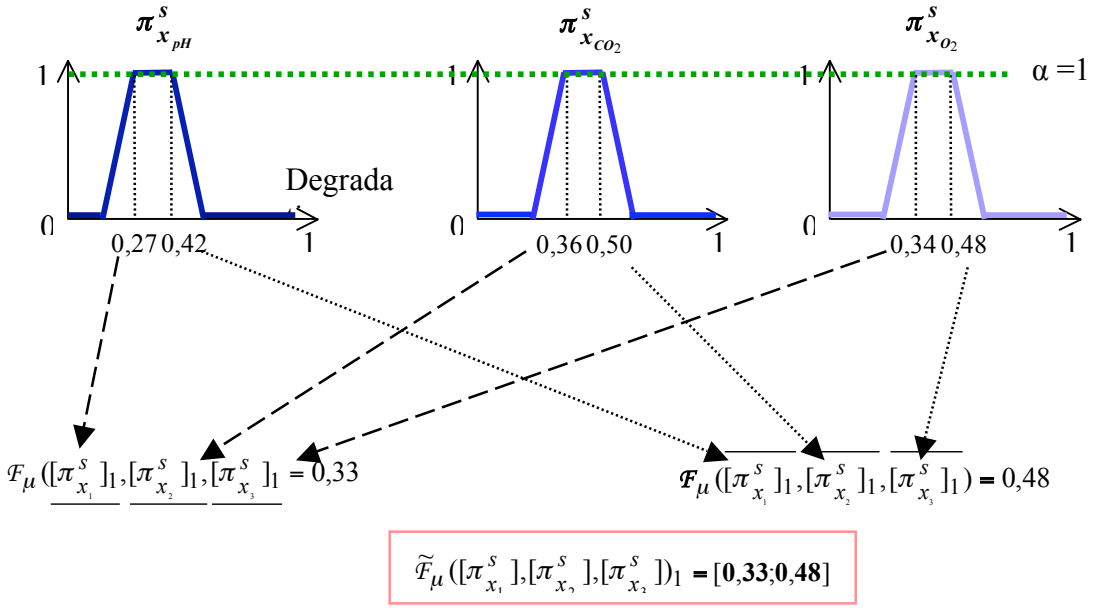

Figure 5 - Closed crisp set for α =1

Each lower and upper bounds of each possibility distribution for the cut equal to 1 are gathered in order to take into account interaction between parameters. Furthermore three α-cuts (α=0;α=0,5;α=1) are sufficient to obtain three closed crisp sets to draw a good representation of calculated possibility distribution.

2.4 The change from the degradation quantitative risk to degradation qualitative risk and Aggregation of degradation qualitative risk: Stage D an E

Last both stages are devoted to calculate three qualitative outputs (low, average and high degradation) with each of their level possibility. Stage D concerns the change from the degradation quantitative risk to degradation qualitative risk in order to have all degradation risks under the same form. Whereas stage E aggregates qualitative risks together, qualitative degradation is issued from qualitative parameters as well as from quantitative ones. These two stages are developed in [7].

3 Computer tool

Computer tool is intended for helping to obtain parameters on the studied site and for automating all stages of developed methodology. Data capture is carried out by means of several dialog boxes which record parameters values. Figure 6 shows dialog box for parameters of cold drinking water.

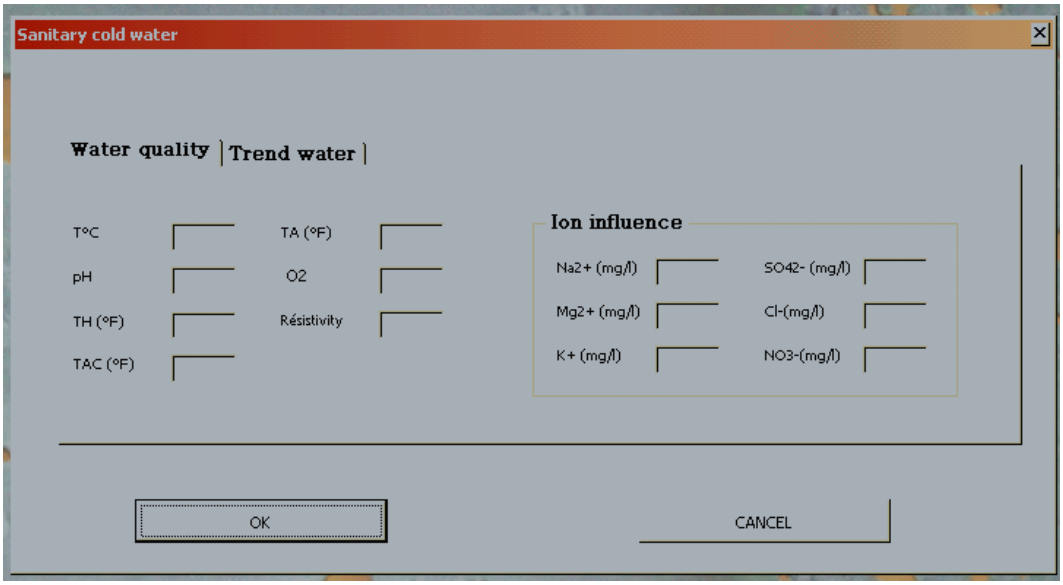

Figure 6 – Measured parameters of cold drinking water

Seven dialog boxes like this one have to be filled in, to realize risk calculation.

Then parameters values are exported to Scilab in order to treat automatically five stages of our general method. Scilab is a scientific software package for numerical computations in a user-friendly environment. The use of computer is illustrated by risk analysis of type II pitting on copper tube.

This corrosion is developed in soft hot water (i.e. greater than 50°C) with low pH. Some studies suggest that ratio of bicarbonate to sulphate is a critical factor. In most cases, there are no corrosion products for this type of corrosion [12].

So both orders are only necessary to lead to results. First, computer tool is launched by means of its name “ACRREAU” (Analyse et Caractérisation des Risques des Réseaux d’Eau). Then the values of characteristics parameters for the studied installation, stocked in a file, are transferred in Scilab and all method stages appear with final risk map represented below on figure 7.

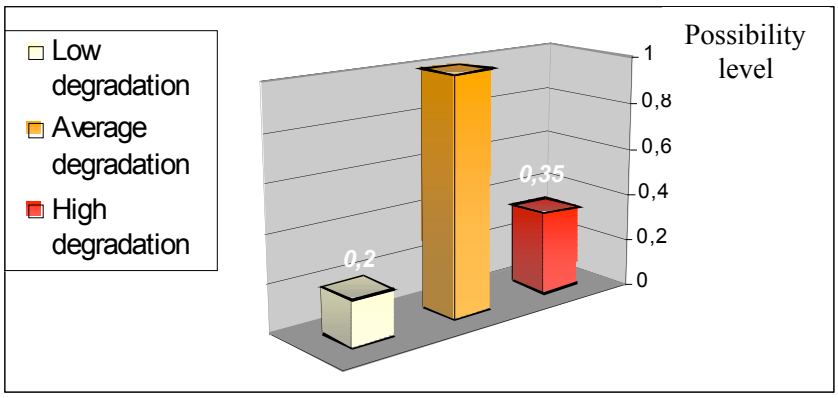

Figure 7 - Final risk map for type II pitting on copper

This graphic points out that average degradation is totally possible therefore modifications of the water system should be made and a monitoring of key parameters has to be done.

4 Conclusion

The method elaborated is an original tool to investigate drinking water distribution system for several reasons. First this task has lead to the accumulation of some information on corrosion and scaling phenomena. Secondly we have built an alarm system to provide building managers with information on the water distribution functioning and so, the possibility to intervene before degradation appears.

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6 Presentation of Author(s)

Olivier Correc is working at Centre Scientifique et Technique du Bâtiment in the division Water and Buildings. He received his PhD degree in Town Engineering on degradation risk assessment in drinking water distribution systems.

Francois Derrien is working at Centre Scientifique et Technique du Bâtiment (France) where he is responsible of the Division Water and Buildings. He is specialised in corrosion and behaviour of materials in contact with water.

Youssef Diab is working at University of Marne La Vallée (France) where he is director of Laboratory of Urban Utilities, Environment and Building. He works on city and urbanism projects integrating sustainable development.

Estimating water consumption in nursery and elementary public schools

M. S. O. Ilha (1), O. M. Gonçalves (2), S. V. de Amorim (3); L. P. Pedroso (4)
(1) msoilha@fec.unicamp.br
(2) orestes.goncalves@poli.usp.br
(3) simar@power.ufscar.br
(4) luppedroso@yahoo.com.br
(1) Department of Architecture and Civil Construction Eng., Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Universidade Estadual de Campinas, Brasil
(2) Civil Construction Department, Escola Politécnica, University of São Paulo, Brazil
(3) Department of Civil Engineering, Universidade Federal de São Carlos, Brasil
(4) Department of Architecture and Civil Construction Eng., Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Universidade Estadual de Campinas, Brasil

Abstract
This paper presents the methodology and results of a study concerning estimation of water consumption developed in public school buildings which take into account the characteristics of the buildings as well as the water consumption indicator. These school buildings are located in the city of Campinas, state of Sao Paulo, Brazil, and the study was developed by a team of researchers from three universities of the State of Sao Paulo.

This study includes a survey of all plumbing fixture pathologies and their remote water consumption monitoring in a sample of schools which involves students of different age ranges and different periods in school. The adopted criteria to select the sample, the employed field data collection methodology and the results obtained are here presented. Finally, a model to estimate the water consumption in this type of building is also presented.

Keywords

Building systems, water consumption, schools, cold water building system.

1 Introduction

Water consumption in Brazilian buildings is usually estimated using a simple consumption indicator expressed by volume divided by consumer (persons in homes, students in schools, beds in hospitals, etc). In the case of school buildings, the values of water consumption indicator are 30 to 50 liters/student/day in a four hour period of school and 50 to 100 liters/student/day in the case of full day period.

However, to estimate water consumption, the characteristics of the building and the region where it is located besides the consumption indicator must be considered. In numbers, Brazil is a country with an area of about 8,514.876.599 km^2, with more than 5,507 cities, different climates and habits of its inhabitants, which affect, besides other aspects, the water consumption.

The Brazilian school system consists of private and public schools, both equivalents in years which include nursery school, elementary school, high school, graduate and undergraduate school.

Table 1: Public and Private Schools - Typologies

Public and Private Schools		Age	Period	Number of periods
Nursery school		three months to four years old	7am to 6pm	1
Pre-school*		three months to 6 years old		
Elementary school	kindergarten	four to six years old	five hours	
	fundamental school	seven to fourteen years old	four hours	3

*Pre-school is the combination of nursery and kindergarten.

Two typologies of pre-school were found:

- one that contains one kitchen to prepare the children's meal and a laundry for the nursery part of the school, and the staff who works to both schools.
- the other one contains two separated schools, each one with its own kitchen, own laundry, own staff and a bathroom exclusively for babies in the nursery unit. The principal and the janitor are the only part of the staff that is shared in this case.

Due to the high number of illiterate and semi-literate adult population in Brazil, there is a program for adult education which uses the public school buildings during the evening period that otherwise are used for nursery, elementary and fundamental education.

In 2000, 68.1% of the students in nursery and elementary schools, 89% of the students in fundamental schools and 78% of the students in high schools belonged to the public school system network. On the other side, in graduate schools, only one third of the students belong to the public education network (IBGE, 2005).

This paper presents an investigation that evaluates the water consumption in a sample of nursery and elementary public schools of the city of Campinas. This investigation includes a survey of all plumbing fixtures pathologies and remote water consumption monitoring in a sample of schools involving students of different age ranges and different school periods.

This study presents the adopted criteria to select the sample, the employed field data collection methodology, the results obtained and at last, the proposed model to estimate the water consumption in this type of building

2 Field Investigation and Results

2.1 Sample Selection

Campinas is a city located in the state of São Paulo, Brazil. Its area is about 797 km² and its population was approximately 967.921 inhabitants in 2000 (Cano&Brandão, 2002).
Although this research project had contemplated the four types of public schools, only the existing 122 units of nursery and elementary schools of Campinas in 2002 constitute the scope of this paper. Based on the water consumption indicator (average volume of water consumed per student in a month), geographic location and type of school, 73 units of nursery and elementary schools for this study (46.2% of the total), were selected. They were distributed as follows:

- 05 **CEMEI** (nursery school) - 71.4 % of the total of this type,
- 41 **EMEI** (kindergarten) - 64.1% of the total of this type,
- 03 **EMEI/FUMEC** (kindergarten with adult education in the evening period) – 50% of this type,
- 23 **CEMEI/EMEI** (pre-school) – 52.3% of this type,
- 01 **CEMEI/EMEI/FUMEC** (pre-school unit with adult education in the evening period) – the only unit of this type.

2.2 Building Characterization and survey of plumbing fixtures

The only documents found in the Municipal Department of Education were the site planning of all schools investigated and the architectural designs of some of these units. Due to the lack of building systems design an inventory of plumbing fixtures was necessary. Besides this inventory, leakage investigation and survey about the water usage were performed. It was also surveyed some variables that characterized the units and its site conditions, for instance, permeable and non-permeable outside areas, number of classrooms, bathrooms, type and number of plumbing fixtures and population.

Check lists were prepared to survey plumbing fixtures and existing leakage. Some lists were used to identify the location of each fixture, the conservation state (existence of spots, scratch, etc) and the operation condition (adequate, leaking, clogged, etc.).

For these analyses, the data surveyed were aggregated in four types of schools. So, the units with and without adults education in the evening period were considered included in the typology.

Regarding the site condition: nursery schools have lesser outside areas (non-permeable and permeable areas); regarding the number of rooms: Nursery and kindergarten units (CEMEI/EMEI) have the major number of rooms (classrooms, bathrooms); and regarding the number of fixtures: lavatory faucet and valve-operated water closet are the most frequent in number.

Concerning the population:

- CEMEI/EMEI units (pre-school) have the major number of students on part time in the day period,
- EMEI/FUMEC units (kindergarten/ adult's education), the daily population represents about 97.9% of the total population, in the CEMEI/EMEI/FUMEC unit (pre-school and adult education in the evening period) this value is approximately 98.7%, and
- CEMEI/EMEI units have greater populations.

The only information concerning the age of schools buildings was that the age range of 61 units varies from 4 to 62 years (base year: 2004).

Visual inspection and specific tests were used for leakage detection. The most frequent problem found in the fixtures was the leakage that occurs when faucets and valves are in operation. Concerning the conservation state, the most frequent problem was the existence of spots in the fixtures and lack of handles in valves.

The number of fixtures in non-conformity with the standards is large due mainly to the low price policy and consequent poor quality in public buildings. Poor maintenance in this type of buildings increases the problem.

From this investigation, a leakage rate (number of plumbing fixtures with leakage divided by total number of plumbing fixtures installed in the school) was calculated. The losses rate (relation between volume lost in leakage during a defined period of time and the total volume consumed in the school in the same period) was also estimated.

Results concerning the plumbing fixture leakage rate indicate that:

- 60.3% of the 58 schools with valve operated WC have leakage rate between 20% and 50%,
- 56.5% of 69 units have lavatory faucets leakage rate between 20 and 50%,
- Leakage rate of other type of faucets is low (more than 80% of the units have this rate equals to zero).

The major values of leakage rate are found in the fixtures that have direct contact with the students. Besides specification of durable components and implementation of

preventive maintenance routine, it is necessary to develop a general program for water conservation awareness in order to reduce the leakage rate.

Considering all plumbing fixtures installed in the surveyed units, it was verified that:

- CEMEI units (nurseries) had a leakage rate of 7.2% and standard deviation of 9.3%. EMEI units (kindergarten) had a leakage rate from zero to 21.4%, with the average equals to 6.8% and a standard deviation of 4.9%. CEMEI/EMEI units had a leakage rate between 1.3 and 15%, with an average of 6.8%;
- Considering that great values of the leakage rate do not always represent great volume of water, water loss rate must be taken into account. The water loss rate estimation can be obtained by means of metering the lost volumes or, when it is impossible, using reference volumes from bibliography;
- As there is no reference for the loss water volume that occurs only during the use of the appliance (most frequent problem found in all schools), this volume was not considered in the loss rate determination;
- In six surveyed schools leakage occurred in the pipe that supplied water to the upper reservoir. Part of this pipe is buried and a leakage in this region can represent a great loss of water due to the high pressure in the water public system. Water losses were estimated from 300 to 14400 liters/day. The lack of information about the consumption of these units do not enabled to estimate the leakage rate;
- The leakage rate of schools that do not have leakage in the supply pipe varied from zero to 60% (about 69.3% of the school had leakage rate between 10% and 20%).

2.3 Water usage

A questionnaire was applied to survey the water usage. The questionnaire concerned the manner that people use water in the bathroom, kitchen, floor cleaning, watering garden and vegetable garden, etc. Table 1 shows the distribution of interviewed in each type of schools investigated.

Table 2: Interviewed population (average).

School type	Percentage of interviewed	
	teachers	Other employers
CEMEI (nursery)	48.8	35.0
EMEI (kindergarten)	50.9	60.9
CEMEI/EMEI (nursery and pre-school)	31.8	33.7

Besides interviews, a field observation was made in three schools to determinate a typical water consumption day and to estimate a consumption distribution. The water consumption distribution in different activities was:

- CEMEI units: 45% in the bathroom, 43% in the kitchen, cafeteria, etc., 8% in the laundry and 4% in external spaces;
- EMEI units: 71% in the bathroom, 25% in the kitchen, cafeteria, etc… and 4% in external spaces;

– CEMEI/EMEI units: 86% in the bathroom, 10% in the kitchen, cafeteria, etc and 4% in external spaces.

Bathrooms are responsible by the major portion of the water consumption; kitchens are in the second place.

Based on this investigation about water usage, a methodology was developed to estimate the water conservation awareness rate (IU), whose description is showed in YWASHIMA (2005). Basically, number of "units" was assigned for each activity and the way how they were performed – rational or non-rational usage. So, the higher this rate, the greater is the users' perception for the rational use of water. Results of the assigned "units" are shown in figure 1 (see example for an EMEI building).

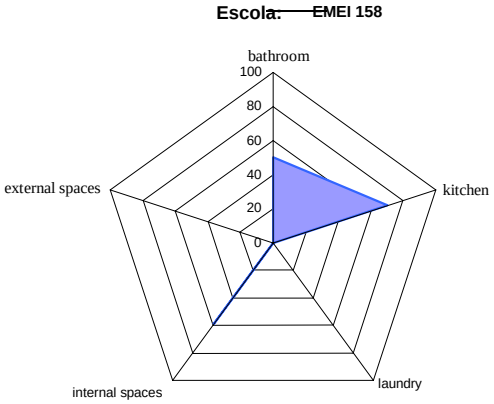

Figure 1: IU of EMEI 158 unit.

Figure 1 shows that the IU is higher for the activities performed in the bathroom and in the kitchen. For the school as a whole, this rate is lesser than 50%. It represents that it is necessary to develop an awareness program involving the activities performed in these rooms.

Considering all activities performed in all studied schools, it was verified that:

– the more frequent IU rate is 63%, but it occurs only in four of the 69 investigated schools. The average IU was 54%, which can be considered low,
– only one school the rate IU equals to zero and only one school had the maximum value of this rate (100%).

The more frequent values of IU for the activities performed in different school areas were:

– bathrooms: 50% (in 29% of the 69 units);
– outside areas: 0% (in 91% of the 66 units);
– inside areas: 100% (in 68.5 of 54 units);
– laundries: 100% (in 43.5% of 62 units) and
– kitchens:70% (in 20.3% of 69 units).

2.4 Water consumption monitoring

A remote metering system was installed in a sample of the surveyed schools, as follows:

- 02 CEMEI (nursery),
- 03 EMEI (kindergarten),
- 01 EMEI/FUMEC (kindergarten with adults' education in the evening period),
- 01 CEMEI/EMEI (nursery and kindergarten) and
- 01 CEMEI/EMEI/FUMEC (nursery and kindergarten with adults' education in the evening period).

The water monitoring was implemented for collect more accurate data, which were after used to formulate a model for water consumption in this type of building.

The employed data collection system was composed by a central computer with a data acquisition software, remote units for signal caption, water meters with a pulse exit, modems and telephone lines for data transmission from schools to metering center. Collected data were transmitted automatically, each 30 minutes, for storage and analysis. The phone line used was a conventional line used by the school and was programmed to send data during the night period.

3. Water consumption estimation model

A multiple regression model was developed based on collected data. The regression parameters were selected using the minimum square principle. The model fitting was checked by the value of the determination coefficient and by the residual analysis. For more details, see DRAPER; SMITH (1980), GUNST; MASON (1980), ELIAN (1988) and BUSSAB (1986). All statistical procedures were made with the following computational programs: SAS System version 8, EXCEL version 2000 e MINITAB version 12.

In order to formulate the model, the independent variable initially considered was the daily water volume consumed in week days (CD).

Dependent variables were classified in six groups:

- Building description: permeable and non permeable areas, number of classes, number of bathrooms and existence of vegetable garden;
- Kitchen usage: meal preparation or not in the school;
- Occupation pattern of the building: school population in each period;
- Environmental condition: maximum daily temperature;
- Plumbing fixtures: number of each type of fixture;
- Operation condition of the plumbing fixtures: number of each type of fixture leaking.

A preliminary analysis indicated the following variables as significant: permeable area (AP), non-permeable area (AI), number of classrooms (Nsa), total number of bathrooms

(NBt), number of employers' bathrooms (NBf), number of valve operated WC (BS/VD), number of valve operated WC with leakage (BS/VD-vz) and maximum daily temperature (Temp).

For a best model fitting, a transformation of the independent variable, that is, square root of the daily water consumption in weekly days ($\sqrt{CD}$) was made. Afterwards, some combination of the selected dependent variables was checked and resulted as follows:

- AI * BS/VD (non permeable area times number of valve operated valves),
- AI * Temp (non permeable area times maximum daily temperature) and
- BS/VD * Temp (number of valve operated valves times maximum daily temperature).

Table 3 shows the adjusted regression model. The estimative of the model parameters (bi) adjusted by minimum square and respective standard errors are presented in Table 3 The statistic t ($= b_i / EP(b_i)$) values and the descriptive levels (p-values) are also shown.

For a confidence level α (for example, equals to 5%), the b parameter considered different from zero if $p<\alpha$ (and null in reverse case). The determination coefficient (R^2) is shown in the last row of this table.

Table 3: Adjusted regression model for water consumption estimation.

	Independent variable : $\sqrt{CD}$			
	Coeficient	Standard error	t	p
Intercept (constant)	27,062	5,668	4,77	0,000
Temp	0,1507	0,2006	0,75	0,453
AI	-0,030276	0,007401	-4,09	0,000
BS/VD	5,8375	0,7785	7,50	0,000
AI* BS/VD	-0,000533	0,000090	-5,90	0,000
AI * Temp	0,001960	0,000260	7,53	0,000
BS/VD * Temp	-0,13460	0,02784	-4,84	0,000
R^2	0,6718			

The regression model to estimate water consumption in nursery and kindergarten units was adequate and is presented below:

$$\sqrt{CD} = 27{,}062 + 0{,}1507 * Temp - 0{,}030276 * AI + 5{,}8375 * BS/VD - 0{,}000533 * (AI * BS/VD) + 0{,}00196 * (AI * Temp) - 0{,}1346 * (BS/VD * Temp)$$

where:
CD – daily water consumption (week days), in L/day;
Temp – maximum daily temperature, in ºC;
AI – non permeable area, including paths, walks, in m²;
BS/VD – number of valve operated WCs.

It must be remarked that the obtained model is valid only for the school population from which the sampled schools were extracted and with similar variable magnitudes.

Figure 2 shows the independent variable CD predicted by the model and metered in the field.

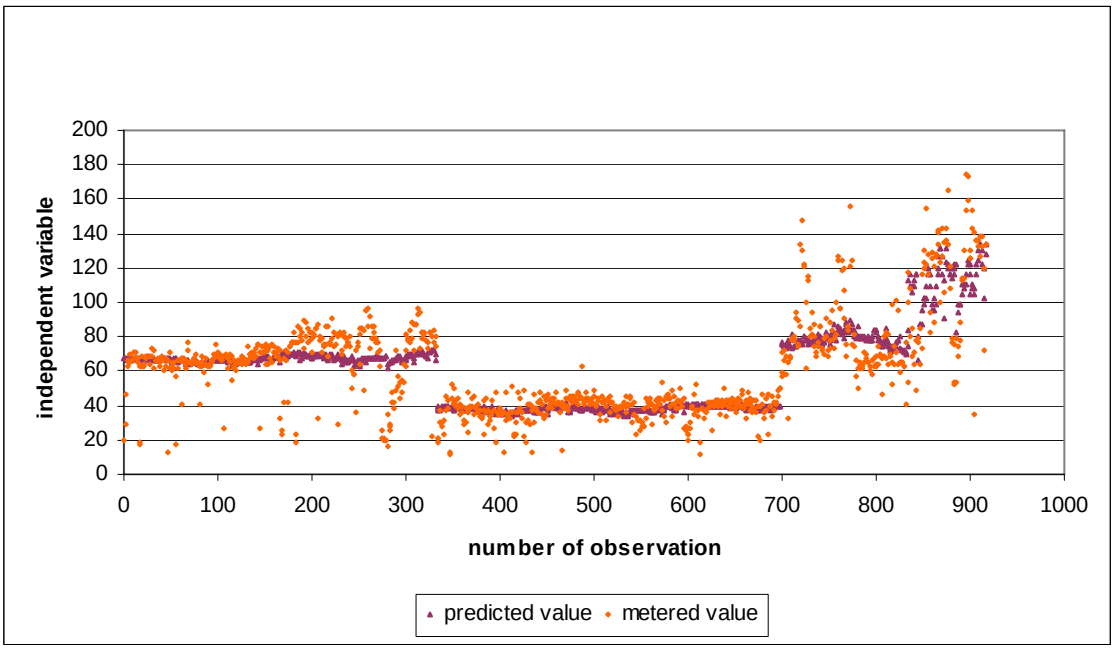

Figure 2: Predicted and metered values of CD.

4 Final comments

In order to develop consistent water conservation public policies, a deeper knowledge of the consumption indicator and water usage in different regions and in different typologies is needed.

This study showed the importance in considering the significant variables in order to determine the water consumption in buildings. The water consumption indicators traditionally used (L/person, L/bed, L/room, etc.) may lead to an inaccurate water consumption estimation, if other important variables like type of user, water usage, climate, etc. are not taken into account.

The model to estimate water consumption developed to the typologies here presented proved to be adequate for the studied population, as it can be seen in Figure 2 and the methodology developed in the study can be extended to other building typologies.

Acknowledgments

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6 Presentation of Main Authors

Marina Sangoi de Oliveira Ilha is Associate Professor at State University of Campinas, Brazil, Faculty of Civil Engineering, Department of Architecture and Civil Construction. She has Post-doctorate Degree in Civil Engineering. She teaches and conducts research in plumbing and fire protection systems.

Orestes Marracini Gonçalves is Professor at University of São Paulo, Brazil, Civil Construction Engeneering Department.

An Analysis on the Loads of Hot water Consumption of the Guest rooms in a Hotel

Hiroshi Takata (1), Saburo Murakawa (2)
Daisaku Nishina (3), Atsushi Tanaka (4)
(1) takatah@hiroshima-u.ac.jp
(2) muraka@hiroshima-u.ac.jp
(3) nishina@hiroshima-u.ac.jp
(4) tanaka.atsushi@takenaka.co.jp
(1), (2), (3) Graduate School of Engineering, Hiroshima Univ., Japan
(4) TAKENAKA Corporation, Japan

Abstract

The purpose of this paper is to clarify the loads of hot water and its usage in the guest rooms of a hotel. This study aims at developing a calculating method for hot and cold water consumption in the various types of buildings by Monte Carlo simulation technique. The authors have studied about the loads of hot and cold water consumption in apartment houses, office buildings, restaurants and so on [1-5]. In addition, the calculating models on these buildings have developed based on the measurement data.

The measurement of the loads of hot water consumption of the guest rooms in a hotel has been carried out from the winter in 2005. It is important to clarify the loads of hot water consumption that have big weight on the energy consumption in the hotel. Also, it is expected that the characteristics of the loads of hot water consumption in the guest room will be different from the characteristics in the housing. Therefore, in this paper, the hot and cold water consumption in each usage such as bathroom, basin and toilet is analyzed.

The detailed measurement was carried out in 3 guest rooms. The volumes and temperature of hot and cold water consumption were recorded by 5 second or 1 minute interval in each room. The data for the number and gender of the guests in each room were offered by the management company. The daily and hourly loads of hot and cold water consumption were analyzed in each number and gender of the guests. The characteristics of water usage in the guest rooms were studied by using the measurement data.

Keywords

Cold Water Consumption, Hot Water Consumption, Hotel, Guest Room

1. Introduction

The various people are staying at the hotel for work or for sightseeing and so on. Therefore, in the guest room, the loads of hot and cold water consumption are varied by the types of guests. To satisfy the demands and requests of the guests, the sanitary equipments are set up on an adequate performance. In addition, it is expected that the characteristics of the loads of hot water consumption in the guest room will be different from the characteristics in the housing. It is important to clarify the loads of hot water consumption that have big weight on the energy consumption in the hotel.

In this paper, the measurements of hot water consumption were carried out in order to clarify the characteristics of the loads of hot water and its usage in the guest rooms. Based on the measurement results, the daily and hourly loads of hot and cold water consumption were analyzed in each number and gender of the guests. Furthermore, the characteristics of water usage in the guest rooms were investigated using the detailed data.

2. Outline of the investigation

2.1 Outline of the hotel

A city hotel, located in downtown Kyoto city, was chosen as the building of the measurement. The outline of the hotel is shown in Table 1. The hotel has 225 guestrooms, 2 banquet rooms, and 3 restaurants, etc. Check in time is 13:00 and check out time is 12:00. Not only businesspeople but also tourists including foreigners use the hotel. Also, it is expected that the volumes of hot water consumption are large in the kitchen as well as guest rooms.

Table 1 - Outline of the hotel

Name	N Hotel	Lot area	2,791.27m^2
Location	Kyoto city, Kyoto, Japan	Building area	1,716.49m^2
Building use	Hotel	Total floor area	21,773.00m^2
Scale	14 stories, 2 basement, 2 penthouse	Structure	Steel-framed Reinforced Concrete structure
Facilities	225 guests rooms, 2 banquet rooms, 3 restaurants (Japanese, French, Chinese), 1 bar, 1 café Shops (Jewelry, Kyoto Specialties), Conference rooms, Wedding Reception, Wedding Chapels, Photo studio, Hairdressing & Esthetic salon, etc.		

2.2 Outline of the measurements

Table 2 shows the outline of the measurement and Figure 1 shows the schematic diagram of water supply system. As for the measurement of hot water consumption of the whole building, the volumes of hot water were measured by setting up the ultrasonic flowmeter on the makeup feed pipe to the hot water storage tanks on the 2nd floor in the basement (Figure 1 a)). Furthermore, 3 guest rooms (A, B, C room) were chosen for the measurement of hot and cold water consumption. The types of the rooms are all twin room. The guest room has a toilet with a low down flush tank, a wash basin with two handle mixed faucet, and a bathroom with a bathtub, two handle mixed faucet, and a

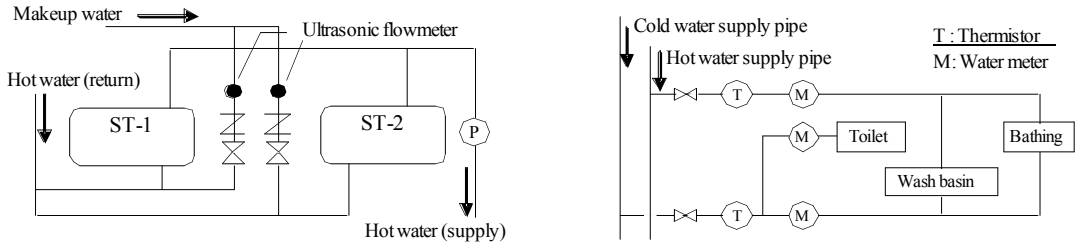
thermostat mixed shower.

The measurements on the volumes and temperatures of hot and cold water consumption in the guest rooms were carried out as follows. The volumes of hot and cold water consumption were measured by setting up the water meters to the hot and cold water supply pipelines respectively. As for cold water consumption, the volumes of the pipeline of the toilet were measured in distinction from the pipeline of the wash basin and bathing. The temperatures of hot and cold water were measured by thermistor in each supply pipeline individually (Figure 1 b)). In addition, the data for the number and gender of the guests in each room were offered by the management company.

In this paper, the results of analysis for the measurement data from February 1st to March 25th, 2005 are shown. The volumes and temperature of hot and cold water consumption were recorded by 1 minute or 3 minute interval. Furthermore, in the guest rooms, the volumes and temperature of hot and cold water consumption were recorded by 5 second interval from March 5th to 6th to clarify the water usage in detail.

Table 2 - Outline of the measurements

Room	Point of measurement	Measuring instrument	Measurement item	Interval
Machine room (B2F)	Makeup feed pipe to the hot water storage tank (ST-1)	Ultrasonic flowmeter	Flow rate (l/min)	3 minutes
	Makeup feed pipe to the hot water storage tank (ST-2)	Ultrasonic flowmeter	Flow rate (l/min)	3 minutes
3 Guest rooms A room B room C room	Cold water branch pipe (Wash basin and Bathing)	Water meter	Flow rate (l/min)	1 minute
	Cold water branch pipe (Toilet)	Water meter	Flow rate (l/min)	1 minute
	Cold water branch pipe	Thermistor	Cold water supply temperature (°C)	1 minute
	Hot water branch pipe	Water meter	Flow rate (l/min)	1 minute
	Hot water branch pipe	Thermistor	Hot water supply temperature (°C)	1 minute



a) Hot water supply system b) Guest room

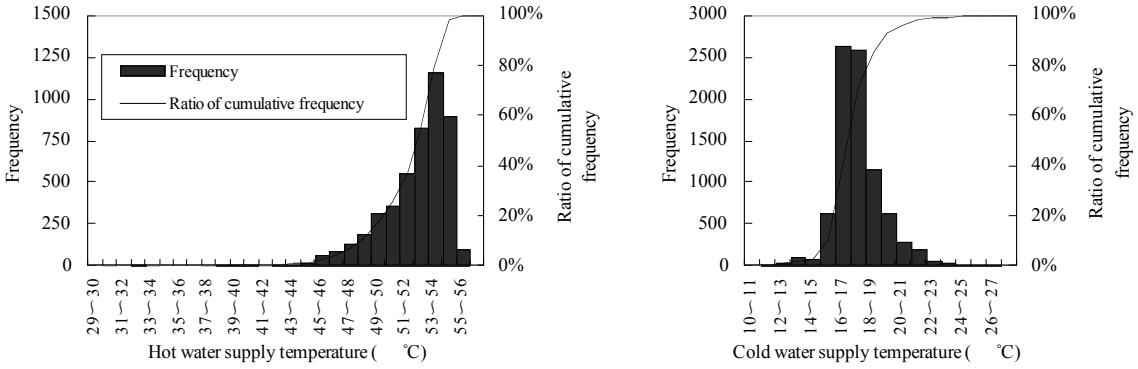
Figure 1 - Schematic diagram of water supply system

2.3 Hot and cold water supply temperatures

Table 3 shows the statistic values of hot and cold water supply temperatures. The values were calculated with the temperatures when the hot and cold water flew in the supply pipelines. As for the average values, hot and cold water supply temperatures are 52°C and 17°C respectively in each room. As for the mode values, hot and cold water supply temperatures are 53-54°C and 17°C respectively in each room. From this result, the hot and cold water temperatures of 3 rooms are almost equal. Therefore, it is possible to deal with the water temperatures in each room as same. Figure 2 shows the distributions of hot and cold water supply temperatures as total of 3 rooms.

Table 3 - Hot and cold water supply temperatures

Item	Hot water supply temperature				Cold water supply temperature			
	Total	A room	B room	C room	Total	A room	B room	C room
Average value (°C)	52.1	51.9	52.3	52.2	17.6	17.4	17.6	17.7
Standard deviation (°C)	2.5	2.1	2.6	2.9	1.7	1.8	1.5	1.6
Maximum value (°C)	55.5	55.3	55.3	55.5	26.7	26.7	26.0	26.0
Mode value (°C)	53.7	53.6	53.8	54.1	16.9	16.9	16.9	17.0
Minimum value (°C)	30.5	31.0	30.5	32.1	11.6	11.6	12.4	12.2
Number of sample	4750	2092	1417	1241	8516	2868	2957	2691



a) Hot water supply temperature b) Cold water supply temperature

Figure 2 - Distribution of the hot and cold water supply temperatures

3. Analysis of daily hot and cold water consumption

On the analysis of daily water consumption, the data which had some lack were expected from the analysis.

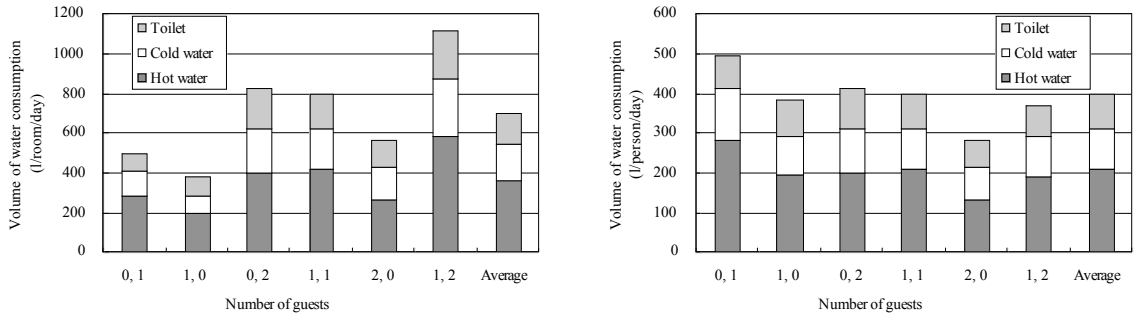
As for the daily water consumption, the volumes of hot water, cold water, toilet, and total water consumption per room or per person were shown in Table 4. The volumes per room are calculated with all data, and the volumes per person are calculated by the guest type. The delimitation hour of the day is check in time (13:00).

Table 4 - Daily water consumption

		Hot water	Cold water	Toilet	Total
Total (l/room/day) n : 65	Average value	367.1	183.2	151.6	701.9
	Standard deviation	198.6	107.8	69.5	338.1
	Maximum value	1049.5	607.4	370.7	1769.7
	Minimum value	1.5	37.1	0.0	111.5
Total (l/person/day) n : 65	Average value	210.6	103.9	86.3	400.8
	Standard deviation	107.1	54.0	32.8	164.1
	Maximum value	554.9	303.7	160.2	890.2
	Minimum value	1.5	31.0	0.0	111.5
Female : 1 (l/person/day) n : 6	Average value	285.7	131.0	79.8	496.6
	Standard deviation	(217.4)	(84.6)	(27.0)	(306.0)
	Maximum value	554.9	233.1	122.5	890.2
	Minimum value	1.5	37.4	50.7	111.5
Male : 1 (l/person/day) n : 12	Average value	199.2	92.9	93.6	385.7
	Standard deviation	84.4	44.4	49.4	126.4
	Maximum value	345.9	150.0	160.2	609.4
	Minimum value	55.0	37.1	0.0	135.6
Female : 2 (l/person/day) n : 10	Average value	203.2	111.5	98.8	413.4
	Standard deviation	72.9	49.4	27.2	136.1
	Maximum value	378.8	192.7	133.4	698.5
	Minimum value	127.2	54.5	38.4	220.1
Male : 1 Female : 1 (l/person/day) n : 31	Average value	211.6	103.7	82.9	398.2
	Standard deviation	100.0	55.6	28.7	157.3
	Maximum value	524.8	303.7	146.2	884.9
	Minimum value	46.3	31.0	19.0	148.5
Male : 2 (l/person/day) n : 3	Average value	137.0	77.6	69.1	283.7
	Standard deviation	(34.7)	(33.3)	(6.2)	(61.6)
	Maximum value	173.2	116.0	76.2	353.9
	Minimum value	104.1	58.4	64.7	238.7
Male : 1 Female : 2 (l/person/day) n : 3	Average value	195.0	97.7	80.2	372.8
	Standard deviation	(91.7)	(41.6)	(40.7)	(173.9)
	Maximum value	295.6	142.7	123.6	561.8
	Minimum value	116.2	60.5	42.8	219.5

Note n : Number of sample
Standard deviation, which were calculated from few data, were shown in parenthesis.

Figure 3 shows the average volumes of daily water consumption per room and per person in each type of the guests. As for the number of guests in the Figure, (0, 1) means that no male guest and 1 female guest stay in the guest room. The volumes of hot water consumption fluctuate largely by the number of guests. It is considered that the fluctuation is influenced by the individual difference of water usage in each guest type. On the other hand, the volumes of toilet water consumption per person have little difference by the number of guests. It is reflected that the toilet usage is occurred by the physiologic factor. As a general tendency, the volumes of water consumption per room increase with the number of guests, and the volumes of water consumption per person decrease with the number of guests. As for the gender of the guests, in comparison with the same number of guests, the tendency is shown that the female guest uses the larger volumes of water than male guest.



Note As for the number of guests, (0, 1) means that no male guest and 1 female guest stay in guest room.

Figure 3 - Daily water consumption

4. Analysis of hourly hot and cold water consumption

Table 5 shows the average daily water consumption, peak time-zone, the hourly water consumption of peak time-zone, and the average hourly water consumption. The values were calculated by using all data. Furthermore, Figure 4 shows the hourly fluctuation of average water consumption. The peak time-zone of total water consumption occurs at "22:00-23:00" and "7:00-8:00". The fluctuations of hot and cold water consumption are similar to the fluctuation of total water consumption. However, the peak time-zone of toilet water consumption occurs at "9:00-10:00".

Table 5 - Daily and hourly water consumption

Item	Hot water	Cold water	Toilet	Total
Average volume of water consumption per day (l/room/day)	367.1	183.2	151.6	701.9
Peak time-zone	22	22	9	22
Volume of water consumption in peak time-zone (l/room/hour)	59.7	26.5	12.9	94.4
Average volume of water consumption per hour (l/room/hour)	15.3	7.6	6.3	29.2
Peak rate	3.90	3.47	2.04	3.23

Note : Peak rates were calculated dividing the volume of water consumption in peak time-zone with the average volume of water consumption per hour.

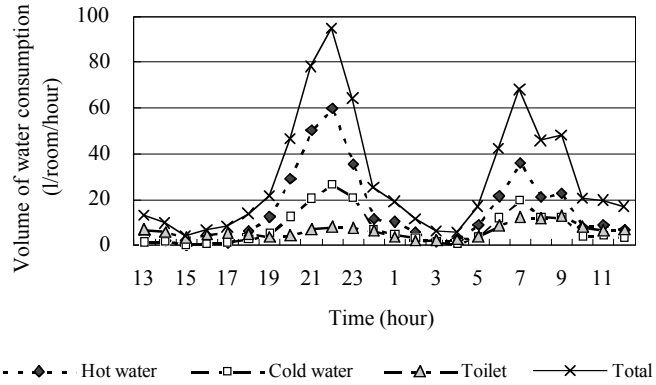


Figure 4 - Fluctuation of hourly water consumption

Figure 5 shows the hourly fluctuation of the average water consumption in each type of the guests. The tendencies of hourly fluctuation are various by the guest type. In the case of 1 female guest, the peak time-zone of total water consumption occurs at "19:00-22:00". In the case of 1 male guest, the peak time-zone of water consumption occurs at "22:00-23:00" and "7:00-8:00". In the case of 2 people, 2 female guests or 1 male and 1 female guests, those fluctuation patterns are similar with 2 peak time-zones. In each peak time-zone, the volumes of hot water consumption are large, therefore it is clarified that the volumes of hot water consumption have a great influence on the fluctuation of total water consumption in the guest room.

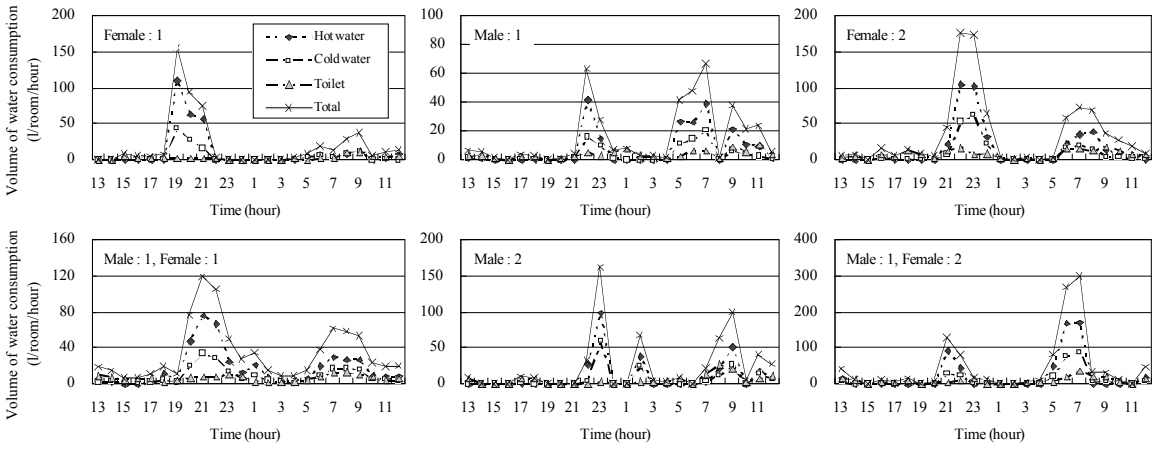


Figure 5 - Fluctuation of hourly water consumption in each number of guests

As for the peak time-zone of water consumption, Figure 6 shows the frequency of the peak occurrence in each time-zone through 65 days analyzed. The time-zone of the maximum values of frequency occurred as peak hour correspond to the peak time-zone of water consumption. However, as for the hot water consumption, the time-zone in which the frequency of the peak shows the highest occurs at "21:00-22:00", though the peak time-zone of hot water consumption occurs at "22:00-23:00".

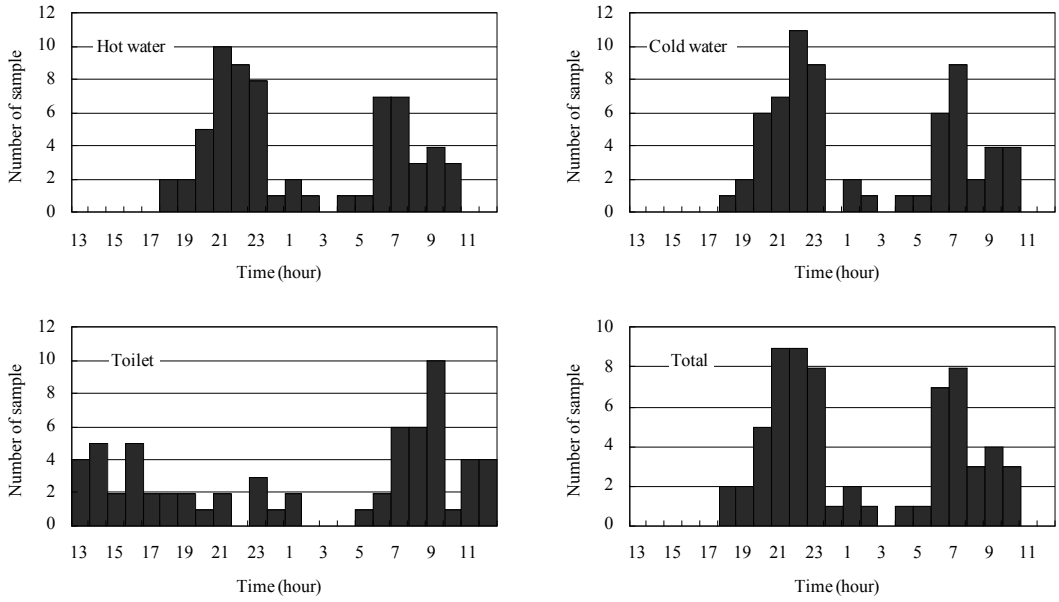


Figure 6 - Frequency of the peak hour of hot water consumption

5. Analysis of water usage

The characteristics of water usage were analyzed based on the volumes and temperatures of hot and cold water consumption, which measured at intervals of 5 seconds in 3 guest rooms on March 5th. The guests were 2 people (1 male and 1 female) in each room.

The measurements were carried out at the time-zone from 14:00 to 10:30 on the next day in consideration of the recorded capacity of measurement instrument. Figure 7 shows the volumes and temperatures of cold and hot water consumption as an example of A room at 20:00-1:00. The continuous usage of water is regard as a water usage on a behavior. Based on the values of the flow rate, the duration time, the volumes of water consumption, and temperature of water usage, it was judged that the water usage was occurred either in the wash basin or in the bathroom.

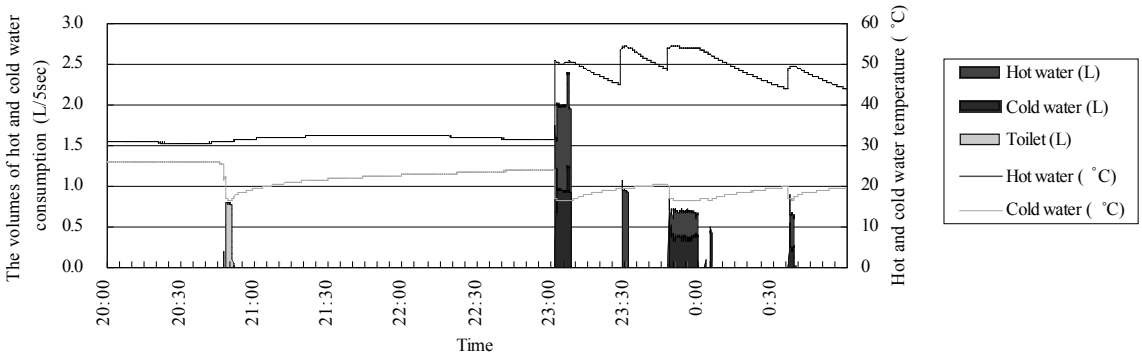


Figure 7 - Water usage in guest room (A room, 20:00-1:00)

Figure 8 shows the relationship between the volumes of water consumption and the temperature of water usage in each room. The water consumption which couldn't be judged in each usage was shown as "Wash basin or Bathroom" in the Figure. Also, the water consumption of the simultaneous uses was dealt with water usage all together. We will have more detail analysis on these points.

As shown in the Figure, the volumes of water consumption in the wash basin are not over 25(L). In the bathroom, the volumes of water consumption more than 100(L) are used by taking a shower or pouring water into bathtub. In the C room, it was expected that the guests close the water faucet frequently during taking a shower. Therefore, in the bathroom, the frequency of the volumes of water consumption under 50(L) is high. The volumes of water consumption are various by the guest's behavior. It is necessary to clarify the characteristics of water usage by the guest's behavior.

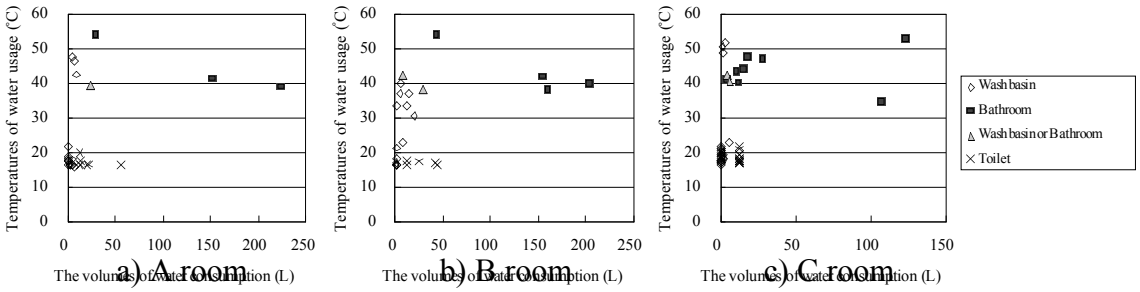


Figure 8 - Distribution of the volumes of water consumption and the temperature of water usage

6. Conclusion

In this paper, the measurements of hot and cold water consumption were carried out in 3 guest rooms of a city hotel. Based on the measurement data, the daily and hourly water consumptions were studied.

First of all, the daily water consumption was analyzed. As for the volumes of hot water, cold water, toilet, and the total water consumption per day, these values are shown by the guest type.

Secondly, as for the hourly water consumption, the hourly fluctuations of water consumption were shown in each type of guests. From the results, it was clarified that the hot water has a great influence on the fluctuation of the total water consumption in the guest room.

Finally, the characteristics of water usage were analyzed based on the volumes and temperatures of hot and cold water consumption. It was shown that the volumes of water consumption were influenced by the guest's behavior. Therefore, it is necessary to clarify the characteristics of water usage by the guest's behavior.

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Main author presentation

Hiroshi Takata is Research Associate at Graduate school of engineering, Hiroshima University. His special field is the planning of cold and hot water supply systems.

An Analysis on the Loads of Hot Water Consumption in the Restaurants

Saburo Murakawa (1), Daisaku Nishina (2)
Hiroshi Takata (3), Atsushi Tanaka (4)
(1) muraka@hiroshima-u.ac.jp
(2) nishina@hiroshima-u.ac.jp
(3) takatah@hiroshima-u.ac.jp
(4) tanaka.atsushi@takenaka.co.jp
(1), (2), (3) Graduate School of Engineering, Hiroshima Univ., Japan
(4) TAKENAKA Corporation, Japan

Abstract

The authors have advanced the development of a calculating method for the time series loads of cold and hot water consumption by Monte Carlo simulation technique. The method in apartment houses and office buildings was proposed at the CIB/W62 symposium (S. Murakawa and H. Takata, 2002, 2003, 2004). As for the restaurants, the measurements of the cold water consumption were carried out in 21 restaurants and the results were analyzed and showed at the CIB/W62 symposium (S. Murakawa, 2004).

The purpose of this study is to obtain the fundamental data of the hot water consumption in the restaurants.

In this paper, the measurements of hot water consumption were carried out in 7 restaurants, which were chosen from the 21 restaurants mentioned above, for 6 weeks in each season; winter, spring, summer and autumn. The temperatures and volumes of cold and hot water were recorded by 20 or 60 second interval. As for the measurement data, the daily and hourly hot water consumption were analyzed in each season. The relationship between the number of customers and the volumes of hot water consumption was analyzed. Also, the relationship between the number of dishes and the volumes of hot water consumption was shown. On the calculation of hot water demands in time series, it is important to typify the hourly fluctuation patterns characterized by the cooking process and routine work in each restaurant. Therefore, the fluctuation patterns of the hourly hot water consumption were studied. As the results, the patterns were classified into 3 types by cluster analysis.

Keywords

Cold Water Consumption, Hot Water Consumption, Restaurant

1. Introduction

It is difficult to estimate the volumes of cold and hot water consumption in restaurants. The water usage is complicated and various in the kitchen. The water demands change with many factors, such as cooking equipments, service food types, store characteristics and so on. Therefore, on the existing design and planning, the volumes of cold and hot water consumption are estimated roughly and the cold and hot water supply systems are not designed optimally. For that reason, the authors have carried out the measurements of the cold water consumption in 21 restaurants to obtain the fundamental data of water usage. The results were analyzed and showed at the CIB/W62 symposium (S. Murakawa, 2004) [1].

Furthermore, the measurements of hot water consumption were carried out in 7 restaurants, which were chosen from the 21 restaurants mentioned above. In this paper, the fluctuation tendencies of cold and hot water consumption are clarified in each season.

2. Outline of the investigation

2.1 Outline of the restaurants

As described above, the measurements of hot water consumption were carried out in 7 restaurants which are in the complex commercial building. The outline of the restaurants is shown in Table 1. Service food types are various in each restaurant. In addition, these restaurants have different scales in the floor area, the kitchen area, and the number of seats.

As for the hot water supply system, each restaurant uses individually the instantaneous water heater by gas. Restaurant F, I, and J have 2 or 3 instantaneous water heaters and the other 4 restaurants have an instantaneous water heater. However, an instantaneous water heater of restaurant I is rarely used.

Table 1 - Outline of the restaurants in the complex commercial building

Restaurant (food type)	Floor area (m^2)	Kitchen area (m^2)	Number of seats (Seat)	Number of employees *1 (Person)	Kitchen ratio *2	Opening time	Closing time	Time-zone		
								Preparation	Rest	Cleaning
C (Japanese food)	279.3	84	142	10	0.30	11:00	23:00	10:00-11:00	15:00-17:00	22:30-23:30
D (Seafood big bowl)	66.5	13	31	11	0.20	11:00	22:00	10:00-11:00	(no rest)	21:00-22:00
F (Chinese food)	472.9	100	275	19	0.21	11:00	22:00	7:00-11:00	15:00-17:00	22:00-23:30
I (Churrasco)	781.9	170	164	19	0.22	11:00	22:30	10:00-11:00	16:00-17:00	22:30-23:00
J (Korean (Dakkarubi)	330.4	79	116	13	0.24	11:00	23:00	10:00-11:00	15:00-17:00	23:00-24:00
K (Grilled meat)	165.7	77	105	6	0.46	11:00	23:00	10:00-11:00	15:00-17:00	22:00-23:00
N (Sushi)	115.7	73	72	12	0.63	11:00	22:30	9:00-11:00	15:00-16:30	22:30-23:30

Note *1 Number of employees is including the number of part-timers.

*2 Kitchen ratio is a ratio of kitchen area to floor area of a restaurant.

2.2 Outline of the measurement

In order to measure the volumes of hot water consumption and hot water supply temperatures in each restaurant, water meters were put in the makeup feed pipelines to the instantaneous water heaters and thermistors were put in the hot water supply pipelines in each restaurant. The temperatures and volumes of hot water were recorded by 20 or 60 second interval in each season. Furthermore, as preliminary measurement, the measurements of 2 second interval were carried out for a day in each season. As for cold water consumption, the volumes of cold water consumption in each restaurant were measured by setting up water meters to the main pipelines. Cold water supply temperatures were measured at the makeup feed pipelines to the instantaneous water heater in restaurant F. Table 2 shows the outline of the measurements

The measurements were carried out from December 2003 to November 2004, for 6 weeks in each season; winter, spring, summer and autumn. However, the measurements in restaurant N weren't carried out from the middle of summer because the restaurant N closed a business.

Table 2 - Outline of the measurements

Season	Period	Item	Interval
winter	December 16, 2003 - January 25, 2004	Volume of cold water consumption Volume of hot water consumption Cold water supply temperature Hot water supply temperature	2 seconds 20 seconds 60 seconds
spring	April 20, 2004 - May 30, 2004		
summer	July 27, 2004 - September 10, 2004		
autumn	October 13, 2004 - November 21, 2004		

3. Cold and hot water supply temperatures

Hot water supply temperatures in each instantaneous water heater are various because the preset temperatures are changed by user's purpose. When analyzing hot water consumption, it is important to consider hot water supply temperatures. Figure 1 shows the distribution of hot water supply temperature in restaurant I as an example. Figure shows the distribution and cumulative distribution of the frequencies when the measurement intervals are changed in 2 seconds, 20 seconds, and 60 seconds. From the Figure, it is found that the distributions of hot water temperature are not changed largely by the measurement intervals. Therefore, in this paper, the values of failure factor 1% of hot water supply temperatures, measured by 60 second intervals, were decided as hot water supply temperatures. As for cold water supply temperatures, it was chosen the mode value as the representative value of the day.

Table 3 shows cold and hot water supply temperatures in each season. Hot water supply temperatures show the values between 45°C and 83°C excluding the instantaneous water heater J1. The instantaneous water heater I2 and J1 supply hot water only to washing machines, the hot water supplied from instantaneous water heater was reheated with the booster.

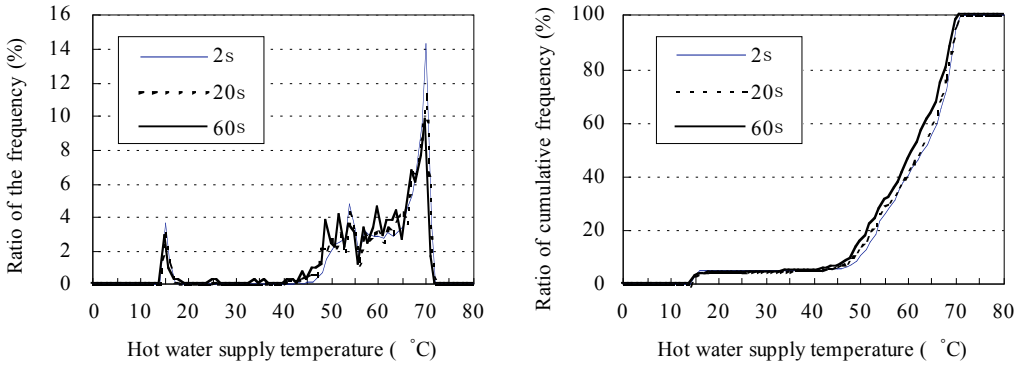


Figure 1 - Distribution of the hot water supply temperatures (Restaurant I)

In this paper, the volumes of hot water consumption were analyzed by converting to the volumes of 60 °C hot water consumption, because hot water supply temperatures of the instantaneous water heaters differ in each other.

Table 3 - Cold and hot water supply temperatures in each season

	Cold water supply temperature (˚C)	Hot water supply temperature of each instantaneous gas water heater (˚C)									
		C	D	F1	F2	I1	I2	J1	J2	K	N
winter	9.8	50	47	73	62	53	68	29	54	45	54
spring	18.7	53	56	68	65	56	73	50	58	49	54
summer	24.9	52	55	68	65	53	79	47	48	51	49
autumn	18.1	55	46	66	64	53	83	53	54	46	–

4. Analysis of daily cold and hot water consumption

4.1 Daily water consumption

As the daily fluctuation of cold and hot water consumption and ratio of turnover, Figure 2 shows the fluctuation of restaurant D in winter as an example. Ratio of turnover is calculated dividing the number of customers per day by the number of seats. The ratio of turnover shows a tendency to become high on Saturday, Sunday, and national holidays. In restaurant D, the fluctuation of ratio of turnover is similar to the fluctuation of cold and hot water consumption. The range of fluctuation is not large on weekday. In this paper, it was defined that “Holiday” means Sunday and national holidays. Therefore, the difference of day on the week was analyzed by 3 divisions such as “Weekday”, “Saturday”, and “Holiday”.

Table 4 shows the percentages of cold and hot water consumption for the total water consumption per day in each restaurant and in each season. As for the percentages of hot water in winter and summer, the winter’s percentages are higher than the summer’s one excluding restaurant I. Restaurant I serves with the buffet style and has a large variety of foods in each season. In winter, Japanese nabe, which is Japanese food like that some vegetables and meats boiled with water in a hot pot, is served. Therefore, it is thought that the percentage of cold water consumption in restaurant I is high in winter season. The hot water consumption is 20-40% in winter and 10-30% in summer excluding restaurant I.

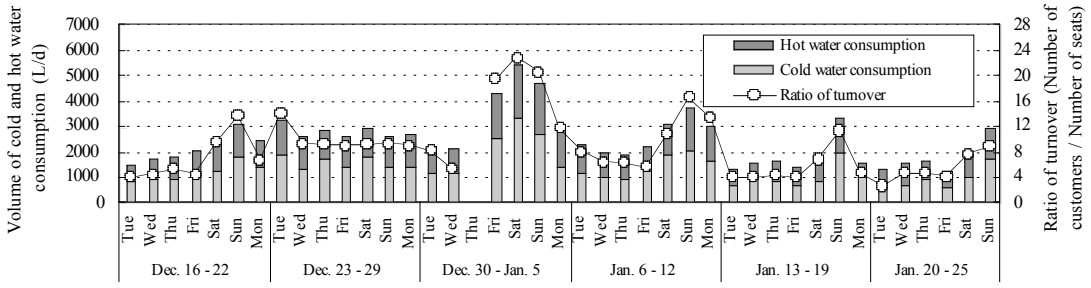


Figure 2 - Daily cold and hot water consumption and ratio of turnover

Table 4 - Percentages of cold and hot water consumption

	Restaurant C		Restaurant D		Restaurant F		Restaurant I		Restaurant J		Restaurant K		Restaurant N	
	Cold water	Hot water	Cold water	Hot water	Cold water	Hot water	Cold water	Hot water	Cold water	Hot water	Cold water	Hot water	Cold water	Hot water
winter	61.5	38.5	68.5	31.5	68.5	31.5	81.7	18.3	64.8	35.2	79.6	20.4	78.5	21.5
spring	68.0	32.0	65.3	34.7	73.2	26.8	75.2	24.8	64.3	35.7	81.0	19.0	83.7	16.3
summer	76.5	23.5	77.9	22.1	73.0	27.0	62.4	37.6	74.0	26.0	86.2	13.8	90.8	9.2
autumn	66.4	33.6	73.9	26.1	72.0	28.0	77.1	22.9	62.7	37.3	82.9	17.1	–	–

Note : unit (%)

The average values, standard deviations, and maximum values of daily hot water consumption in each restaurant and in each season are shown in Table 5. In most of restaurants, the average values of hot water consumption decrease in summer. However, the average value of summer is bigger than that of winter by about 1000(L/d) in restaurant I. Focusing on the maximum value, the value of summer in restaurant I (10712(L/d)) is the maximum and the value of winter in restaurant F (9449(L/d)) is second biggest value. Both of restaurant I and F have some similarities such as the floor areas are comparatively large and more than 2 instantaneous water heaters are set up in the kitchen.

Table 5 - The daily hot water consumption in each restaurant and in each season

Restaurant			C	D	F	I	J	K	N
winter	Average value	(L/d)	2739	778	3552	3972	2542	1083	945
	Standard deviation	(L/d)	309.3	259.0	1210.4	1207.5	950.5	252.7	176.3
	Maximum value	(L/d)	3456	1477	9449	6084	4953	1736	1455
spring	Average value	(L/d)	1776	987	2303	4830	2360	1056	876
	Standard deviation	(L/d)	652.2	350.6	710.3	1236.5	949.0	435.1	172.8
	Maximum value	(L/d)	3317	1964	4899	7911	5523	2324	1272
summer	Average value	(L/d)	1291	645	2144	4823	2002	904	440
	Standard deviation	(L/d)	200.6	143.6	341.2	1374.4	577.5	285.8	90.9
	Maximum value	(L/d)	1754	1006	2870	10712	3824	1565	639
autumn	Average value	(L/d)	1925	685	1958	4045	1866	644	–
	Standard deviation	(L/d)	354.1	166.6	342.1	929.9	759.4	167.0	–
	Maximum value	(L/d)	2949	1115	3120	5893	3700	1036	–

4.2 Factors influenced on the daily hot water consumption

As the factor which will have influence on the daily hot water consumption, the number of customers and the number of dishes were analyzed in each restaurant. Figure 3 shows the relationship between the number of customers and the volume of hot water consumption on Weekday, Saturday, and Sunday. According to the increase of the number of customers, the volumes of hot water consumption increase in each restaurant. On the correlation coefficients that were calculated by using all data of Weekday, Saturday, and Sunday, the value of restaurant C was 0.502. However, the other restaurants had the values between 0.682 and 0.822. Therefore, both of the items have a strong relationship with each other.

The numbers of dishes served per one customer were grasped by having interviews with the restaurant managers. The number of dishes per day was calculated multiplying the number of customers by the number of dishes per a menu which is ordered most frequently. Figure 4 shows the relationship between the number of customers and dishes. In the Figure, the regression line and the correlation coefficient are calculated by using 6 restaurants' data, excluding restaurant N whose number of dishes are not grasped because the restaurant N closed a business. The correlation coefficient of the number of customers and the volume of hot water consumption is low, however the correlation coefficient of the number of dishes and the volume of hot water consumption is high. From the results, it was supposed that the fluctuation of daily hot water consumption was influenced by the frequencies of washing machine usage or how to wash the dishes.

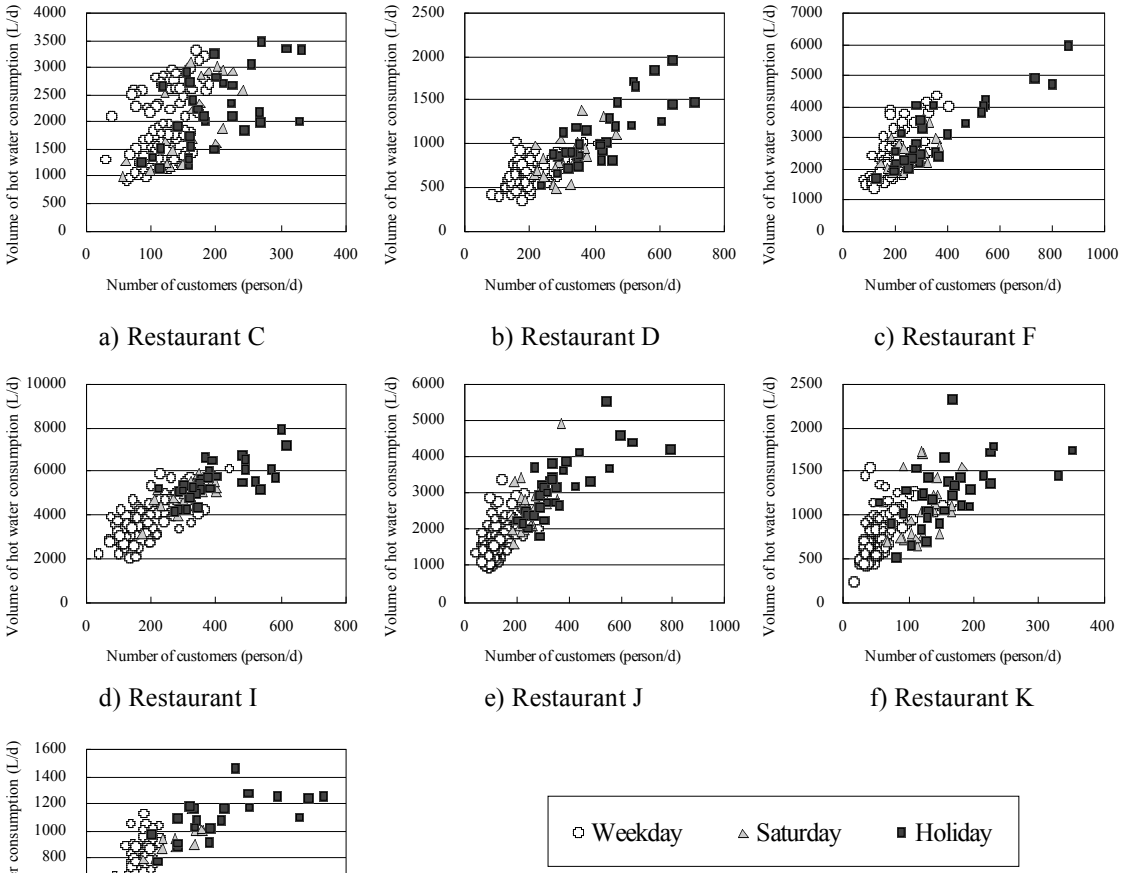


Figure 3 – Relationship between the number of customers and the volume of hot water consumption

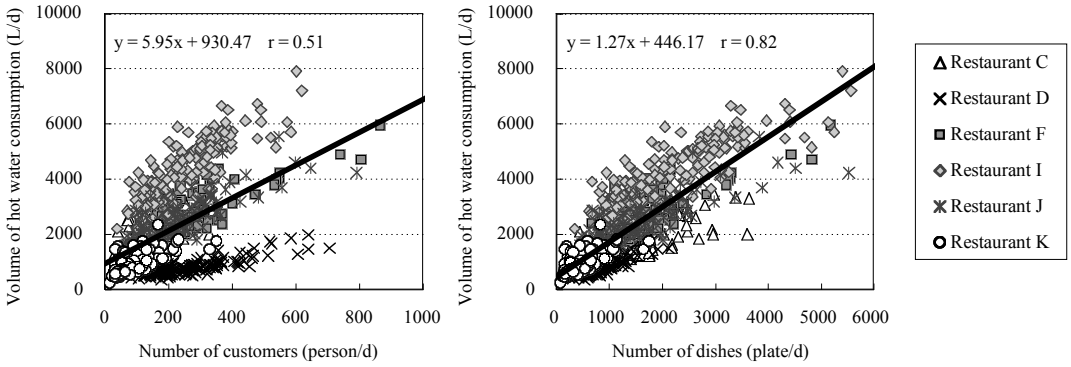


Figure 4 – Relationship between the number of customers and dishes

Based on the number of customers and the floor areas of the restaurants, the hot water consumption units were calculated in each restaurant. Table 6 shows average value, standard deviation, maximum value, and minimum value of the hot water consumption units per day. As for the average values, the hot water consumption per customer are almost in the range of value from 8 to 20 (L/person/day) excluding restaurant D (3.2

(L/person/day)). The values of restaurant C, I, J are bigger than the value of reference [2] (8 - 12 (L/person/day)). The hot water consumptions per floor area are almost in the range of value from 5 to 7 (L/m^2/day) excluding restaurant D (12 (L/m^2/day)). These values are small in comparison with the value of reference [2] (20 - 25 (L/m^2/day)).

Table 6 - Hot water consumption units per day

Restaurant	Hot water consumption per customer (L/person/day)				Hot water consumption per floor area (L/m^2/day)			
	Average value	Standard deviation	Maximum value	Minimum value	Average value	Standard deviation	Maximum value	Minimum value
C	14.9	6.5	52.3	6.1	6.9	2.4	12.4	3.3
D	3.2	0.8	6.5	1.7	11.7	4.2	29.5	5.2
F	11.6	4.0	44.8	5.9	5.2	2.0	20.0	2.9
I	20.2	7.6	58.2	9.6	5.6	1.6	13.7	2.6
J	13.0	4.6	29.9	5.3	6.6	2.6	16.7	2.8
K	12.6	5.5	42.6	4.4	5.6	2.1	14.1	1.4
N	8.2	2.4	15.3	3.3	7.3	2.0	12.6	3.0

5. Analysis of hourly hot water consumption

5.1 Hourly hot water consumption

Figure 5 shows the hourly fluctuation of the hot water consumption as an example of restaurant D. Left figure shows the average values of hourly hot water consumption on Weekday, Saturday, and Sunday. The peak hours of hot water consumption occurs at the time-zone of 12:00-15:00. At the time-zone, the volumes of hot water consumption on Saturday and Sunday are larger than that on Weekday. However, at the preparation of cooking time-zone (7:00-11:00), the volumes of hot water consumption are almost equal in each. Right figure shows the average values of hourly hot water consumption in each season. As same as the tendencies on Weekday, Saturday, and Sunday, the peak hours of hot water consumption occurs at the 12:00-15:00 in each season. The volume of hot water consumption at the time-zone of 20:00-21:00 is large in spring. At the peak hours, the volumes of hot water consumption in winter and spring are larger than that in summer and autumn. At the preparation of cooking time-zone or after the peak hours, the volumes of hot water consumption are almost equal in each season.

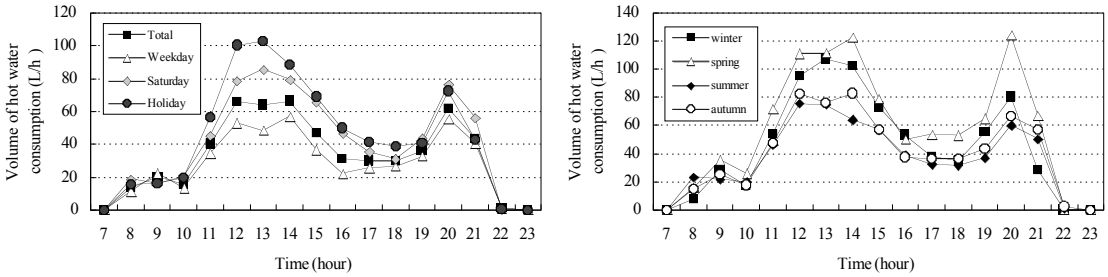


Figure 5 - The hourly fluctuation of hot water consumption

Table 7 shows average value, standard deviation, and maximum value of the hourly water consumptions in each restaurant and in each season. The values were calculated by using data in the time-zone of water usage (7:00-24:00). Each restaurant has various average values in the range from 25.7 to 283.4 (L/h). In comparison with each season, 5 restaurants, excluding restaurant D and I, has large average values in winter. As for the

maximum values in each restaurant, the values are from 3 to 6 times larger than the average values. Restaurant F in autumn and restaurant K in spring, summer, and autumn have the maximum values which are from 7 to 9 times lager then the average values.

Table 7 - The hourly hot water consumption in each restaurant and in each season

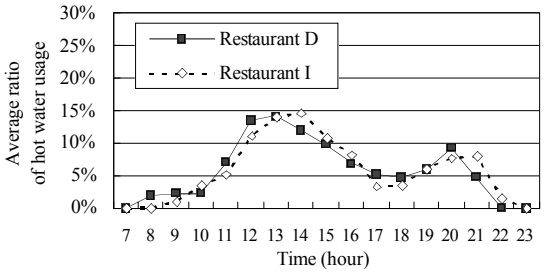
Restaurant			C	D	F	I	J	K	N
winter	Average value	(L/h)	156.6	45.8	193.8	233.6	146.9	63.7	55.4
	Standard deviation	(L/h)	87.6	46.2	160.8	237.1	142.6	63.5	45.6
	Maximum value	(L/h)	543	277	909	1022	645	327	226
spring	Average value	(L/h)	102.5	58.1	135.4	279.6	137.0	62.1	51.3
	Standard deviation	(L/h)	86.5	55.2	126.6	268.5	146.2	84.7	39.3
	Maximum value	(L/h)	418	275	839	1156	698	504	230
summer	Average value	(L/h)	75.9	38.0	126.3	283.4	112.7	53.2	25.7
	Standard deviation	(L/h)	65.2	33.1	112.4	276.6	97.6	69.9	21.3
	Maximum value	(L/h)	376	161	580	1623	505	409	106
autumn	Average value	(L/h)	113.2	40.3	115.2	237.4	107.1	37.7	−
	Standard deviation	(L/h)	93.4	34.4	112.9	220.1	103.2	45.6	−
	Maximum value	(L/h)	553	207	892	994	555	332	−

5.2 Type of the fluctuation pattern for hourly hot water consumption

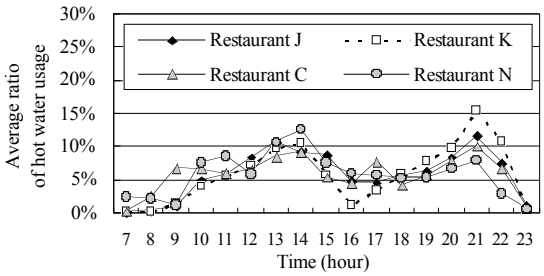
As for the calculation of hot water consumption in time series, it is important to typify the fluctuation patterns characterized by the cooking process and routine work in each restaurant. Based on the data of time-zone of 7:00-24:00 on Holiday and Weekday, the fluctuation patterns for hourly hot water consumption were studied.

The fluctuation patterns in each restaurant were shown as the ratio of hot water usage that divided the hourly volumes of hot water consumption by the total volumes of hot water consumption at the time-zone of 7:00-24:00. The patterns were classified to 3 types by cluster analysis both on Holiday and on Weekday. Figure 6 and Figure 7 show the restaurants which belonged to the fluctuation patterns of the 3 types on Holiday and on Weekday respectively.

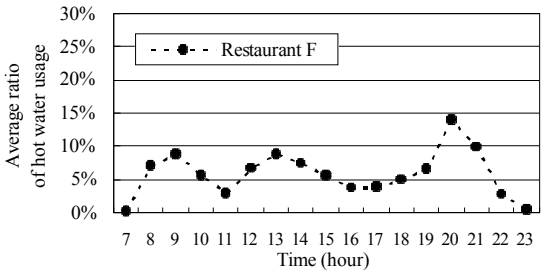
Pattern A and Pattern B have 2 peaks at the time-zone of 12:00-15:00 and 20:00- 23:00. Pattern A has a bigger peak at lunch-time and Pattern B has a bigger peak at supper-time. Pattern C has 3 peaks in the morning, lunch-time, and evening. The 3 types of fluctuation patterns are similar on Holiday and on Weekday. Therefore, when the volumes of hot water consumption are calculated, it is possible to use the Holiday's pattern or the average pattern without category of Holiday and Weekday.



a) Pattern A

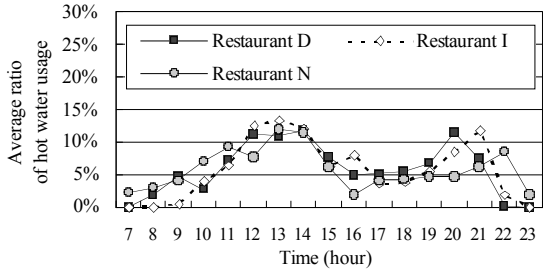


b) Pattern B

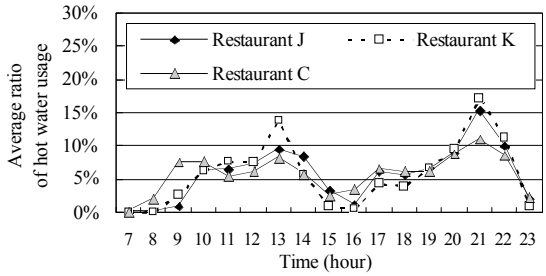


c) Pattern C

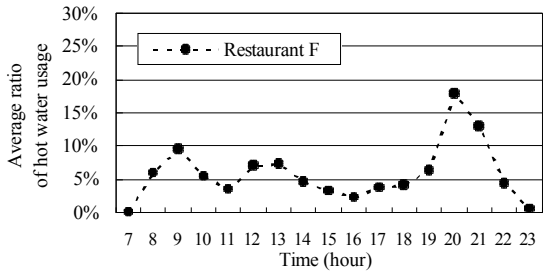
Figure 6 - The fluctuation patterns of average ratio of hot water usage (Holiday)



a) Pattern A



b) Pattern B



c) Pattern C

Figure 7 - The fluctuation patterns of average ratio of hot water usage (Weekday)

6. Conclusion

In this paper, the authors studied about the daily and hourly hot water consumption in the restaurants.

First of all, the measurements for volumes and temperatures of hot water were carried out in each season. On the basis of these data, the cold and hot water temperatures were studied.

Secondly, the relationship between the daily hot water consumption and the number of customers was analyzed. Also, the relationship between the daily hot water consumption and the number of dishes was analyzed. From the results, the correlation coefficient of the number of dishes and the volume of hot water consumption was high.

Finally, the hourly hot water consumption was studied. Based on the data of Holiday and Weekday, the fluctuation patterns for hourly water consumption were studied. The fluctuation patterns were classified to 3 types by cluster analysis.

Acknowledgements

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Main author presentation

Saburo Murakawa is the Professor at Graduate school of engineering, Hiroshima University. His special fields are building and city environmental engineering, plumbing engineering and environmental psychology.

Empirical approach to transmit energy for hot water plumbing system

M.C. Lee (1), C.L. Cheng (2), Y.H. Lin (3)
(1) D9113006@ mail.ntust.edu.tw
(2) CCL@mail.ntust.edu.tw
(3) M9213210@mail.ntust.edu.tw
(1)(2)(3) National Taiwan University of Science and Technology, Department of Architecture, 43 Keelung Road Sec.4, Taipei, Taiwan, R.O.C.

Abstract

Heat loss energy calculated equation in transmission part was almost quoted by air conditioner technology which estimates by heat-conduction and heat transfer coefficient. Some parameters are defined as ranges because of different pipe material component that causes architectures or interior designers difficult selecting a correct value in the ranges while designing. This research uses the pipe network length as the main factor and other factors relate material specific such as heat-conduction and heat transfer coefficient translated into temperature drop mechanism to correct the parameters and simplifies the calculated equation in energy consumption. The temperature drop mechanism using logarithms regression to content with various lengths is established by empirical approach results to replace some factors of the heat loss equation. Comparison with the energy consumption results of the quoted equation and the simplified equation shows that they are almost approach and the simplified equation can be used.

Keywords

Hot water supply system, residential building, empirical approach, temperature drop

1 Introduction

The energy consumption of the hot water system can separate in three partitions, which are heating conversion efficiency in heating part, exothermic hot water in transmission part and separately consumption in using part. 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. Most results in energy consumption of hot water usage were presented in previous researches, but few heat loss results in transmission part. Heat loss energy calculated equation in transmission part was almost quoted by air conditioner technology which estimates by heat-conduction and heat transfer coefficient. In the whole calculated equation, some parameters are defined as ranges because of different pipe material component. When architectures or interior designers design the hot water plumbing network, the energy consumption in transmission pipe is a problem to estimate because of selected a correct value in the ranges.

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.

This research will be directed against this problem and try to correct the parameters to simplify the calculated equation in energy consumption of hot water transmission. Using the pipe network length, the main consideration of space design, as the main factor and other factors relate material specific such as heat-conduction and heat transfer coefficient translated into temperature drop mechanism. The temperature drop mechanism is established by empirical approach results to replace some factors of the heat loss equation quoted by air conditional technology. And the simplified heat loss equation is established by temperature drop mechanism as the main factor.

2 Methodology

In order to find temperature drop mechanism (TD), this research refers heat lose equation by air conditional technology to design a questionnaire to investigation the influence factors of hot water transmission pipe installation. The heat loss equation for distribution pipes is shown as Eq.1. From this equation, it is known that heat loss relates with 6 factors, such as the pipe caliber D_i, pipe shell thickness D_o, heat transfer coefficient h_i and h_o, heat conduction by the pipe material k_p, ambient temperature various $(\theta_i - \theta_o)$, and pipe length L_p. Energy consumption of hot water transmission is multiplied by heat loss and transmission time as Eq.2. Via the investigation results, some specific factors are selected to design an experiment to measure the transmission hot water temperature drop caused by ambient temperature. These factors are selected from popular using pipes specifics such as caliber, length, heat-conduction, heat transfer coefficient, and installed method. The experiment is based on these factors to design a long term, multiform, and varied ambient temperature to measure the temperature drop while hot water is remaining in the different condition transmission pipes. Based on the experiment results, the temperature drop mechanism in any different form is analyzed by statistics method.

$$q_P = \frac{(\theta_i - \theta_o) \times L_P}{\frac{1}{2\pi}\left(\frac{2}{D_i h_i} + \frac{1}{k_p}\ln\frac{D_o}{D_i} + \frac{2}{D_o h_o}\right)} \quad (1)$$

$$E_P = q_P \times t_t \quad (2)$$

3 Investigation

The first task before designing the experiment was to identify the major factors for hot water linking pipe features: pipe material, pipe caliber, and pipe length. To identify the factors besides specialist visit, 600 questionnaires were also designed and distributed to three metropolitan areas. The random sampling questionnaire was used to investigate and the household as a sample unit. Three metropolitan areas were examined—Taipei (North-25°02'N, 120°30'E), Taichung (Central-24°09'N, 120°41'E), and Kaohsiung (South-22°34'N, 120°18'E). Two hundred questionnaires were distributed in each area. 451 effective questionnaires were obtained, including 167 row houses, 26 one family houses, and 258 apartments.

Based on the questionnaire results, linking pipe differs in constituent materials and age.

Before 1990, there was no regular to stipulate materials for hot water supply pipes in Taiwan. Therefore, pipe material was determined by economic considerations. In February 1992, the Taipei Water Department (1992) instituted a regulation that ”hot water supply pipes be made of stainless steel or copper …”. Since then hot water supply pipes have been regulated to these materials. As shown in ‘Fig.1’, stainless steel pipes (SP) have replaced lead and galvanized iron pipes (GIP). The investigation results demonstrate the hot water supply distribution pipe features in residential buildings. The pipe materials include SP, GIP, and CP (copper pipe). The connections in SP were separated into compression connects and screw connects.

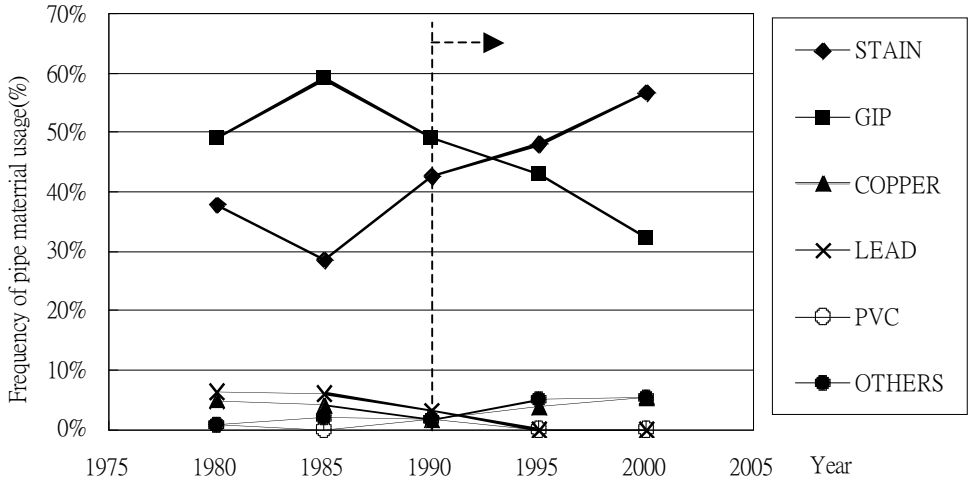


Figure 1 - Frequency of pipe material usage from 1980

According to reference ‘#30, Chapter Equipment of the National Building Code in Taiwan’ (2005), the most common linking pipe caliber used in water supply systems is 13mm in diameter. Therefore, over 80% of the pipes used in residential hot water supply systems are 13mm in diameter. There are a few pipes with 19mm or 25mm diameters and insulation that cause heat loss from the linking pipes system by ambient temperature.

Linking pipe lengths are different due to the distance between the hot water use location and the heater position. The investigation results showed the shortest length only 0.5m, the longest length was 22.0m, and the average length was 6.56m. Table 1 summarizes the hot water supply pipe lengths in different building types.

Table 1 - Summary of hot water supply pipe length in different building types

Building type	Under 5m	5-10m	10-15m	Over 15m	Average length (m)
Row house	79	52	17	19	6.63
Apartment	68	146	32	12	6.68
One family house	18	3	2	3	5.02
Summary	165	201	51	34	6.56

4 Experiment

We examined factors that may influence temperature drop in pipe distribution. The influence factors are pipe material, pipe caliber, pipe thickness, and pipe length. Generally, heat loss in bigger, thicker and longer pipes is slower than that in smaller, thinner and shorter pipes, regardless of the pipe material because of larger caloric capacity. In addition to the 4 major temperature drop factors, the other relevant factors are summarize in Table 2, and runs 80 groups of experiments to examine all pipe system configurations.

Table 2 - Experiment design factors and forms

Factors	Form 1	Form 2	Form 3
A: connection	Screw	Compression	
B: material	Stain Pipe (SP)	Galvanized Iron Pipe (GIP)	Copper Pipe (CP)
C: caliber	13mm	19mm	25mm
D: installation	Exposed	Insulation	
E: length	2m	4m	8m

This experimental schematic is shown in ‘Fig.2’ and uses common hot water supply pipes based on the investigation results. An electric heater with a temperature sensor was set to ensure hot water begin flowing temperature stability. All pipes were installed using different materials, calibers, and lengths. The setting pipe lengths in the experiment were 1m, 2m, 4m, and 8m, because the lengths include the average length in 6.56m and they easily define the results in logarithms regression. The experiment measures the water temperature drop in different pipes as shown the real status in ‘Fig.3’. Each pipe ending joint was installed with a temperature sensor to measure the temperature drop caused by the ambient temperature and time. The results were recorded in different pipe and used linear regression analysis to calculate the temperature drop gradient.

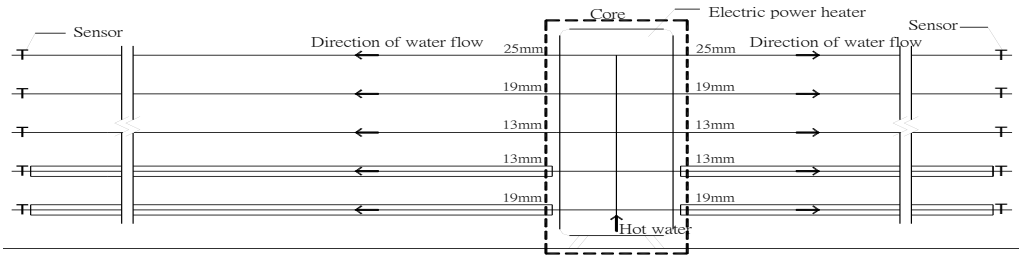


Figure 2 - Experimental schematic drawing

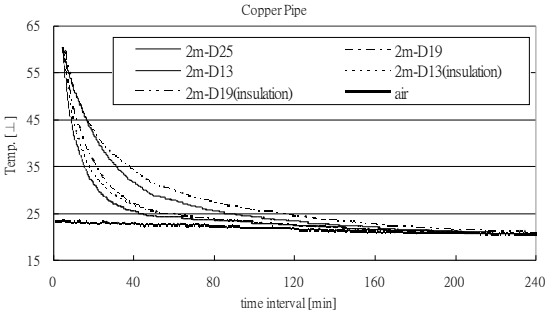
Figure 3 - Experimental instruments and pipes storage

5 Results

Referencing Eq.1 knows that in the same pipe material, the heat loss is different due to different caloric capacities. In this experiment results also show the phenomenon under every experiment conditions and two examples show the phenomenon in 'Fig.4'. Figure 5 shows the temperature drop on same pipe form in different ambient temperature, SP as one sample to show. A higher ambient temperature causes the hot water temperature dropping slowly and a lower ambient temperature causes the hot water temperature dropping fast towards the ambient temperature. When hot water flowed through the

stainless pipe for 30 minutes, the temperature dropped fast as a linear function, then remained close to the air (ambient) temperature. Other results in different pipes also had different gradient, but the temperature drop finally remained close to the ambient temperature.

TD at different caliber and installation in 2m copper pipe



TD at different length in 25mm caliber compressed and non insulation SP

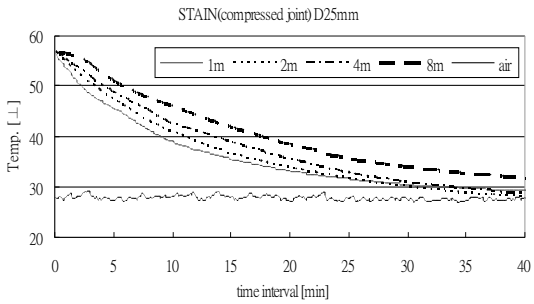


Figure 4 - Temperature drop for different pipe features

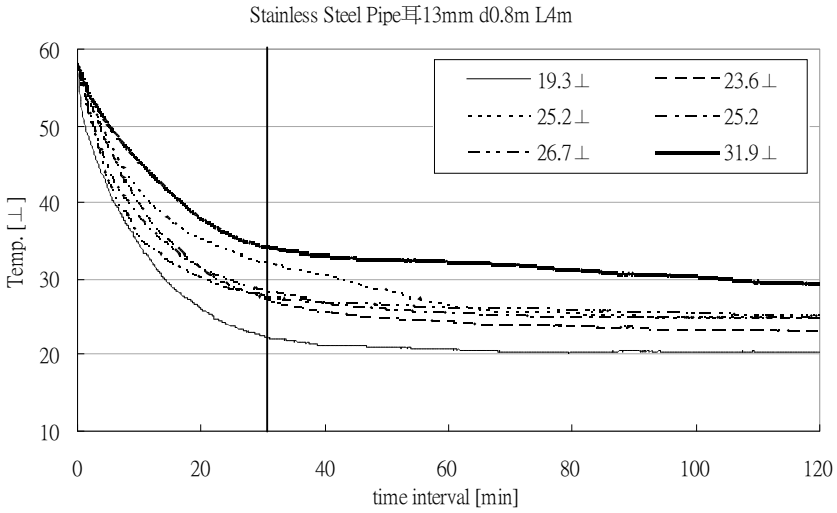


Figure 5 - Temperature drop on same pipe from in different ambient temperature

Hot water temperature must be set within a range between 35.0℃ to 55.0℃ when conducting temperature drop mechanism analysis. Because the average human body temperature is 36.5℃, a person would feel that water with a lower temperature was cool. Conversely, heater outlet is usually set between 55.0℃ to 60.0℃ for safety reason, JSHASE (1999). According to the Jaćimovic et al. (1998) linear function, our analysis performed a linear regression analysis based on every pipe configuration to calculate the linear temperature drop mechanism gradient. The adopted gradient of temperature

variation and during time presents in 'Fig.6' and the equation is shown as follow.

$$T_D = \frac{\Delta T}{t} \tag{3}$$

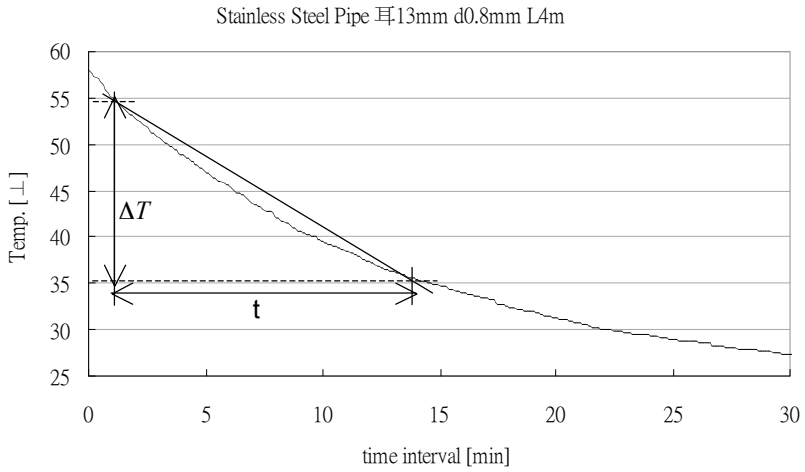


Figure 6 - Temperature drop mechanism gradient

Results of temperature drop in the same pipe feature and different ambient temperature are different, each result was modified on 20℃ for standardized and the value was defined as T_{D-20} as shown in 'Fig.7'. Numerous experiments were therefore performed with different ambient temperatures to approach the real status. A statistical method was used to correct the different temperature drop mechanism in every experiment from various ambient temperatures, and the correct coefficients were defined as C as shown in Table 3.

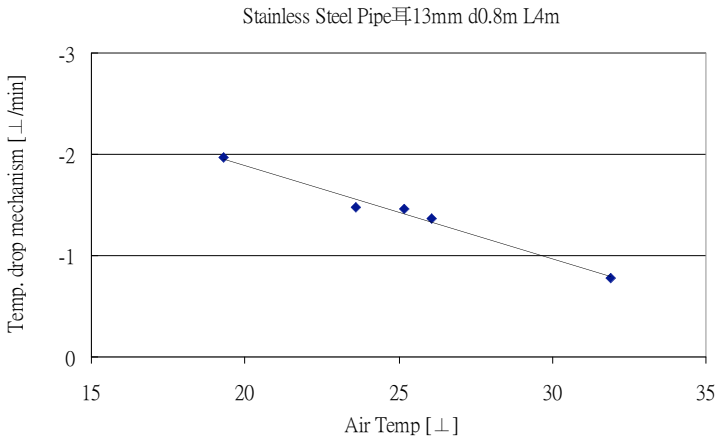


Figure 7 - T_{D-20} is corrected by regression in various ambient temperature

Table 3 - Temperature drop gradient in different pipe form

Material	Installation	Caliber (mm)	Thickness (mm)	Temperature drop mechanism (℃ / min)							
				1	1	2	2	4	4	8	8
				TD-20℃	C	TD-20℃	C	TD-20℃	C	TD-20℃	C
Stain Pipe (Screw connect)	Non insulation	13	2.5	-2.558	0.223	-2.266	0.1004	-2.000	0.1164	-1.762	0.3643
		19	2.5	-1.608	0.129	-1.445	0.0661	-1.301	0.0668	-1.145	0.0736
		25	3	-1.043	0.090	-1.014	0.0438	-0.987	0.0562	-0.961	0.0623
	Insulation	13	2.5	-1.5763	0.1306	-1.283	0.0682	-1.147	0.0802	-0.926	0.1129
		19	2.5	-0.7036	0.0553	-0.627	0.0265	-0.557	0.032	-0.512	0.0391
Stain Pipe (Compression connect)	Non insulation	13	0.8	-2.4632	0.1181	-2.1831	0.1444	-1.8889	0.092	-1.615	0.099
		19	1	-1.3292	0.0944	-1.3011	0.0777	-1.2523	0.0613	-1.235	0.0755
		25	1	-0.986	0.0526	-0.9559	0.0725	-0.9198	0.0438	-0.894	0.0487
	Insulation	13	0.8	-1.4139	0.0556	-1.3496	0.0841	-1.284	0.0812	-1.221	0.0767
		19	1	-0.7939	0.0387	-0.6823	0.0363	-0.6065	0.0352	-0.5391	0.0347
Galvanized Iron Pipe	Non insulation	13	2.8	-2.4852	0.1499	-2.4195	0.1466	-2.1286	0.114	-1.7119	0.0749
		19	2.9	-1.5534	0.0794	-1.4775	0.0901	-1.3776	0.0624	-1.3023	0.0534
		25	3.4	-1.1265	0.0567	-1.0368	0.0563	-0.9863	0.0451	-0.8891	0.0402
	Insulation	13	2.8	-1.1873	0.0736	-1.16	0.0442	-1.0155	0.1086	-0.948	0.0678
		19	2.9	-0.594	0.0352	-0.557	0.0312	-0.5196	0.0397	-0.484	0.0342
Copper Pipe	Non insulation	13	1.5	-2.561	0.1239	-2.316	0.1367	-2.1002	0.126	-1.7997	0.1055
		19	2.2	-1.5157	0.1078	-1.4512	0.0956	-1.4186	0.071	-1.3381	0.0529
		25	2.8	-1.0742	0.0725	-1.0467	0.0717	-0.998	0.0545	-0.9577	0.0492
	Insulation	13	1.5	-1.664	0.0891	-1.4165	0.086	-1.211	0.0699	-0.983	0.0591
		19	2.2	-0.9187	0.0593	-0.743	0.0579	-0.684	0.0567	-0.531	0.0517

We then developed an empirical approach model to calculate the temperature drop mechanism in different pipe features and installations as Eq.4, some factors in this equation are reference by Table 3.

$$T_D = T_{D-20℃} + C \times (T_A - 20) \tag{4}$$

The Length of linking pipes is not a regular due to different site plan and hot water supply system installation type that caused T_D must re-modify to fit every case. So the fixed lengths in the Table 3 are converted to fit any case by logarithms regression that based on the results to select an approach statistic method, one example is shown as Fig.8. Then, the new simplified model is developed as Eq.5 and some factors such as slope, intercept, and modified temperature corrective coefficient are transfer to a1, a2,

and a3 those listed at Table 4. In the Eq.5, *a1* is length corrective coefficient by logarithms regression, *a2* is re-modified temperature drop, and *a3* is ambient temperature corrective coefficient.

$$T_D = a_1 \times \ln(L) + a_2 + a_3 \times (T_A - 20) \quad (5)$$

Table 4 - Parameters of Temperature drop gradient transfer

Material	Type	Caliberm (mm)	Thickness (mm)	a1	a2	a3	R^2	Ratio of TD based on SP 13mm (a2)
Stain Pipe (Screw connect)	Non insulation	13	2.5	0.383	-2.545	0.054	0.9996	1.0
		19	2.5	0.221	-1.604	0.022	0.9965	0.6
		25	3	0.040	-1.043	0.017	0.9996	0.4
	Insulation	13	2.5	0.301	-1.546	0.026	0.9977	0.6
		19	2.5	0.093	-0.697	0.010	0.9845	0.3
Stain Pipe (Compression connect)	Non insulation	13	0.8	0.410	-2.463	0.030	0.9907	1.0
		19	1	0.048	-1.329	0.021	0.9325	0.5
		25	1	0.045	-0.986	0.015	0.9998	0.4
	Insulation	13	0.8	0.093	-1.414	0.020	0.9995	0.6
		19	1	0.121	-0.782	0.010	0.9607	0.3
Galvanized Iron Pipe	Non insulation	13	2.8	0.377	-2.578	0.032	0.9996	1.0
		19	2.9	0.123	-1.556	0.019	0.9969	0.6
		25	3.4	0.110	-1.124	0.013	0.9966	0.4
	Insulation	13	2.8	0.124	-1.207	0.020	0.9976	0.5
		19	2.9	0.053	-0.593	0.009	0.9998	0.2
Copper Pipe	Non insulation	13	1.5	0.361	-2.569	0.033	0.9907	1.0
		19	2.2	0.082	-1.516	0.022	0.9826	0.6
		25	2.8	0.057	-1.079	0.017	0.9999	0.4
	Insulation	13	1.5	0.324	-1.656	0.020	0.9533	0.7
		19	2.2	0.176	-0.903	0.015	0.9967	0.4

The parameters relation is found on Table4. The ratio of temperature drop has a regulation that adopts the parameter a2 at 13mm non insulation stainless pipe, the popular one, to be a standard. And a2 in every different form compares with the standard one; the ratios are also presented as Table 4. If the temperature drop ratio in non insulation and caliber 4/8" is 1.0 then others in 6/8" and 8/8" are almost 0.6 and 0.4. And the temperature drop ratio in insulation and caliber 4/8" and 6/8" are almost 0.6

and 0.3. Therefore, the temperature drop difference in different pipe material is not noticeable; the main influent difference is water caloric capacities inner pipe, such as pipe capacity. In the temperature drop ratio in insulation type is also presented a phenomenon that is increasing insulation thickness without caliber to enlarge caloric capacity.

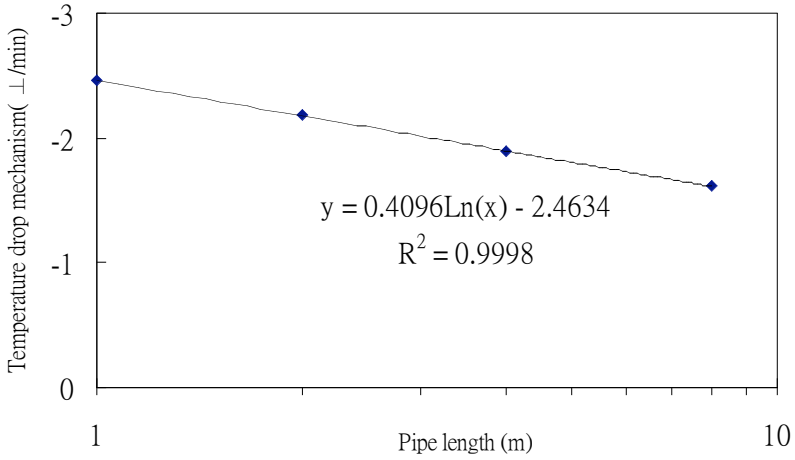


Figure 8 - Temperature drop mechanism in various pipe length

Based on the general energy consumption equation, it is related with water volume inner pipe, specific heat of water, and water temperature variation. We adopt the temperature drop mechanism T_D and water transmission during time t_t to be the factors of temperature variation, because T_D includes 5 factors of pipe feature and temperature variation per minute. And one simplified computer model is developed by the general energy consumption equation that is presented as Eq.6. This model just only gets the pipe's cross section, length, temperature drop mechanism (calculated by Eq.5) and transmission during time to calculate energy consumption of linking pipe.

$$E_P = A_P \times L_P \times S_w \times \rho_w \times T_D \times t_t \tag{6}$$

6 Discussion

The results of empirical approach model are compared with the results of the model quoted by air conditional technology to check the accuracy. This study adopts 6 factors by the pipe caliber, pipe shell thickness, heat conduction by the pipe material, heat transfer coefficient, ambient temperature various, and pipe length in different pipe form that are based on experiment design to calculate the heat lose. Energy consumptions in

every case by experiment design are calculated by heat lose and transmission time that are based on Eq.2. The energy consumptions also calculated by empirical approach model that includes cross section of pipe, length, specific heat of water, TD, and transmission time. All calculated factors are included different pipe forms on Table 2, and the energy consumption results are calculated and compared by these two models shown in 'Fig 9', the air temperature adopts the highest of monthly average in 29.3□ in experimental location.

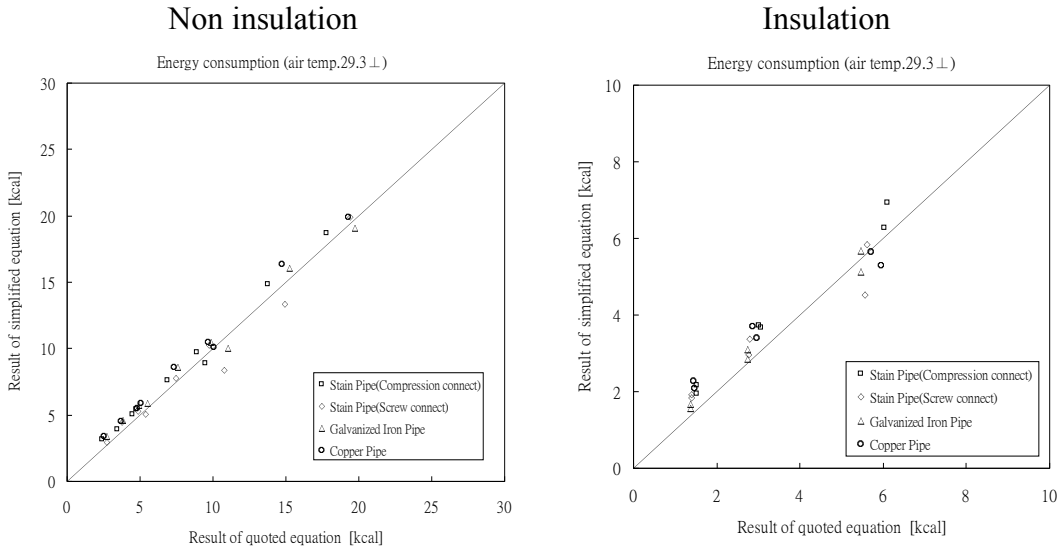


Figure 9 - Results of quoted equation compare with result of simplified equation

The two group results verification are referred to Pearson's correlation to check the relationship, and the Pearson product-moment correlation coefficient is 0.96 that means two results are 96% similar. So, the empirical approach model can be simplified running by architecture and designer while designing.

7 Conclusion

The experiment results show that water caloric capacity inner pipe affects temperature drop. The temperature drop of high water caloric capacity inner pipe is slower than it of low water caloric capacity inner pipe. Water volume affects water caloric capacity so that the water caloric capacity in long and thick pipe is higher than it in short and small pipe. It matches the theory energy consumption equation.

The empirical approach model can replace the quoted equation, because their calculated results are similar and most parameters of empirical approach model can be checked by

table to estimate. It is easy for architecture or interior designer to calculate the energy consumption of hot water transmission in their design space.

However, the experiment results of temperature drop are not linear proportional to pipe length but they are presented in a logarithm proportional. Perhaps the radiant heat is not concerned by the quoted equation. This issue will be studied in the further research.

8 Nomenclature

A	：Cross section on inner pipe（m2）	ρ	：Density (kg/m^3)
a	：Parameter（-）	θ	：Pipe temperature（℃）
C	：Corrective coefficient（-）	Subscript：	
D	：Diameter（m）	A	：ambient
E	：Energy consumption（kcal）	D	：drop
h	： Heat transfer coefficient (kcal/m2・h・℃)	D-20℃	：drop basis on 20℃
k	：Heat conductivity（kcal/m・h・℃）	i	：inner
L	：Length (m)	o	：outer
S	：Specific heat (kcal/kg・℃)	p	：pipe
T	：Temperature（℃）	t	：during time
t	：Time（min）	w	：water

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10 Presentation of Author

Meng-Chieh Lee is a Ph.D candidate majoring in hot water utilization and energy consumption at National Taiwan University of Science and Technology, Department of Architecture. He is also a lecturer at National Taichung Institute of Technology and National Chin-Yi Institute of Technology. His major is building environment control, sustainable building and multimedia for architecture design.

Recent Movement for Countermeasure to Legionella in the Public Bath in Japan

F. Kiya(1), N. Ichikawa(2), S. Koshimizu(3), H. Akai(4), M.Ogawa(5)

(1) kiyaf001@kanagawa-u.ac.jp

(2) nichi@js7.so-net.jp

(3) s-koshimizu@kakurakogyo.com

(4) akai@tinet-i.net.jp

(5) ogawa@uni-sekkei.co.jp

(1) Professor, Kanagawa University, Japan

(2) Professor, Tokyo Metropolitan University, Japan

(3) Manager, Kakura Kougyou Co,Ltd., Japan

(4) Engineer, Yurtec Cooperation, Japan

(5) President, Uni Consultants Inc., Japan

Abstract

Countermeasure to Legionella in Japan has been carried out as mainly maintenance of the systems such as cleaning, sterilization and so on. However, by the considering of cause might be in the system itself, the committee for research of the problems was set up in The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan.

In Japan, Legionellosis has been occurrence recently in relation to the big bath-tub having circulation system installed in hotels, spa facilities, public bath, training facilities and so on.

Two years, 2003 and 2004, investigation of the facilities having troubles, and experiments on systems such as filtration facilities, flow in the bath-tub, sterilization of water and so on were carried out.

In this paper, outline of the activities of the committee are introduced, and experiment on the visualization of flow in the bath-tub are described.

The experiments were carried out in the model bath-tub, and actual spa facility. The model bath-tub was 2m wide, 3m long, and 0.8m depth, and has 4 outlet changing use each other, and a pump changing flow rate from 50 L/min. to 100 L/min.

Visualized flow of colored water was get by 2 video cameras from upward and forward, and analyzed.

Keywords

Bath Facilities, Legionella, Flow Visualization

1. Introduction

In Japan, Legionellosis has been occurrence recently in relation to the big bath-tub having circulation system installed in hotels, spa facilities, public bath, training facilities and so on. And countermeasure to Legionella has been carried out as mainly maintenance of the systems such as cleaning, sterilization and so on.

The outline of those trend in Japan was presented in the report of CIB-W62 symposium 2001. 1)

However, by the considering of cause might be in the system itself, the committee for research of the problems was set up in The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan. The committee was carried out investigation of the facilities having troubles, and experiments on systems such as filtration facilities, flow in the bath-tub, sterilization of water and so on. 2)

In this paper, outline of the activities of the committee are introduced, and experiment on the visualization of flow in the bath-tub are described.

2. Public Bath in Japan

There are many public bath and spa facilities in Japan by reasons that Japanese persons very like to take bath for sanitation in wet and warm condition, and for relaxation. Almost those facilities have big bath-tub shown in Photo-1, and 2.

Photo-1 shows the sample of indoor bath-tub, and Photo-2 shows the sample of open space bath-tub. Fig.-1 shows the big bath system with circulation and filtration.

Usually the filtration system are used same as the swimming pool. There are two types that over flow is separated to drain, and collected to circulation system.

3. Research Works of the Committee

The committee was carried out investigation of the facilities having troubles, some experiments, review of former research reports and study on designing guide line.

The experiments were performance of filtration facilities including back washing, flow visualization in the bath-tub, sterilization of water and so on. The committee with 16 members has been established in two years, 2003 and 2004, and now operating to set the designing guide line for structure of big bath facilities.

4. Experiment of the Flow Visualization

4.1 Experiment Facility

Photo-3 shows the outward view of the experiment installation, and Fig.-2 shows the detail of the experiment installation.

The experiment was carried out in the model bath-tub, and actual spa facility. The model bath-tub was 2m wide, 3m long, and 0.8m depth, and has 4 outlets changing use each other, and a pump changing flow rate 50 L/min.(outlet speed 0.75m/s), 80 L/min.(1.20m/s), and 100 L/min.(1.50m/s). Partition, 0.6m height with over flow, was set in the place of 200~270cm. 3 ways over flow was able to set, and using floor and wall drain each other.

Visualized flow was get by 2 video cameras from upward, 4.0m height, center of the

model bath-tub, and forward 1.2m height, 7.0m from side of the model bath-tub, and analyzed.

4.2 Elements of the Experiment

Table-1 shows the elements of the experiment including type of drain, place of outlet, flow rate, distance of partition, and so on. Additionally convex and concave wall, person in the bath-tub were set up. Total 73 patterns were set up.

4.3 Method of Analysis

Arrival distance, diffusional angle and flow pattern of colored water were analyzed. Fig.-3 shows the measurement of arrival distance, and Fig.-4 shows measurement of diffusional angle.

4.4 Results of the Experiment

By finishing one element experiment, it was added chlorine for decolorization and neutralized by sodium thiosulfate. And the next element was carried out.

Fig.5~7 show the behavior of arrival distance of each condition. Flow rate are most effective to the arrival distance.

Table-2 shows the average diffusional angle of each condition. $\theta 1$ and $\theta 4$ are increasing by decreasing flow rate. In the case of 50 L/min., flow is going upward.

Photo-4 shows samples of flow visualization, and Photo-5 shows flow visualization in the actual bath-tub. Person in the bath-tub, front and back sitting are effective to the flow pattern.

5. Acknowledgments

The authors acknowledge to members of the committee and supported persons of the experiment, Mr.T. Kobayashi, Mr.Y. Hayashi and Mr. D.Muroi.

6. References

1) F. Kiya, H.Kose : Research Works and Guide Line for Prevention of Legionellosis, CIB-W62 symposium, 2001.9, Slovenia
2) Report of the committee : Countermeasure of Legionella in the bath facilities,2005.3

7. Presentation of Author

Fumitoshi Kiya is Professor of Kanagawa University, in the Department of Architecture, Faculty of Engineering, and Professor emeritus of Tokyo Institute of Technology.

He is specialist in the field of plumbing and built environment. He has been in W62 since 1972, the first symposium held in BRE, England.

Photo-1 Sample of the big bath-tub (indoor)

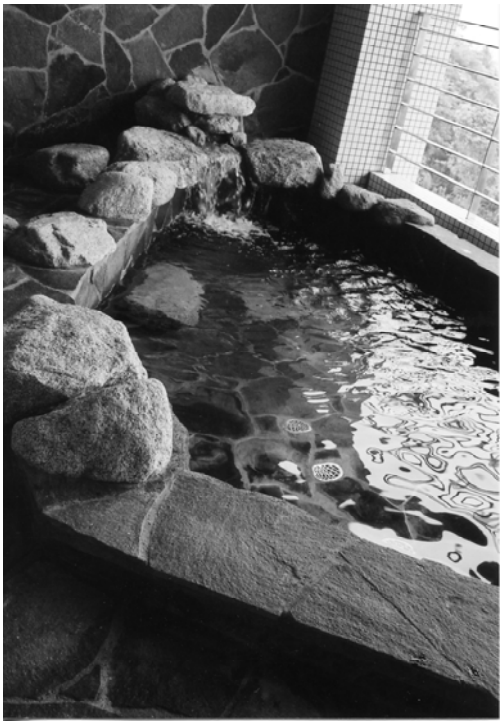
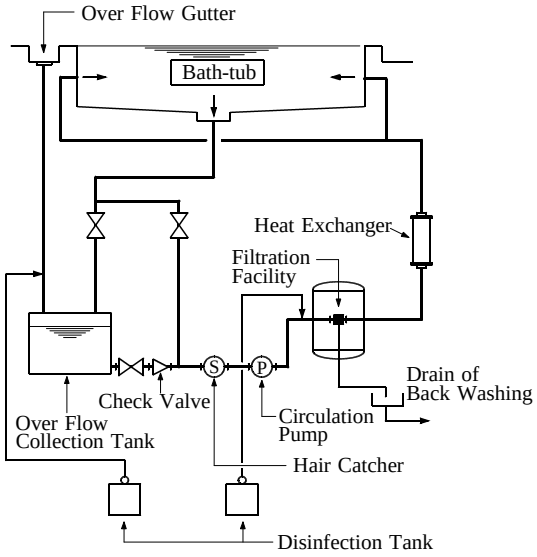


Photo-2 Sample of the big bath-tub (open space)



(sometimes the over flow line is separated)

Fig. -1 Big bath-tub with circulation system

photo-3 Outward view of the experiment installation

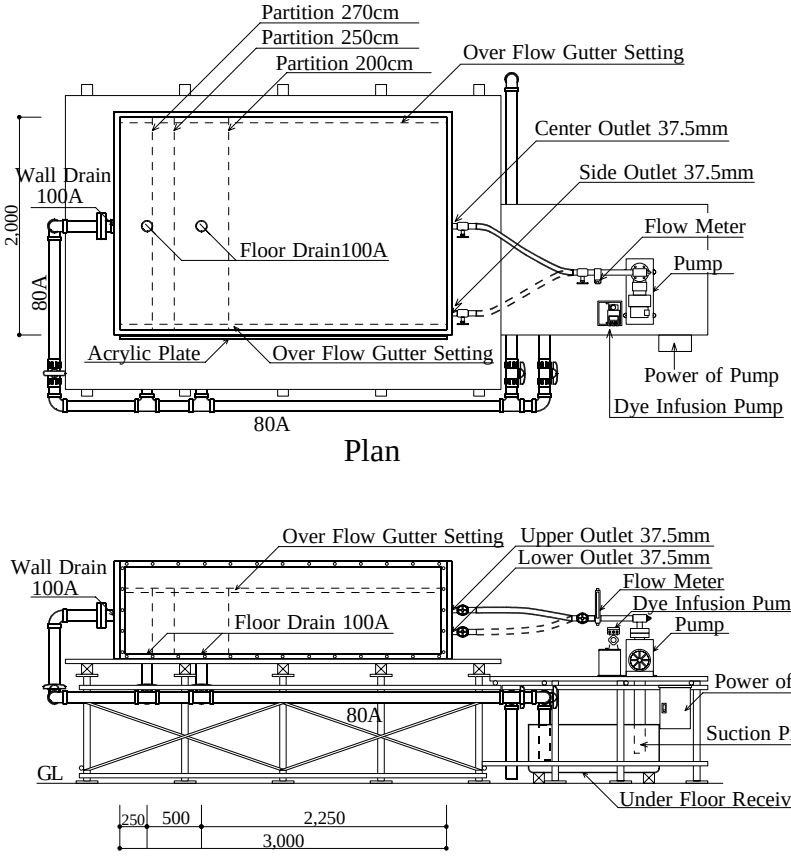


Fig. -2 Detail of the experiment installation

Table-1 Elements of experiment

Type of drain	Place of outlet		Flow rate (L/min)	Distance to partition(cm)				Concave wall	Convex wall
				200	250	270	300		
1 way overflow	Cent.	Upper	100		○			○	○
			80	○	○	○		○	○
			50		○			○	○
		Lower	100	○	○	○		○	○
			80	○	○	○		○	○
			50	○	○	○		○	○
	Side	Upper	100		○				
			80	○	○	○			
			50		○				
		Lower	100		○				
			80	○	○	○			
			50		○				
3 way overflow	Cent.	Upper	100		○				
			80	○	○	○			
			50		○				
		Lower	100		○				
			80	○	○	○			
			50		○				
Floor drain	Cent.	Upper	100		○		○		
			80		○		○		
			50		○		○		
		Lower	100		○		○		
			80		○		○		
			50		○		○		
Wall drain	Cent.	Upper	100				○		
			80				○		
			50				○		
		Lower	100				○		
			80				○		
			50				○		

The others

Full open floor drain (550L/min - 250cm , 100&50L/min , Cent. Lower)
Full open wall drain (520L/min - 300cm , 100&50L/min , Cent. Lower)
Person in the bath (front , back , - 250cm , 80L/min , Cent. Upper)

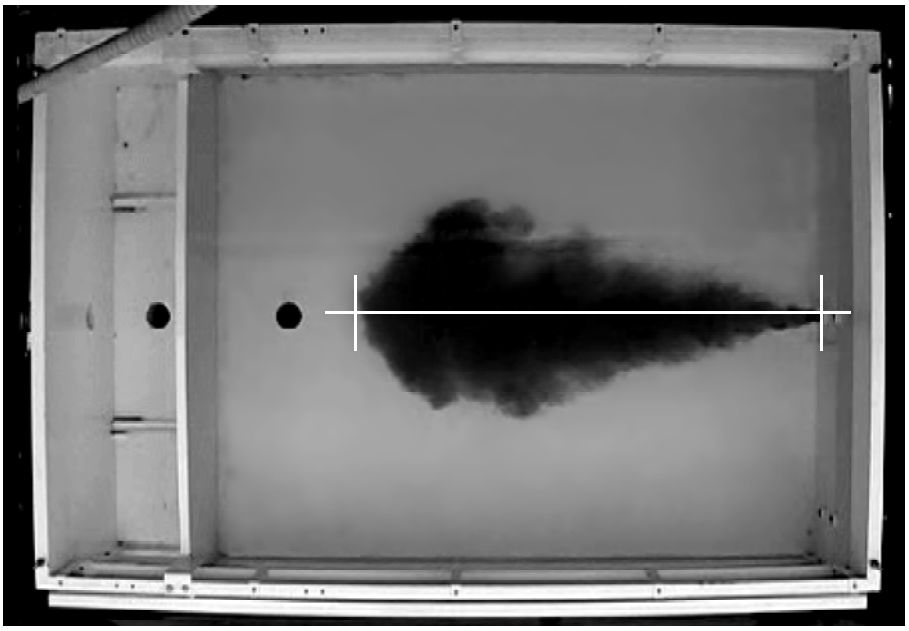


Fig. -3 Measurement of arrival distance

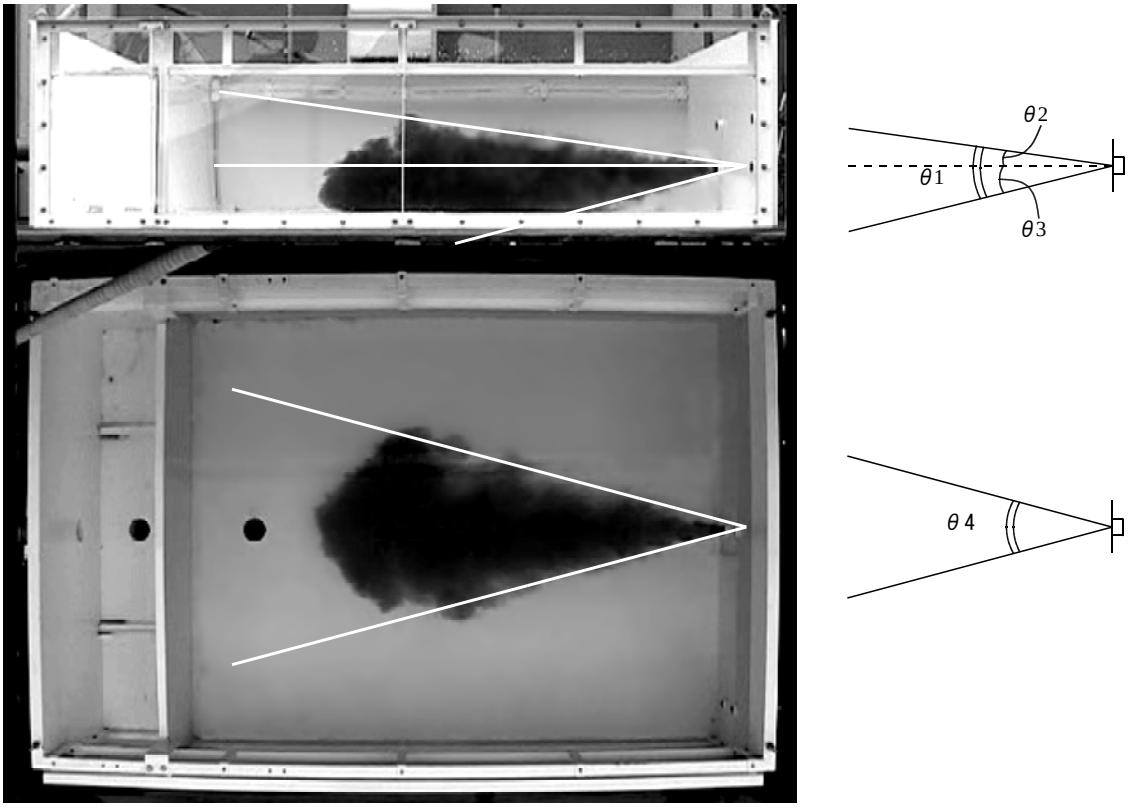
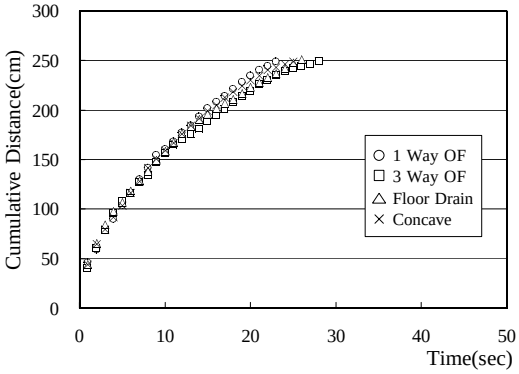
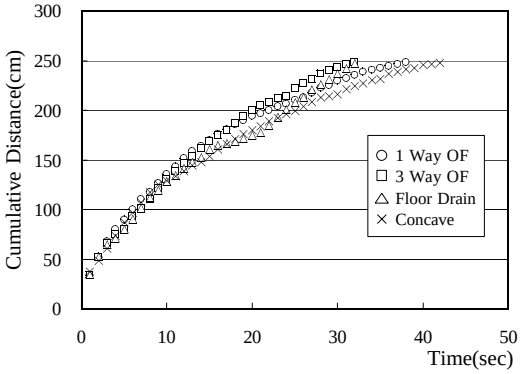


Fig. -4 Measurement of diffusional angle



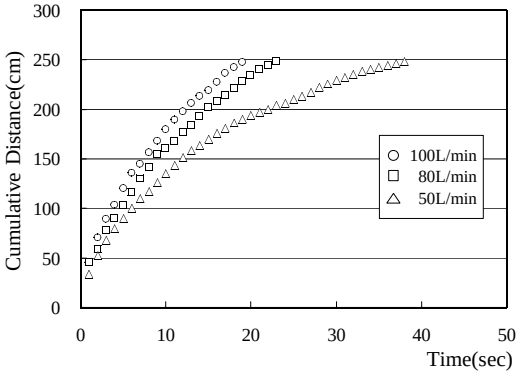
Place of Partition 250cm , Flow Rate 80L/min
Center Upper Outlet

Fig.-4 Distance of Each Drain



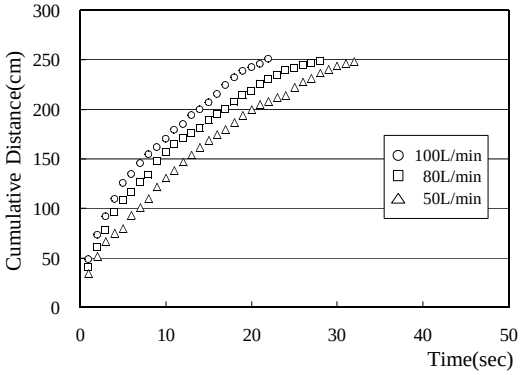
Place of Partition 250cm , Flow Rate 50L/min
Center Upper Outlet

Fig.-4' Distance of Each Drain



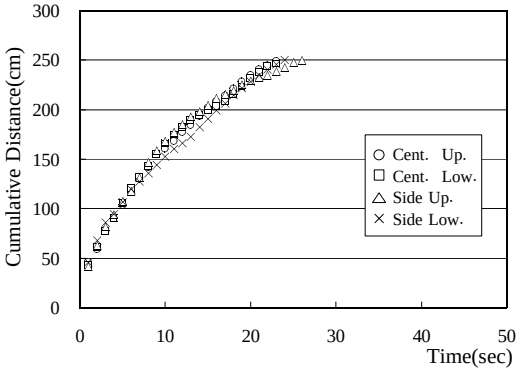
Place of Partition 250cm , 1 Way OF Drain
Center Upper Outlet

Fig.-5 Distance of Each Flow Rate



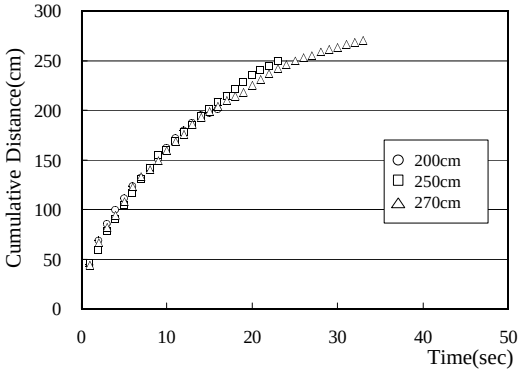
Place of Partition 250cm , 3 Way OF Drain
Center Upper Outlet

Fig.-5' Distance of Each Flow Rate



Place of Partition 250cm , 1 Way OF Drain
Flow Rate 80L/min

Fig.-6 Distance of Each Outlet

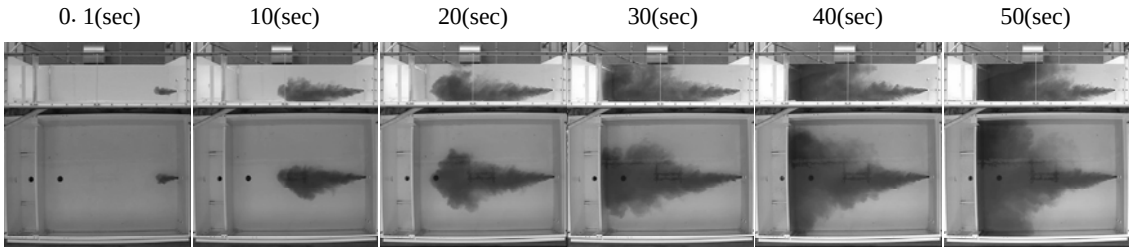


1 Way OF Drain , Flow Rate 80L/min
Center Upper Outlet

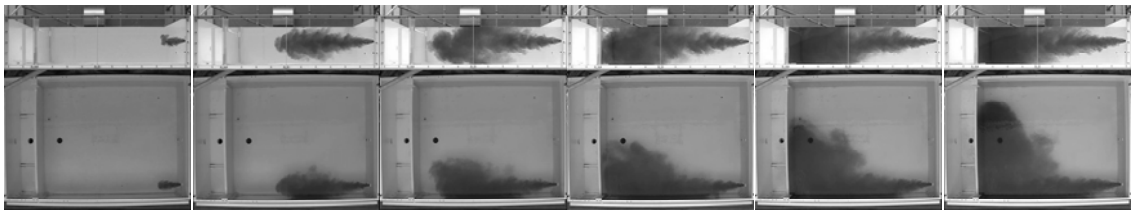
Fig.-7 Distance of Each Partition

Table-2 Average diffusional angle of colored water

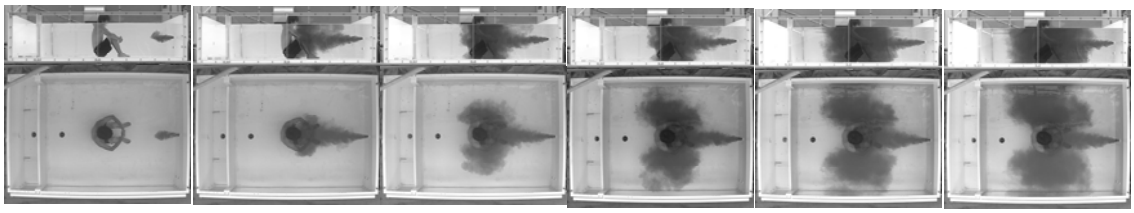
		Vertical diffusional angle									Horizontal diffusional angle		
		100L/min			80L/min			50L/min			100L/min	80L/min	50L/min
		θ1	θ2	θ3	θ1	θ2	θ3	θ1	θ2	θ3	θ4	θ4	θ4
Average		22.0	6.6	15.4	22.4	7.5	14.9	25.1	17.4	7.7	27.1	28.5	31.3
Drain methods	1 Way OF	21.6	6.5	15.1	22.6	8.0	14.6	24.3	15.5	8.8	27.7	28.3	30.7
	3 Way OF	24.3	7.8	16.5	21.9	7.2	14.8	25.5	18.0	7.5	28.0	29.2	31.3
	Floor drain	21.6	6.6	15.0	21.5	6.4	15.1	25.3	19.6	5.6	26.8	29.0	31.0
	Wall drain	22.3	6.5	15.8	22.3	7.3	15.0	27.8	20.0	7.8	26.5	28.3	32.5
	Curved wall	21.9	6.4	15.5	23.3	7.6	15.6	24.5	16.4	8.1	26.5	27.6	31.9
Place of partition	200cm	21.5	7.0	14.5	21.5	7.2	14.3	24.0	18.5	5.5	27.0	27.9	31.5
	250cm	22.0	6.5	15.5	22.9	7.4	15.5	24.7	16.4	8.3	26.9	28.0	31.5
	270cm	22.0	8.0	14.0	22.9	8.5	14.5	23.0	18.5	4.5	27.0	29.0	32.5
	300cm	21.9	6.5	15.4	22.5	7.5	15.0	26.6	19.8	6.9	26.4	28.5	31.4
Place of outlet	Cent. Upper	22.2	6.4	15.9	22.5	7.2	15.4	25.3	17.6	7.8	26.1	27.8	30.9
	Cent. Lower	21.9	6.9	15.1	22.2	7.3	15.0	24.7	18.8	5.8	27.7	29.0	32.1
	Side Upper	21.0	8.0	13.0	23.0	10.0	13.0	24.0	11.0	13.0	26.0	28.5	27.5
	Side Lower	22.5	5.0	17.5	21.5	6.8	14.7	27.0	9.0	18.0	30.5	28.8	26.5



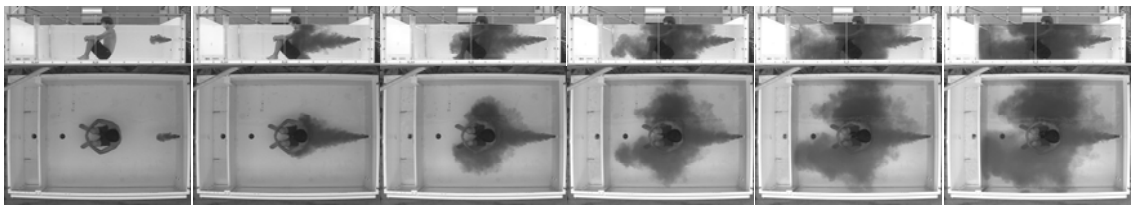
a) 1 way overflow , Distance to partition 250cm , Flow rate 80L/min , Center lower outlet



b) 1 way overflow , Distance to partition 250cm , Flow rate 80L/min , Side upper outlet



c) 1 way overflow , Distance to partition 250cm , Flow rate 80L/min , Center upper outlet
Person in the bath (front)



d) 1 way overflow , Distance to partition 250cm , Flow rate 80L/min , Center upper outlet
Person in the bath (back)

Photo.-4 Samples of flow visualization

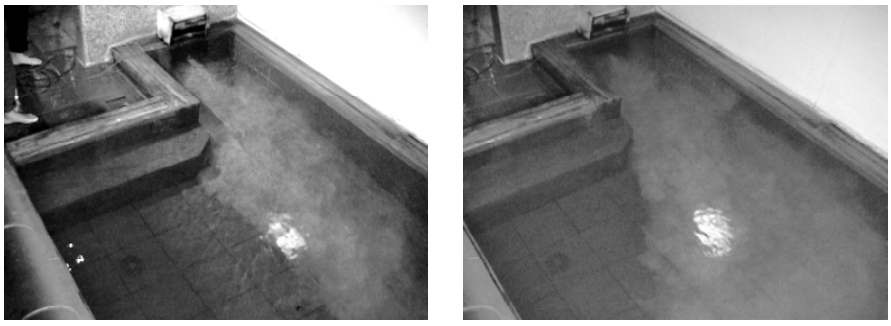


Photo.-5 Flow visualization in the actual bath-tub

Regulation on Legionella prevention in collective water systems

W.G. van der Schee
w.g.vd.schee@wolterendros.nl (TVVL)

Abstract

This paper focuses on the regulation on Legionella prevention in collective water systems in the Netherlands. After the outbreak of the Legionella epidemic January 1999 the Minister of Housing, Spatial Planning and the Environment sent the Legionella Prevention Action Plan to the lower house of the Dutch parliament. The aim was to have a quick reaction on a serious problem, which could threaten the public health. The technicians of TVVL and ISSO published two guidelines: Publication 55.1 "Legionella prevention in collective water systems" and Publication 55.2 "Legal responsibility for Legionella prevention in collective water systems". Both publications require technicians to make a Risk analysis and control plan.

Keywords

Legionella prevention; Collective water system; Risk analysis; Control plan.

1 Introduction

After the the Legionella epidemic of January 1999 in the Netherlands in Bovenkarspel, sent the Minister of Housing, Spatial Planning and the Environment a Legionella Prevention Action Plan to the Tweede Kamer (the Dutch Lower House) on 17 May 1999. This plan expressed the intention to develop a ministerial regulation as soon as possible, aimed at the prevention of legionnaire's disease, in so far as contamination can be related to the supply of mains water that is designated for drinking, showers, washing or other domestic purposes.

The minister can adopt a regulation, in the event he should deem an immediate provision to be necessary with a view to preventing or limiting a serious public health hazard. The Interim Regulation was made by the Minister of Housing, Spatial Planning and the Environment on October 2000.

The Interim Regulation was mainly directed at collective water systems and collective water distribution systems: an amount of about 600,000 objects.

This interim regulation was in force until October 2002 and had to be followed up by a definitive regulation for Legionella Prevention. In December 2004 new rules for Legionella Prevention were put into force. This Definitive regulation for Legionella Prevention divides the 600,000 objects in two groups:
High and middle risk class. 10,000 objects
Low risk class about 590,000 objects

2 Definitive regulation for Legionella Prevention in high and middle risk classed objects

This definitive regulation for collective water systems is obligatory in the 10,000 objects with a so-called high and middle risk class:

- In a hospital facility
- Hotels
- In a centre for Asylum Seekers
- In a building with a cell function (Jails)
- In a bathing establishment
- On camping-sites
- In a port offering berthing and mooring of pleasure vessels

3 ISSO-publication 55.1: "Legionella prevention in collective water systems"

The manual "ISSO-publication 55.1" gives an elaboration on the risk analysis of collective drinking water systems and gives proposals of adaptation of the system and rules for drawing up the management for such systems. The manual gives information about solutions for large water systems with a small amount of aerosol producing tap points, model working instructions, information about the automation of control measures, alternative control measures and alternative detection methods.

There are two options for the risk analysis of a collective water system, i.e. a) a limited analysis or b) an extensive analysis. Although the new rules only speak of a risk analysis and does not mention the limited and extensive risk analyses, one has chosen to maintain the distinction in the manual. It is namely practical to carry out the limited analysis at first (mainly consisting of an inventory of the aerosol producing tap points) to determine whether simple measures are sufficient.

In both approaches, the results of the risk analysis are recorded. If control measures need to be taken on a regular basis, a management plan to this extent will be drawn up. Its implementation will be recorded in a logbook.

3.1 The risk analysis

A risk analysis shall be performed by performing one or more of the following steps in succession:

1. Inventory of tap outlets for anticipated aerosol formation;
2. Collection of data relating to the collective water supply or the collective pipe network;

3. Subdivision of the collective water supply or the collective pipe network into main functions;
4. Risk analysis from component to system.

3.1.1 Inventory of tap outlets for anticipated aerosol formation

For the execution of the inventory, the extent to which when using tap outlets forming part of, or connected to a collective water supply or collective pipe network, aerosols as well as legionella bacteria carried by them, whether or not in conjunction with other micro-organisms, can be released in quantities which, when inhaled, may have adverse effects on public health (referred to below as relevant quantities of inhalable aerosols) must be assessed.

The following aspects shall be established for each tap outlet:

- location of the tap outlet (description of the room);
- type of tap outlet (e.g. sink, washbasin, bath, shower, fire hose);
- an assessment as to whether relevant quantities of inhalable aerosols may be released on use.

3.1.2 Prevention at tap outlets

If following the execution it is shown that there are one or more tap outlets at which relevant quantities of inhalable aerosols may be released, at least one of the following measures shall be taken:

a. the aerosol-forming tap outlets must be removed;
b. in the supply pipe to the tap outlet concerned, a treatment technique must be applied which eliminates to a sufficient extent the legionella bacteria that have grown in the collective water supply or collective pipe network. At the request of the inspector, it must be demonstrated that this technique is effective and has no unacceptable side-effects on public health or the environment;
c. in accordance with paragraphs 3.1.3 to 3.1.5, a risk analysis must be performed for the section of the pipe between the (central) point of delivery of the collective water supply or the collective pipe network and the tap outlet concerned. A section of pipe that only supplies non-aerosol forming tap outlets may be excluded from the risk analysis provided that a regulatable non-return valve is present at the beginning of this section of pipe and the branch is located directly after the (central) point of delivery. See figure 1.
d. in accordance with paragraphs 3.1.3 to 3.1.5, a risk analysis must be performed for the whole of the collective water supply or collective pipe network.

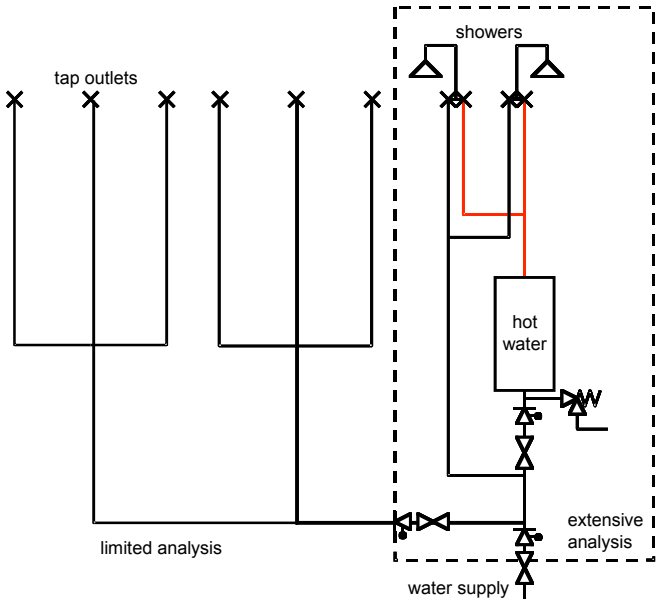


Figure 1 - Water supply separated by a regulatable non-return valve

To the extent that regular measures are required in order to manage the risk of infection from the aerosol-forming tap outlets, a control plan shall be compiled and implemented.

3.1.3 Collection of data relating to the collective water supply or the collective pipe network

For the purpose of the risk analysis, at least the following data shall be collected with regard to the installation:

- installation drawings or equivalent drawings, diagrams or descriptions showing the course of the pipe, the position of devices and relevant fittings (non-return valves) and tap outlets;
- a list of the devices used;
- the method of operation and temperature settings (design and in practice);
- the temperature of the tap water at the tap outlets located at a long distance from the (central) point of delivery or the hot water device, tap outlets with a long draw-off pipe and tap outlets that are used infrequently.

For the purpose of the risk analysis, at least the following data shall be collected with regard to the environment:

- room temperature (design, maximum daily average);
- temperatures above suspended ceilings or in ducts or (technical) rooms in which pipes are located;
- temperatures of walls, floors or ceilings in which other hot pipes are located.

To get an indication in new buildings of hot spots in shafts TNO developed a tool to calculate the temperature. See figure 2.

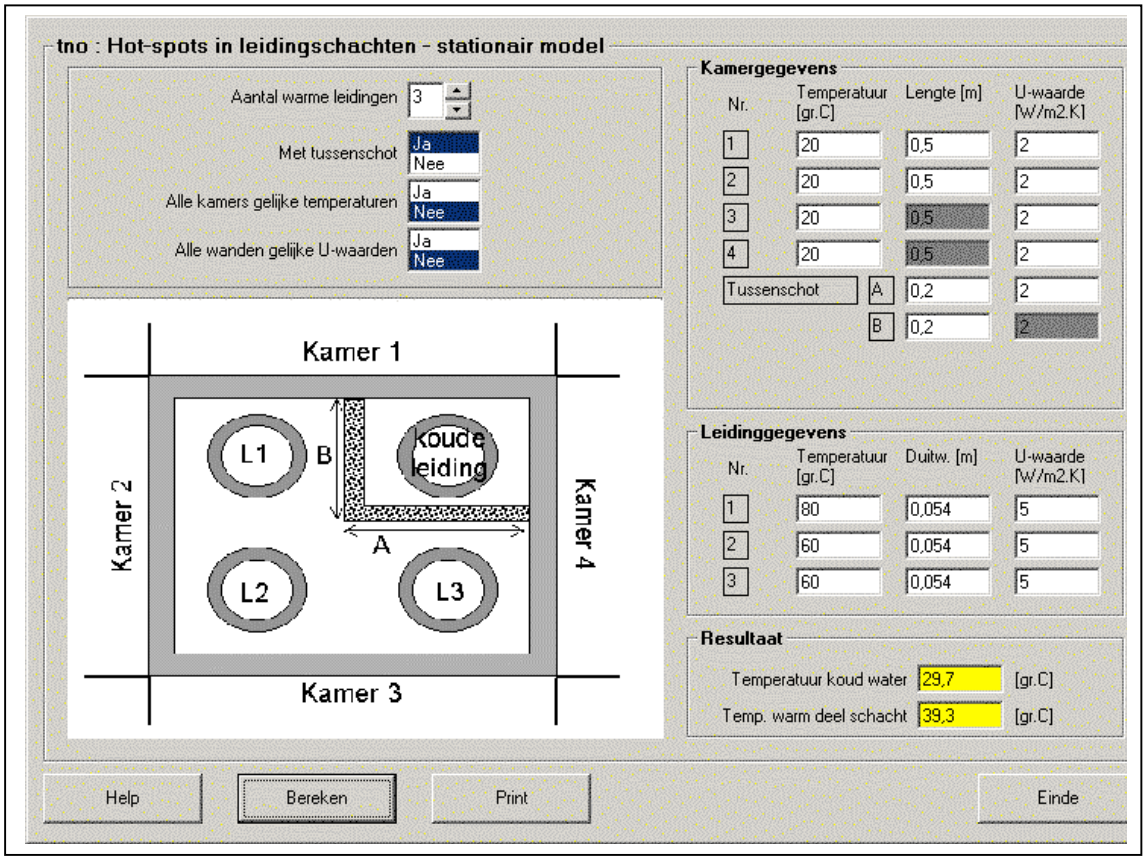


Figure 2 - Results of the calculation for the temperature in shafts

For the purpose of the risk analysis, at least the following data shall be collected with regard to use:

- operating times, including the periods in which the installation is not used on account of, for example, holidays or seasonal closures;
- use functions of the building (or part of the building);
- frequency of use.

The data as mentioned above shall be such that the following data may be derived from it for the purpose of the risk analysis:

- the function of the installation component;
- the material data of the installation component;
- the method of operation of the installation component;
- the temperature of the installation component.

3.1.4 Subdivision of the collective water supply or the collective pipe network into main functions

For the purpose of the risk analysis, the collective water supply or the collective pipe network is subdivided into five main functions:

1. the raw material, being the quality of the water at the point where the installation is connected to the point of delivery;
2. the drinking water or domestic water installation, being the pipe network between the central point of delivery and all tap outlets;
3. the hot tap water preparation system, being all hot water devices and their interconnection by means of pipes;
4. the hot water pipe network, being the pipe network between the outlet of the hot tap water preparation system and all tap outlets, including any circulation systems. If water mixing devices are used, this includes both the water mixing device and the distribution system to the tap outlets behind the water mixing device;
5. the tap outlets, being the points at which water is drawn off by the user and the points at which water is used for other domestic purposes, as a result of which it can come into contact with people.

3.1.5 Risk analysis from component to system

For each main function, as referred to in regulation 3.1, of the collective water supply or collective pipe network, the risk analysis shall specify whether there is a risk of growth of any legionella bacteria present.

The following procedure shall be followed for the risk analysis:

1. the collective water supply or the collective pipe network is subdivided into separate components for each main function as described in regulation 3.1;
2. a risk analysis is then carried out per component;
3. thereafter, a risk analysis per main function is carried out for the entire installation.

In the execution of the regulation, the following factors which may cause a change in the risk factors must be taken into account:

- pipe branch. Whether the function of a pipe and therefore the intensity of use changes is particularly important.
- room. Each room is checked to establish whether it poses an increased risk of hot spots for the drinking water installation pipes and hot water draw-off pipes.

Devices shall be regarded as separate components.

The components shall be numbered, starting at the inlet of the main function and ending at the termination points, and then listed.

The numbering of the components shall be marked on the installation diagram.

The data required for each component shall be entered in a list. The data referred comprises:

- a unique name or description of the component;

- the function, in order to indicate the regularity and intensity of the flow;
- the visibility of the component. If components are completely concealed in the structure of the building, this shall be recorded;
- the water content of storage devices and drinking water tanks;
- nature of the room(s), in order to indicate the anticipated maximum temperatures;
- dead legs:
- hot spots;
- description of series of pipe(s) / tap outlet(s).

The risk analysis for each component in the collective water supply or collective pipe network is based on the component data described in 3.1.3. On the basis of this data, the anticipated (different) operating statuses of the installation component concerned shall be determined. The risk qualification and any actions to be taken shall be determined in combination with the risk factors and risk qualification pertaining thereto as specified in 3.1.7.

In order to determine which operating situations, or combination of operating situations, that can reasonably be expected, may result in a maximum risk of growth of legionella bacteria, the following aspects shall at least be taken into account:
- resident, user and manager behaviour;
- faulty operation of installation components.

Risk analysis per main function and for the entire installation.
1. The risk analysis for the entire installation is based on the risk analysis per main function as referred to in 3.1.3.
2. The risk analysis per main function may be performed as follows:
    - the simple method, which requires that none of the components of the main function may have a negative risk assessment after any actions have been performed;
    - the formal risk analysis, using the symbols specified in regulation 3.1.7. For this purpose, the risk assessment determined previously per component is added up in accordance with the rules provided.

Recording the results of the risk analysis.
The results of the risk analysis, the data used for this purpose and any measures taken are recorded in writing, stating the date, an indication of the tap water installation to which the risk analysis relates, as well as the name and capacity of the person who performed the risk analysis.

3.1.6 Risk factors and risk qualification to be applied in the risk analysis

In the risk analysis, the owner's starting point shall be the risk factors referred to in regulation 3.1.6.1 and the risk qualification referred to in regulation 3.1.7.

3.1.6.1 Risk factors

The risk analysis shall at least take the following risk factors that promote the multiplication of legionella bacteria in tap water systems into account:
- water temperatures between 25°C and 50°C;
- stagnant water;
- long residence time;
- biofilm and sediment.

The risk analysis shall at least take the following risk-limiting factors into account:
- water temperatures below 20°C;
- water temperatures between 20°C and 25°C, in so far as water is standing for no more than one week and there is good flow;
- water temperatures above 50°C;
- water temperatures above 60°C (at which bacteria die off);
- flow;
- short residence time.

In cases in which the risk analysis shows that there are favourable circumstances for legionella growth and the owner chooses to manage this risk by reheating the water or increasing the temperature of the pipe network on a weekly basis (thermal disinfection), the owner shall adhere to one of the following ratios between temperature and time:

Table 1 - Ratios between temperature and time

Temperature	Reheating time	Standing time for weekly thermal disinfection
60°C	10 minutes	20 minutes
65°C	1 minute	10 minutes
70°C	10 seconds	5 minutes

Installations shall be designed and operated in such a way that temperatures between 25°C and 45°C are avoided as far as possible, particularly in combination with large volumes of water, stagnant water or long residence times.
This means that:
- there must be no dead legs in either cold or hot water systems;
- sections of drinking water or domestic water installations or of non-flowing hot water draw-off pipes must be prevented from heating up to above 25°C;
- if alternative disinfection methods are used, the removal or killing factors shown for that method must be used in the risk analysis to the extent that control measures are implemented that guarantee that the method consistently has this level of effectiveness in practice.

Cold water pipes that are not used for longer than one week shall be flushed through on a weekly basis. When doing so, water shall be drawn off for up to 10 seconds after a stable temperature has been reached.

Hot water pipes that are not used for longer than one week shall be flushed through on a weekly basis. When doing so, water shall be drawn off for up to 10 seconds after a stable temperature has been reached

3.1.7 Risk qualification

In the risk qualification, the symbols + (legionella bacteria dying off), 0 (neutral) and - (growth of legionella bacteria) shall be used. A concentration of less than 100 cfu/l shall be used as the reference. The meaning of multiple minuses and pluses is given below.

Table 2 - Meaning of symbols for risk qualification

Symbol	Meaning
0	No growth
-	Risk of slight growth
--	Risk of moderate growth
---	Risk of extensive growth
+	Limited reduction
++	Moderate reduction
+++	Extensive reduction

If components or clusters of components are connected in series, the following calculation rules apply to the symbols:

1. If multiple components or clusters score minuses or zeroes, the total score is given for the lowest score in the series. The component with the most minuses determines the total score. Multiple components with a negative score are therefore not totalled.
2. If one or more components together have a negative score, this can be compensated for by one or more pluses. If components that are connected in series have pluses, the positive scores may be totalled.
3. A minus can only be compensated for by a plus downstream; pluses cannot be ‘saved’.
4. Every main function must meet the requirement for a zero score.

The risk qualifications for various combinations of risk factors are given below.

Table 3 - Risk qualification as a function of risk factors

Risk factors		Pipe volume > 1 litre
Temperature (°C)	Duration of temperature in component	Risk qualification (+ dying off; - growth)
< 20°C	unlimited	0
20 – 25	unlimited	0[1]
> 25 – 45	< 2 days	0[2]
> 25 – 45	> 2 days < 1 week	0[3]
> 25 – 45	> 1 week	---
> 45 – 50	unlimited	--
> 50 – 55	unlimited	0
> 55 – 60	> 1 hour	+
> 55 – 60	> 2 hours	++
> 55 – 60	> 3 hours	+++
> 60 – 65	> 3 min	+
> 60 – 65	> 5 min	++
> 60 – 65	> 10 min	+++
> 65 – 70	> 20 sec	+
> 65 – 70	> 40 sec	++
> 65 – 70	> 1 min	+++

Notes:

1. At temperatures between 20°C and 25°C in combination with standing times of longer than one week or poor flow, slow development of bacteria may occur up to a level above the detection limit.

2. In this temperature phase, the risk qualification '0' is only given in a situation in which the water is heated up to a temperature above 60°C after the two days in accordance with the standing time specified in table 2. If this requirement is not met, the period with temperatures between 25 and 45°C is longer and the risk qualification must be determined for the whole period.

3. In this temperature phase, the risk qualification '0' is only given in a situation in which the water is heated up to a temperature above 60°C after the seven days in accordance with the standing time specified in table 2. If this requirement is not met, the risk qualification will be '---'. In the case of weekly preventative thermal disinfection, there may occasionally be a situation in which legionella bacteria occur in concentrations above the detection limit. It does not necessarily follow that this will result in high concentrations, so these situations can be regarded as safe. The risk qualification for pipe volumes of less than 1 litre at all temperatures above 25°C is neutral (0) provided there is good flow.

4 Regulation for Legionella Prevention in low risk classed objects

The owners of the other 590.000 low risk classed objects are obliged to care for the quality of the supplied water. They have to deliver drinking water with a high quality. Legionella is one of the parameters.

The new manual "ISSO-publication 55.2" helps the owners of the low risk classed objects to check the collective drinking water system on the risk of Legionella.

5 ISSO-publication 55.2: "Legal responsibility for Legionella prevention in collective water systems"

The manual ISSO-publication 55.2 "Legal responsibility for Legionella prevention in collective water systems" address to managers (owners, consultants and installers) of collective water systems which are not covered by the Water Supply Decree. The aim of the manual is to consult them on a easy, open and surveyable way to ensure the availability of reliable water. This manual focuses on the aspect Legionella.

The owner of a collective water system, which is not covered by the Water Supply Decree, is solely responsible for to ensure the quality of the supply.

The manual propose the next options:

- Inventory of the tap points by a limited analysis. The aim is to assess or and at how much tap points with relevant quantities of inhalable aerosols may be released on use. This inventory can be done by the owner themselves and focuses on the tap points.
- Further there are three possibilities:
  - If there are no tap points with relevant quantities of inhalable aerosols, the analysis is finished.
  - If there are a few tap points with relevant quantities of inhalable aerosols it is possible to take measures on those tap points.
  - If there are a large number of points with relevant quantities of inhalable aerosols, a risk analysis must be performed for the whole collective water supply or collective pipework.
- The results of the risk analysis, the data used for this purpose and any measures taken are recorded in the control plan.

In a water system with a small amount of there are three different approaches:

- Divide the water system just after the flow-meter (segmentation)
- Disinfection on the taps
- Local disinfection in the supply to the aerosol producing tap points

6 References

ISSO Publication 55.1 "Legionella prevention in collective water systems", Rotterdam, February 2005

ISSO Publication 55.2 " Legal responsibility for Legionella prevention in collective water systems", Rotterdam, March 2005

7 Presentation of Author

Walter van der Schee is a representative of the Netherlands 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; organizing symposia; subcontracting research and co-financing university-chairs.
For further information see www.tvvl.nl.
Walter van der Schee is working at Wolter & Dros were he is responsible for the engineering of installations in buildings.

8 Annex

The Water Supply Decree

A summary with the most important rules of the Water Supply Decree follows below.

Article 1
Definitions:
- The owner: the owner of a water supply company and the owner of a collective water supply;
- Domestic water: tap water that is exclusively intended for flushing toilets, use in washing machines or watering the garden;
- Domestic water supply: a facility which draws or treats water that is made available to third parties in the form of domestic water by means of a pipeline or distribution network;
- Hot tap water: a heated water supply;
- The Act: the Water Supply Act
- Aerosols: water particles with a diameter of between 1 and 10 micrometres dispersed in the air;
- Legionella bacteria: bacteria belonging to the legionella family;

Tap outlet: the place where tap water is made available for use;

Article 4
1. The tap water that the owner makes available to third parties may contain no micro-organisms, parasites or substances in numbers per volume unit or concentrations which may have adverse consequences for public health.

Article 15
The owner of a water supply company shall monitor the residential installations, collective water supplies and collective pipe networks and other tap water installations

directly or indirectly connected to his company's pipe network for the risk of contamination of his company's pipe network.
The owner of a water supply company shall likewise monitor the collective water supplies and collective pipe networks directly or indirectly connected to his company's pipe network for the risk of contamination of the tap water made available to third parties.

Rules on the prevention of legionella in tap water

A small summary of the Rules on the prevention of legionella in tap water follows below.

§ 1 General provisions

Article 17j

1. Tap water that is made available or used at the tap outlets in such a way that aerosols as well as legionella bacteria carried by them, whether or not in conjunction with other micro-organisms, are released in quantities which, when inhaled, may have adverse effects on public health, must contain less than 100 colony-forming units of legionella bacteria per litre.
2. The owner of a collective water supply or a collective pipe network shall ensure that the tap water made available by him to third parties complies with the provisions of paragraph 1 at the point of delivery.

§ 2 Risk analysis and control plan for collective water supplies and collective pipe networks

Article 17k

2. The owner of a collective pipe network shall perform a risk analysis in respect of the risk of non-compliance with Article 17j, paragraph 1.
3. The risk analysis referred to in paragraph 1 or 2 shall be performed prior to the commissioning of the collective water supply or collective pipe network.
4. The risk analysis referred to in paragraph 1 or paragraph 2 shall be repeated no later than three months after every change to the collective water supply or collective pipe network or the use thereof that is relevant to the risk referred to in paragraph 1 or paragraph 2, or a change in factors that may influence that risk. The first sentence does not relate to changes applied on the basis of Article 17n, paragraph 1 or Article 17o, paragraph 1.
5. The owner of the collective water supply or the collective pipe network shall ensure that the results of the risk analysis performed on the basis of paragraph 1, 2 or 4, together with an overview of the data used in that analysis and the measures taken, are available for inspection by the supervisor at the location of the collective water supply or collective pipe network, and are sent to the supervisor at his request in a form specified by him.
6. If the supervisor is of the opinion that the risk analysis referred to in paragraph 1, 2 or 4 has been performed inaccurately or incompletely or otherwise does not comply with the regulations set out in Annex F, he may require the owner referred to in

paragraph 1 or paragraph 2 to amend, supplement or repeat the risk analysis within a specified period of time.

Article 17l

5. The control plan shall at least comprise the following parts:
   a. drawings or descriptions indicating the location and layout of the collective water supply or collective pipe network;
   b. details of the devices in the collective water supply or collective pipe network with which hot tap water is made available, pipes and other devices;
   c. details of the origin, nature and quality of the water used in the preparation of tap water, including hot tap water;
   d. the results of the risk analysis performed;
   e. the measures that have been or are being taken, the work instructions for the execution of the measures and the regulations applied to the operation, maintenance and monitoring of the collective water supply or the collective pipe network, to the extent that these relate to the management of the risks identified in the risk analysis, along with an indication of who has been charged by the owner with the execution of the measures, what powers exist in this regard and in what way and with what frequency the measures are executed;
   f. the tap outlets at which and the frequency with which the tap water is tested for the presence of legionella bacteria in accordance with Article 17q;
   g. in the case of a collective water supply or a collective pipe network in an institution as referred to in Article 17i, paragraph 1, under a. or b.: a description of the steps taken in order to avoid the risk of scalding by persons who on account of their physical or mental capacity are incapable or insufficiently capable of adjusting the temperature of the tap water used in bodily care or otherwise to a safe level;
   h. the measures taken if there are indications that Article 4, paragraph 7 or Article 17j, paragraph 1, are not being complied with.

Article 17m

1. If the owner of a collective water supply or collective pipe network is required to compile a control plan on the basis of Article 17l, he shall ensure that this control plan is available for inspection by the supervisor at the location of the collective water supply or collective pipe network. At the request of the supervisor, the control plan shall be sent to him in a form specified by him.
2. If the supervisor is of the opinion that the control plan referred to in Article 17l, paragraph 1 or 3, is inaccurate or incomplete or otherwise does not comply with the regulations set out in Article 17l, paragraph 5, he may compel the owner to amend, supplement or redraft the control plan within a specified period of time. Paragraph 1 shall apply *mutatis mutandis*.

Article 17n

1. The owner of a collective water supply or a collective pipe network shall carry out measures and monitoring in accordance with the control plan.
2. The owner referred to in paragraph 1 shall keep records of the measures, monitoring and tests carried out pursuant to this Section as well as the results thereof in a logbook. This information shall be kept for a period of three years.
3. The owner referred to in paragraph 1 shall ensure that the logbook is available for inspection by the supervisor at the location of the collective water supply or the collective pipe network or, with the agreement of the supervisor, at another place to be determined by him. At the request of the supervisor, the logbook shall be sent to him in a form specified by him.

§ 3. Monitoring, reporting and measures

Article 17o

1. In circumstances which the owner of the collective water supply or collective pipe network may reasonably know or suspect may endanger or hinder compliance with Article 4, paragraph 7, or Article 17j, paragraph 1, he shall immediately inform the supervisor thereof and as a precaution shall implement the measures and monitoring specified in the control plan in view of such circumstances or, to the extent that no such measures have been provided for in the control plan or if a control plan is not applicable, the measures and monitoring that he may reasonably be required to implement in such circumstances, unless the supervisor specifies otherwise. In this case, the consumers shall also be informed and advised immediately about the health protection measures they should take, unless the supervisor is of the opinion that the exceedance of the standard will not have adverse effects on the health and welfare of the consumers.
2. If the owner of the collective water supply or collective pipe network establishes that tap water does not comply with Article 17j, paragraph 1, as a result of a circumstance originating in a residential installation, collective water supply or collective pipe network connected to his pipe network, he shall immediately inform the owner thereof and shall advise him as to the remedial action to be undertaken. He shall also inform the supervisor immediately.

Article 17p

1. Sampling and analysis of samples in execution of this Section shall take place in accordance with NEN 6265 or an equivalent method.
2. An equivalent method as referred to in paragraph 1 may only be applied with the prior permission of the inspector. All information relevant to the assessment of the equivalence of the method referred to must be submitted to the inspector in the form specified by him along with the application.

Article 17q

The owner of a collective water supply or collective pipe network shall test the tap water for the presence of legionella bacteria at the tap outlets referred to in Article 17i, paragraph 4, as part of the execution of the risk analysis referred to in Article 17k, paragraph 1 or 2, and thereafter at least every six months. The number of measurement points to be included in this test shall be determined in accordance with table 4. The

supervisor may require the measurement frequency or the number of measurement points to be included in the test to be reduced or increased.

Total number of tap outlets in the collective water supply or collective pipe network	Associated number of measurement points to be tested
Up to 50	2
51-100	4
101-200	6
201-400	8
401-800	10
801-1600	12
More than 1600	14

Table4: Definition of the number of measurement points for testing tap water for the presence of legionella bacteria in accordance with Article 17q