# WATER DISTRIBUTION SYSTEMS FOR BUILDINGS

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## 1. INTRODUCTION

Due to rapid growth of population and its concentration in cities the vertical expansion of buildings is inevitable.The provision of water supply system in buildings with adequate flow and pressure at all floors is prevelant problem in developing countries. Depending upon the height, buildings are classified as multistorey (up to 25 metre)and high rise (beyond 25 metre).Water supply in buildings is done either by upfeed system when pressure in the public main is sufficient and supply is full time (24-hours) or down feed system when pressure in public main is inadequate and supply is intermittent.The down feed system is more common and most suitable for multistorey buildings. The water from public main is collected in the underground tank (suction tank) and pumped to roof tank and then distributed to branch pipes of different floors by down feed pipe. The typical details of down feed system is depicted in Figure-1

The design of water supply , system in building comprises of balacing the available head with various modes of head loss in the system ensuring that a minimum terminal pressure is available at critical outlet (fixture) with designed flow rate. Central Building Research Institute Roorkee carried out studies and recommended following points for design[1].

i) Flow rate of 15 mm diameter water outlet (tap) which is common fixture in residental buildings may be taken as 12.5 litres per minute.

ii) Residual pressure of 0.18 kg/cm2 is adequate to ensure flow of 12.5 lpm at the critical fixture. A critical fixture may be taken either as farthest or highest located fixture or the one which is likely to have the lowest terminal pressure.

## 2. DESIGN OF PIPE SIZES

The water from public main is fed to different appliances in buildings through a net work of pipes. For comfortable use of these appliances a certain minimum hydraulic pressure is required. The pressure may be obtained from public main or overhead tank as the case may be . An efficient design of pipe sizes for given situation should offer minimum required pressure at critical fixture during peak demand. There are different recommendations for design of pipe sizes which varies from country to country depending upon peak demand (based on simultaneous use of appliances) and residual pressure. A typical design procedure for down-feed system is described below :-

## 2.1 DESIGN OF DOWN-FEED SYSTEM

The local bye-law does not permit use of booster pump in the direct public main to feed over head tank for supply. A suction tank is therefore provided at the ground to store water from public main and the overhead tank is filled by pumping stored water. The storage capacity of suction tank and overhead tank is kept half day's water requirement which is 200 litres per captia per day for residential buildings. The various steps to design system are as under:-

i) Estimate the total fixture units (F.U) provided in the building as given in table-1 of I.S 12183 (part-I) 1987[2] " Fixture Unit" is value asigned to different sanitary appliances based on their use time and flow rate.

ii) Estimate the simultaneous flow (Fig. 1, IS-12183-1987)[2] .

iii) Minimum residual pressure of 0.18 $kg/cm^2$ (0.18 $N/mm^2$) at the critical outlet.

iv) Ascertain available pressure from over head tank to critical outlet.

v) Calculate developed length up to critical outlet. Developed length is summation of actual length of pipe and equivalent pipe length corresponding to fittings.

vi) Calculate permissible head loss per unit developed length.
permissible Head loss = Available Head - ( Residual Head ) / developed length.

Vii) Estimate the pipe diameter for calculated simultaneous flow rate and permissible head,using universal pipe friction diagram[3].

The same procedure is used for designing branch pipes. The minimum branch pipe diameter shall be kept 15 mm.

## 3. FALLACIES IN DESIGN

Although water supply systems are designed by following accepted norms and procedures and designer always endevour to ensure equitable pressure and flow at different floors. It is observed that lower floors enjoy high pressure and high flow rate and upper floors low pressures and low flow rate. Thus the water supply system fails to provide functional requirements with respect to availability of discharge and terminal pressure at different floors under dynamic and critical operation conditions. The verious reasons for mal functioning of the system are:-

i) Design of water supply system is usually made under static condition.

ii) loss of head through different pipe fittings is not available for Indian cinditions, other country codes are followed for calculation of head loss.

iii) Pipe size and fittings manufactured in India are 15 mm of diameter and hence it is necessary to adopt minimum 15mm diameter branch pipes although theoratically lesser diameter is sufficient to meet the designed flow rate and pressure requirement at lower floor levels.

iv) For estimation of pipe diameter, Hazen William's formula is used which has certain limitations.

v) Diameter of G.I pipes are expressed in terms of internal dimension, whereas the plastic pipes are expressed in their out side dimensions. Also there is wide variation in the equivalent diameter of GI pipe and plastic pipe, Which results in serious problems while designing pipe diameters.

**4. PRESSURE EQUALISATION METHODS**

For efficient performance of water supply system in multistorey building it is necessary to achieve pressure equalization at different floor levels. Some of the methods used are :-

i) Control of Pressure by adjusting opening of gate valves / stop valves provided on branch pipe. The system is effective but tempered by occupants to get higher flow rates. Also valves are costly, and head loss is quite high.

ii) Use of pressure reducing valves. These are suitable for high rise buildings.

iii) Separate feed pipes for different floors. The system is quite effective since top floors are not effected by withdrawl of water at lower floors. But involves extra pipe work and space, hence costly. Multiple pipes also spoils aesthetics of buildings.

iv) Use of reduced diameter feed pipe, this system proves effective but behaviour of system under peak demand condition is quite different and causes noise problem.

CBRI, Roorkee, conducted experiments on a 8-storeyed Mockup structure to achive presure equalization in water distribution system under dyanamic conditions and studies revealed[4] that :-

a) There is necessity of regulating (reducing) pressure at lower floors of multistoreyed buildings.

b) Insertion of pressure reducing orifice of 10 mm diameter in 15 mm branch pipe gave a flow rate of 12.0 liters per minute and terminal pressure of 0.25 kg/cm$^2$ at farthest located tap when all the three taps are running full open in ground floor of 8-story mockup having static head of 25 meter.

Further experiments were carried out to establish head loss through different diameter openings of orifice for different flow rate. Also an equation based on experimental data was found to determine orifice opening for desired flow rate and head loss. The studies concluded[2].

i) $Q = m\, d^2 \sqrt{H}$

Where Q = Flow in litres per minute.
d = Diameter of orifice opening in cm
H = Head available for loss through orifice or pressure orifice in metre
m = Dischage co-efficient, 11.56 for 4 mm thick alluminium plate orifice.

ii) Percentage head loss for differnt diameter ratios (Do/Dp) of orifice and branch pipe is 85 percent for 0.4 and 28 percent for 0.8 depicted in Figure-2.

**5. RATIONAL DESIGN.**

Based on experimental studies and trials on a 8-storeyed mockup structure at CBRI, Roorkee a design procedure for multistoreyed building is described below :-

1. Calculate total number of appliances in the building say 'n'
2. Consider flow rate of 12.5 liters per minute for each appliance.
3. Simultaneous peak demand will be $Q = 12.5 \sqrt{n}$ lpm
4. Consider terminal pressure of 0.18 kg/cm$^2$ at critical tap.
5. Calculate developed length (l) = (actual pipe length + equivalent pipe length for fittings considered on network).
6. Calculate head availabel for friction loss.

   Head available for = Totoal head - Terminal pressure
   friction loss (h)
7. Calculate permissible head loss per unit length of pipe

   $f = h / l$
8. Determine pipe diameter for flow rate (Q) and permissible head loss (f) (Refer universal pipe flow diagram)

Design all branches, using same procedure. Since minimum pipe diameter is 15 mm and pressure available at lower floors is high and small diameter could meet the required flow rate. It is recommended to calculate orifice diameter using orifice equation.

$$Q = m\, d^2 \sqrt{H} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where Q = Flow rate in liters per minute.
m = Coefficient of discahrge.
d = Diameter of orifice opening in cm.
H = Head available for loss through orifice or Pressure drop at orifice in metre.

Now
a) Determine simultaneous flow rate branch pipe (Q)
b) Calculate head available for loss through orifice (H)
H = Total head available at branch - (terminal pressure + head loss through branch pipe and fittings ).
C) Consider m = 11.56 for 4 mm thick alluminium orifice plate.

Putting above values in equation (1) unknown diameter (d) of orifice opening could be worked out.

## 6. CONCLUSIONS.

i) The insertion of orifice of required opening at lower floors equalises flow rate and pressure at all floors of multistoreyed building

ii) There is necessity of studying head loss through GI pipes and fittings to determine accurate equivalent pipe length.

iii) The recommended design procedure shall be installed in multistoreyed buidlings for performance studies under operating conditions.

## 7. ACKNOWLEDGEMENT.

The author is thankful to the Director, Central Building Research Institute, Roorkee (U.P.) India for permitting to present paper in the Seminar on Building Water Supply and Drainage organsied by CIB-W62 at Lostorf, Switzerland.

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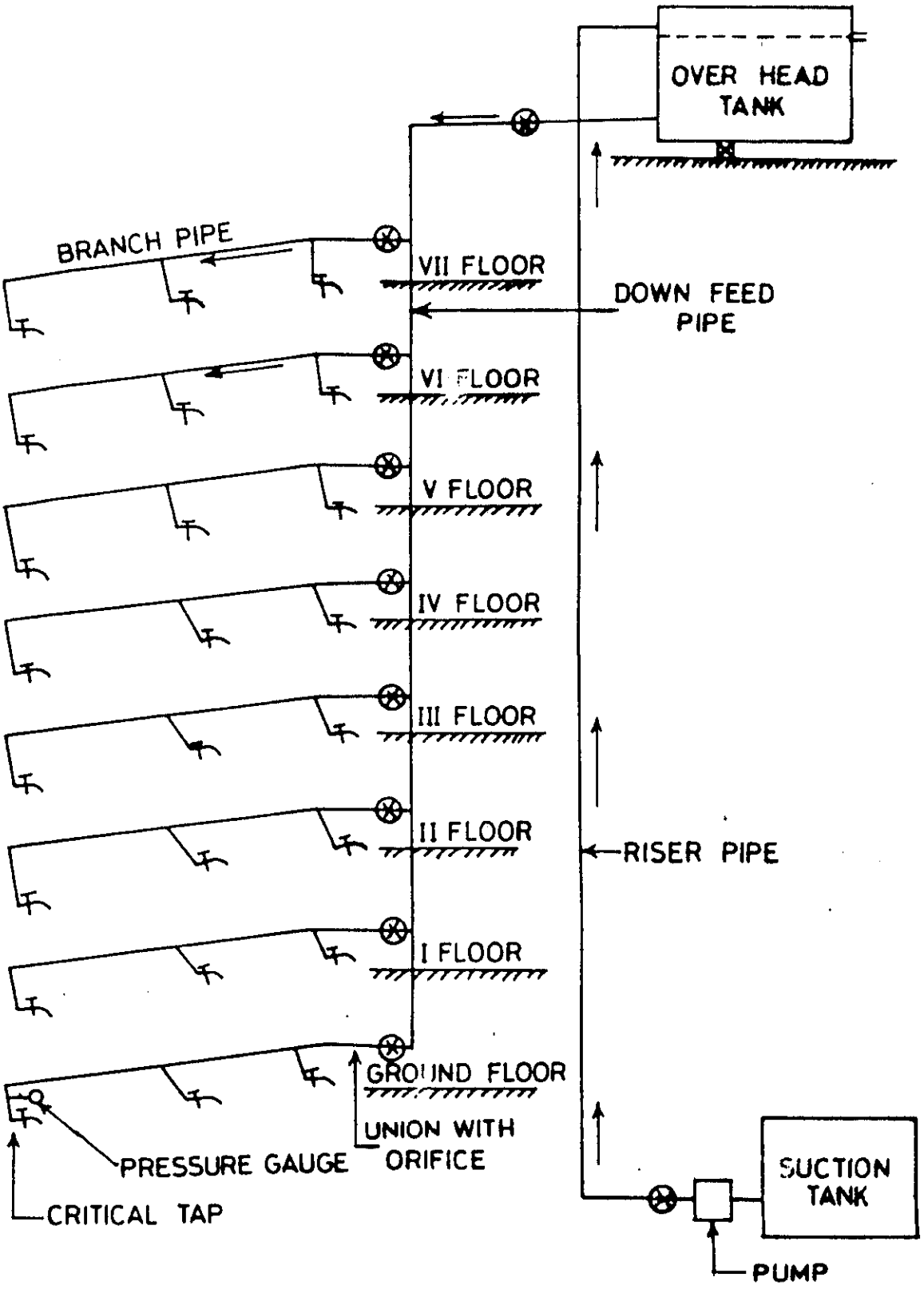



FIG. 1 WATER DISTRIBUTION SYSTEM AT THE EXPERIMENTAL 8 STORYED MOCK UP

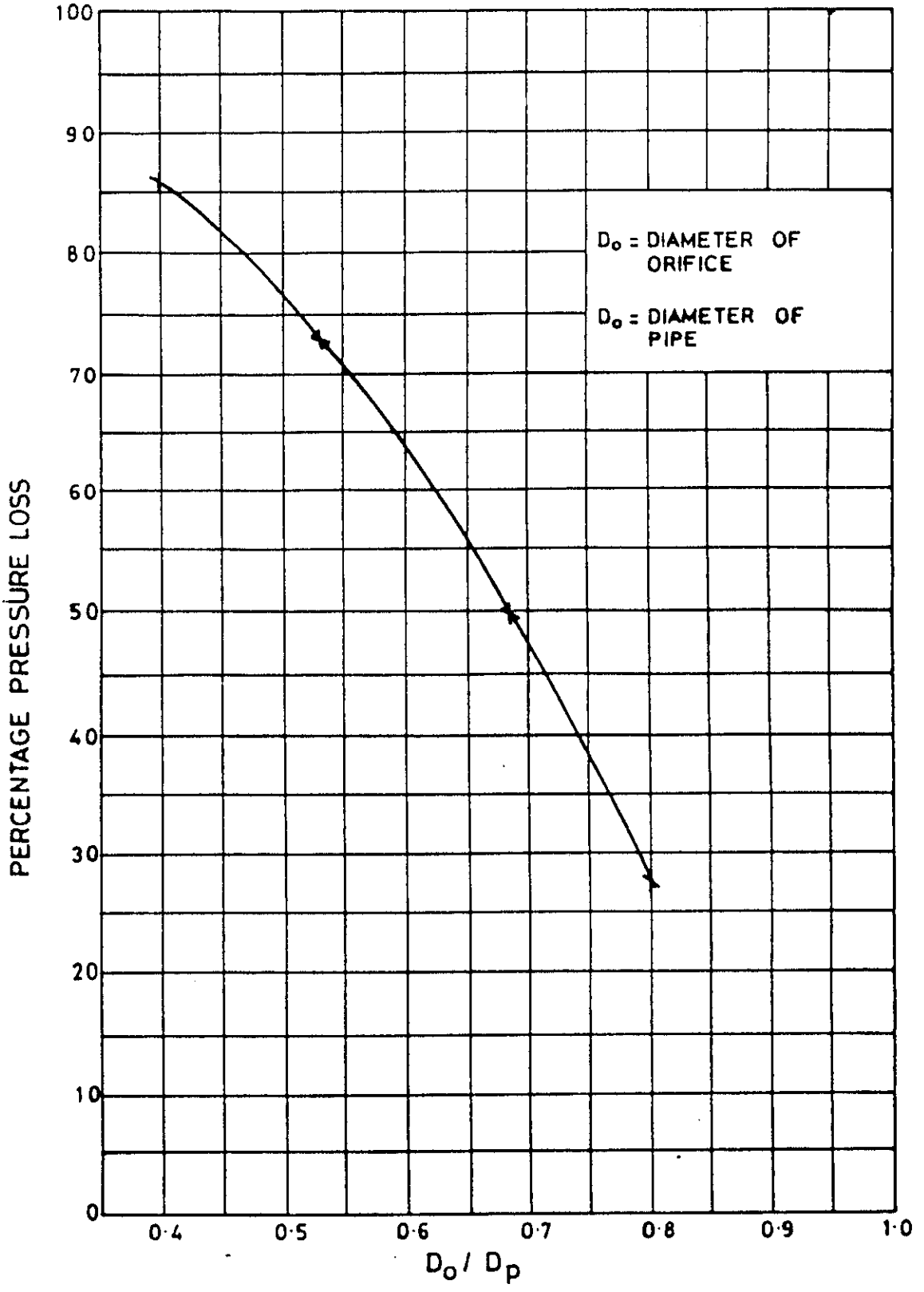



FIG 2 PERCENTAGE PRESSURE LOSS FOR DIFFERENT $D_o / D_p$ RATIO

# Topic A2

## Hot Water Installations: Health Risks associated with the use of Expansion Vessels

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# Hot water installations: potential health risks associated with expansion vessels

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## Executive summary

This report has been prepared by the Public Health Engineering Section of the Building Research Establishment for the Department of the Environment and was managed by the Drinking Water Inspectorate.

The work required the microbiological examination of expansion vessels installed in unvented (closed) hot water storage systems to assess the potential health risks associated with their use. The contents of 35 expansion vessels, of known service lives, were analysed, along with their associated hot and cold water services, including a risk assessment. In addition, water was sampled on a regular basis from four expansion vessels over a three month monitoring programme.

Regulatory authorities, water suppliers, test houses, and equipment manufacturers (targeting those with a specific interest in this field) were surveyed to establish current practice throughout the world. This revealed different approaches to the use and application of expansion vessels, including prohibition in some countries.

The analysis of the expansion vessels revealed one installation in which the vessel contained legionella bacteria. Thirty of the 35 expansion vessels examined had positive bacteria counts. The presence of a biofilm in the majority of expansion vessels is contrary to clause 3.2 (b) of British Standard BS 6144:1990: Expansion vessels using an internal diaphragm for unvented hot water supply systems, which states that materials used in the construction of expansion vessels that are in contact with water should 'not support microbial growth'.

/continued

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# CIB W62 Paper

## Hot water installations: potential health risks associated with expansion vessels

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Consideration is given to the choice of materials used in expansion vessels and their ability to support a biofilm. British Standard BS 6920: Suitability of non-metallic products for use in contact with water intended for human consumption with regard to their effect on the quality of water: Section 2.4 contains a test for determining whether there is microbiological growth. The Water Fittings Byelaws Scheme* approval is given subject to membrane proving satisfactory when tested in accordance with the appropriate parts of this British Standard. Thus, approved expansion vessels have been shown to support microbial growth.

The gas charges of 17% of the expansion vessels examined were found to be depleted. A depleted gas charge allows a quiescent zone where water can stagnate.

All the expansion vessels examined had a single connection to the unvented hot water storage system, ie the connection acts as the inlet and the outlet. Alternative types of expansion vessels are available. One alternative is a modification of the single connection expansion vessel which has integral inlet and outlet flow-ways, allowing water to flow through the expansion vessel each time water is drawn from the system. A second alternative is a 'flow-through' expansion vessel, with separate inlet and outlet connections, this device allows an exchange of water contained in the vessel each time water is drawn from the system. These alternative types of expansion vessels do not allow a quiescent zone to occur even under fault conditions, ie depletion of gas charge, so there is less likelihood of stagnation.

Overall, in specific applications the use of expansion vessels could present a health risk, primarily through the presence of bacteria. Risk situations may include healthcare facilities, such as hospitals and nursing homes, where occupants may be immuno-compromised. Guidance is given in this report on the installation and maintenance of expansion vessels for use with drinking water systems to reduce this risk.

*Note: The Water Fittings and Materials Directory is published by the Water Research Centre contains the Water Byelaws Scheme list of approved fittings and materials. The Directory is consulted by UK Water Byelaw inspectors of the water industry to enable compliance with the Water Byelaws to be ascertained. It also contains a list of substances, products, and processes for use in connection with the supply of water for drinking, washing, cooking, or food production purposes and is published by the Department of the Environment's Drinking Water Inspectorate in the UK.

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# Hot water installations: potential health risks associated with expansion vessels

By M Shouler BSc MSc and J Hall BEng PhD

## 1 Introduction

This project was undertaken for the Department of the Environment in order to carry out an investigation of the potential for expansion vessels, installed with unvented hot water storage systems, to support and encourage the growth of bacteria, including legionella. In order to assess the potential health risks associated with the use of expansion vessels a microbiological examination of their contents and the water in contact with them was made. Thirty-five expansion vessels, of pre-selected ages, were removed from unvented hot water installations to enable their contents to be examined. Four expansion vessel installations were monitored for a period of three months to assess the changes in the levels of bacteria, if present, in the vessel. This involved sampling water from the expansion vessel, at two-weekly intervals. The hot and cold water supplies at each of the removal and monitoring installations were analysed to examine the levels of bacteria in the water delivered at the taps. A risk assessment of each system was carried out.

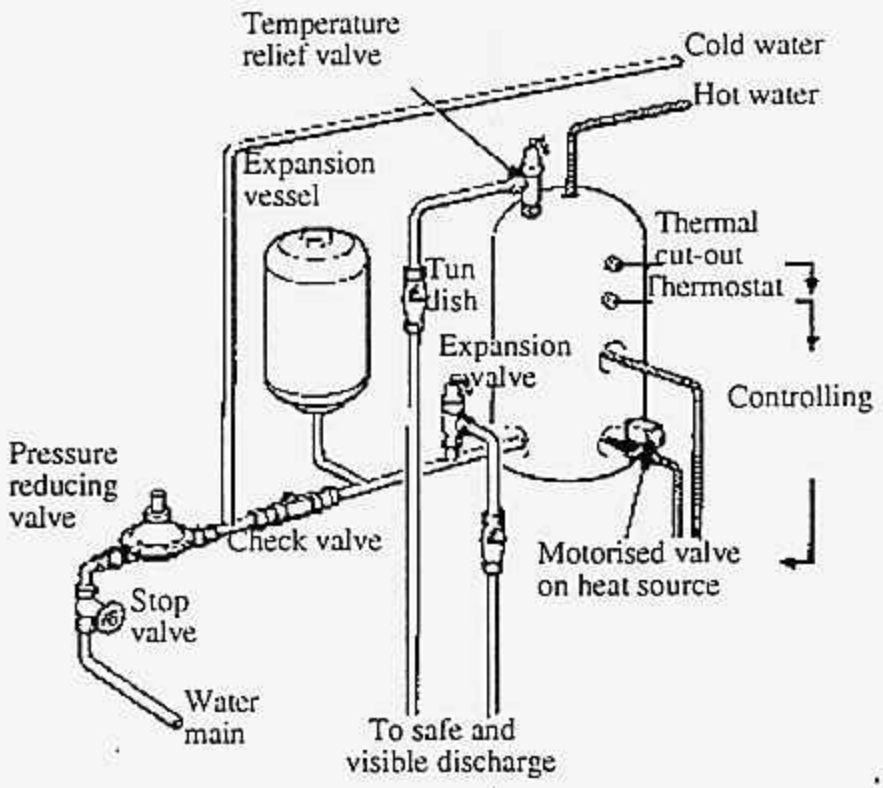
In order to establish best current practice, a literature survey and a worldwide survey of the use and experiences in other countries were carried out to establish any known health risks associated with expansion vessels.

## 2 Expansion vessels

When water is heated in an unvented (closed) hot water storage system the stored water undergoes thermal expansion. If a check valve is fitted in the cold feed to the system and expansion is not accommodated elsewhere, then the water pressure will increase with the possibility of a failure of the cylinder or associated pipework by splitting. To prevent the waste of the water that has expanded during heating in an unvented hot water storage system, the Water Byelaws[1] (Byelaws 90 and 91) require that either provision be made for: the accommodation of expanded water within the water heater apparatus or cylinder itself (eg 'bubble top system'), the accommodation of water in a separate expansion cistern or vessel (see figure 1), or the accommodation of water in the cold feed supplying

the system. When installed, the expansion vessel is sized to have a capacity of 4% of the volume of the unvented hot water storage system it serves. BS 6144[2] specifies the requirements for the manufacture and testing of expansion vessels for use with unvented hot water storage systems. Clause 3.2 of this British Standard requires that all material used in the construction of the expansion vessels should 'not support microbial growth'. The Water Byelaws (Byelaw 7) requires that 'No material or substance which causes, or is likely to cause, contamination of water shall be used in the construction or installation of any pipe or water fitting which conveys or receives water supplied for domestic purposes.'. The requirements for testing non-metallic materials, such as expansion vessel membranes, are specified in BS 6920[3].

Figure 1 - Expansion vessel in an unvented hot water storage system (diagrammatic and not to scale)




## 3 Site procedures

The expansion vessels examined were selected from a database of unvented hot water storage systems compiled at BRE since 1987. The choice of installations for the study was determined by Drinking Water Inspectorate's requirement that they conform to a selected age in service and the type

of building the unvented hot water system served, eg healthcare facility or domestic. At each installation a risk assessment of the water system was undertaken to assign a level of health hazard.

Table 1 - Service age of expansion vessels

| Service age of expansion vessel | Number examined* | Number specified by DWI |
|---|---|---|
| between one and two years | 8 | 4 vessels |
| between two and three years | 8 (1) | 4 vessels |
| between three and four years | 9 (3) | 6 vessels |
| over four years | 10 | 10 vessels |

**Numbers in parentheses indicate the age group of the four monitoring installations*

### 3.1 Hot and cold water sampling

The procedure adopted for all sampling, except for the four monitoring sites, was to collect water samples taken from the hot and cold water taps and the expansion vessels. The samples from the taps were taken after allowing the water to flow for two minutes, noting the minimum and maximum water temperatures. In general, the cold water was sampled from the main water supply, eg kitchen tap, and the hot water was sampled from an outlet near the water heater. A chemical analysis of the cold water was undertaken to indicate the 'hardness' of the water supply.

### 3.2 Expansion vessel removal

A total of thirty-five expansion vessels were removed for analysis (this included the four long-term monitoring installations). At each installation the procedure for removing the expansion vessel and replacing with a new vessel, as described in appendix I, was followed. The procedure allowed a quantity of water from the system to be included in the expansion vessel which was necessary for the analysis. The vessels were transported, at ambient temperature, to the laboratory for microbiological analysis within twenty-four hours of removal.

### 3.3 Monitoring of the four expansion vessel installations

An assessment was required of the changes of the microbial parameters at four long-term monitoring sites. The locations selected were two private dwellings, a hospital, and a school:

Site A School,

Site B Private dwelling,

Site C Private dwelling, and

Site D Hospital.

To enable samples to be taken, a sampling valve was installed near the expansion vessel. Water samples were taken at two weekly intervals for a period of three months, see appendix I, giving a total of seven samples for each location. At the end of the sampling period the expansion vessels were removed and transported, at ambient temperature, to the laboratory, within twenty-four hours of removal, for analysis.

## 4 Microbiological assessment technique

The samples from the hot and cold water supplies (section 3.1) and the expansion vessels (section 3.2 and 3.3) were analysed for:

- total colony counts at 22°C and 37°C,
- total coliforms at 37°C,
- E coli,
- pseudomonads,
- aeromonads, and
- legionella.

Appendix II gives the procedure used to obtain water/biofilm samples from the expansion vessels and details of the analyses undertaken and appendix III is a record of the results.

## 5 Survey of the use of expansion vessels in other countries

Information was sought on the use of expansion vessels throughout the world by contacting regulatory authorities, water suppliers, test houses, and equipment manufacturers. A questionnaire (see appendix IV) was sent to identified experts. In summary, some countries, (Australia, Holland, Ireland, Finland, and Denmark), do not use expansion vessels with hot water storage systems and about half those responding were aware that there were health risks associated with expansion vessels. In Germany a new specification for expansion vessels is in preparation, draft DIN 4807

(NHRS 1.46 UA 5 N 30) which requires that materials in contact with the drinking water shall comply with DVGW specification W 270 (Microbiological growth on materials intended for use in drinking water systems).

## 6 Microbiological results

Appendix III gives the results of the microbiological analysis of the 35 expansion vessels, including the monitoring sites. In addition, hot and cold water sample analyses are shown. In comparison, the UK Water Supply (Water Quality) Regulations[4] require that water supplied to a premise should not exceed the values shown in table 2.

Table 2 - Maximum allowable concentration of microbial parameters

| Parameter | Units of measurement | Maximum allowable concentration |
|---|---|---|
| Total coliforms | number/100 ml | 0* |
| Faecal coliforms | number/100 ml | 0 |
| Colony counts | number/1 ml at 22°C or 37°C | No significant increase over that normally observed |

** subject to criteria 3(6) of the Water Supply (Water Quality) Regulations, ie*
*95% of the samples taken during the preceding year establish the absence of such coliforms, or*
*if less than 50 samples have been taken, the last 50 samples taken establish the absence of such coliforms*

At seven installations only the contents of the expansion vessel were analysed. These were additional to the requirement of the specified programme The hot and cold water samples at these installations were not analysed. These are shown in Table 4c.

The bacteria and the legionella counts are discussed in sections 6.1 and 6.2.

### 6.1 Total bacteria count

In the present study 30 of the 35 of the expansion vessels examined contained a higher bacteria counts than the incoming cold water supply, although bacteria counts from the biofilm/water content of the expansion vessel cannot be directly compared with water bacteria counts. A visual inspection of the expansion vessels by the microbiological laboratory indicated that most of the membranes within the expansion vessels supported a biofilm and contained discoloured water, although there was no correlation between the discoloration of a sample and its bacteria count.

The four monitoring installations exhibited a large variation in bacteria counts over the three month period of monitoring. Figures 2a to 2d show the variation of the total bacteria counts, in colony forming units (cfu) per ml, cultured for 24 hours at 37°C, and 72 hours at 22°C for the four sites. Site D, the hospital, had a consistently higher total bacteria count than the other monitoring installations. The total bacteria counts at the four monitoring installations varied with maxima as recorded in table 3.

Figure 2a - Total bacteria count 24hr/37°C and 72hr/22°C for monitoring installation A

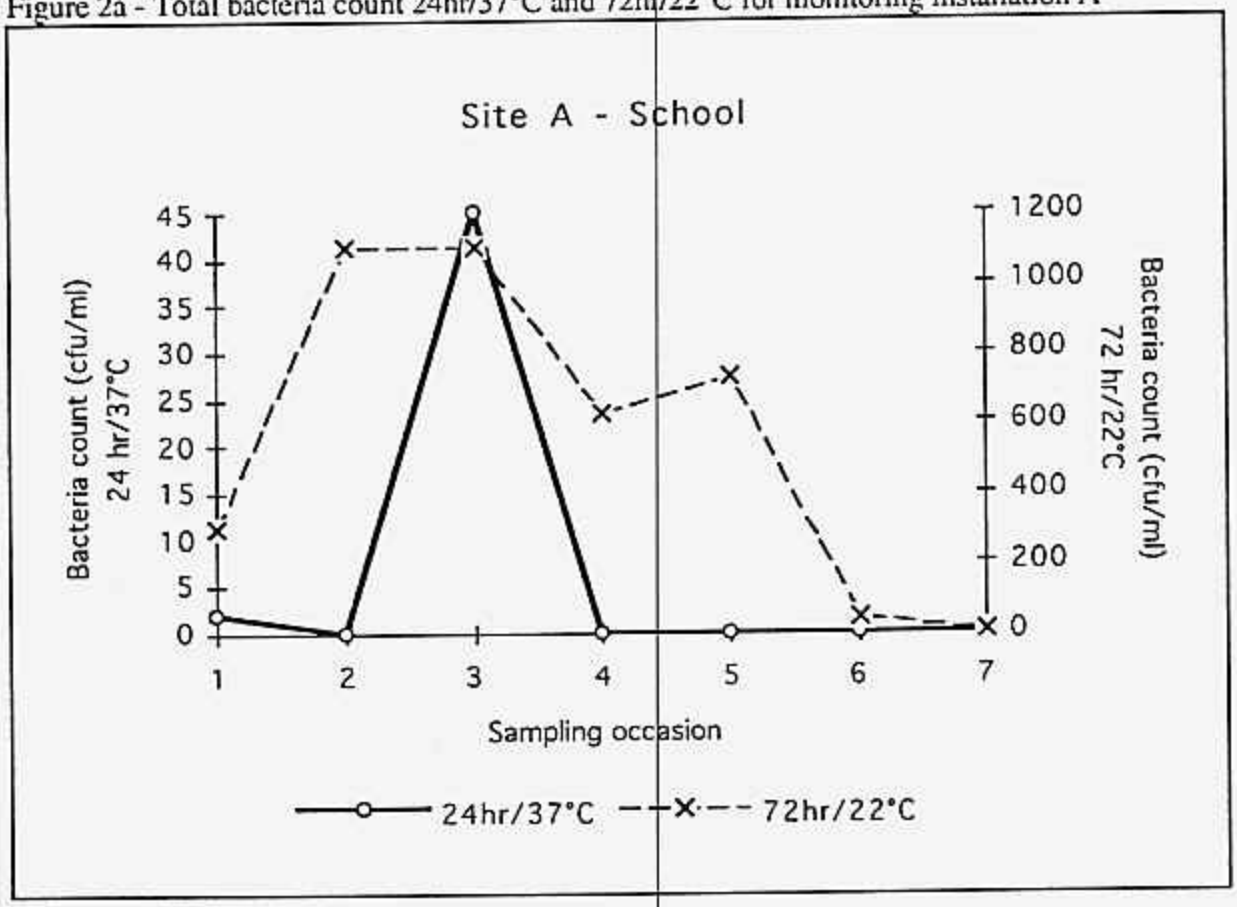


Figure 2b - Total bacteria count 24hr/37°C and 72hr/22°C for monitoring installation B

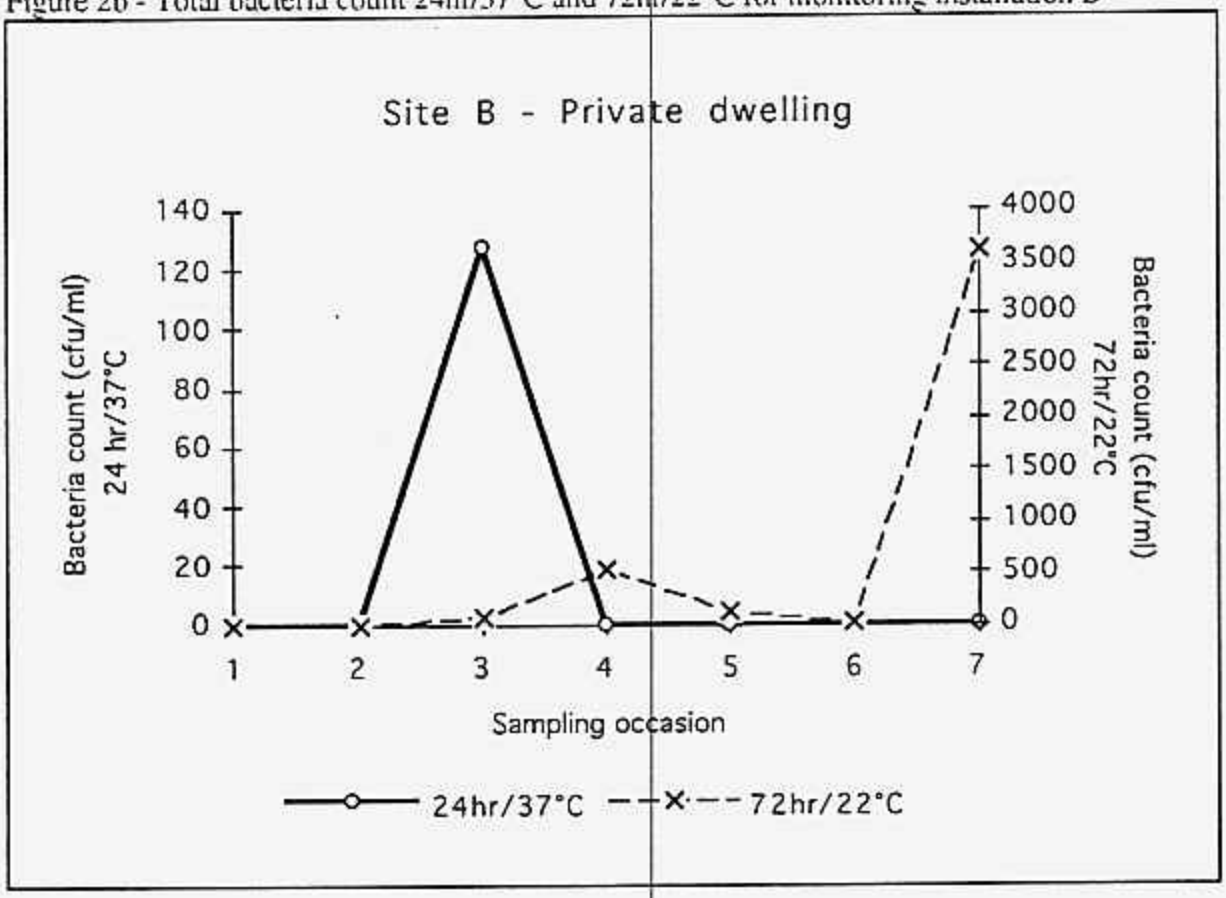



Figure 2c - Total bacteria count 24hr/37°C and 72hr/22°C for monitoring installation C

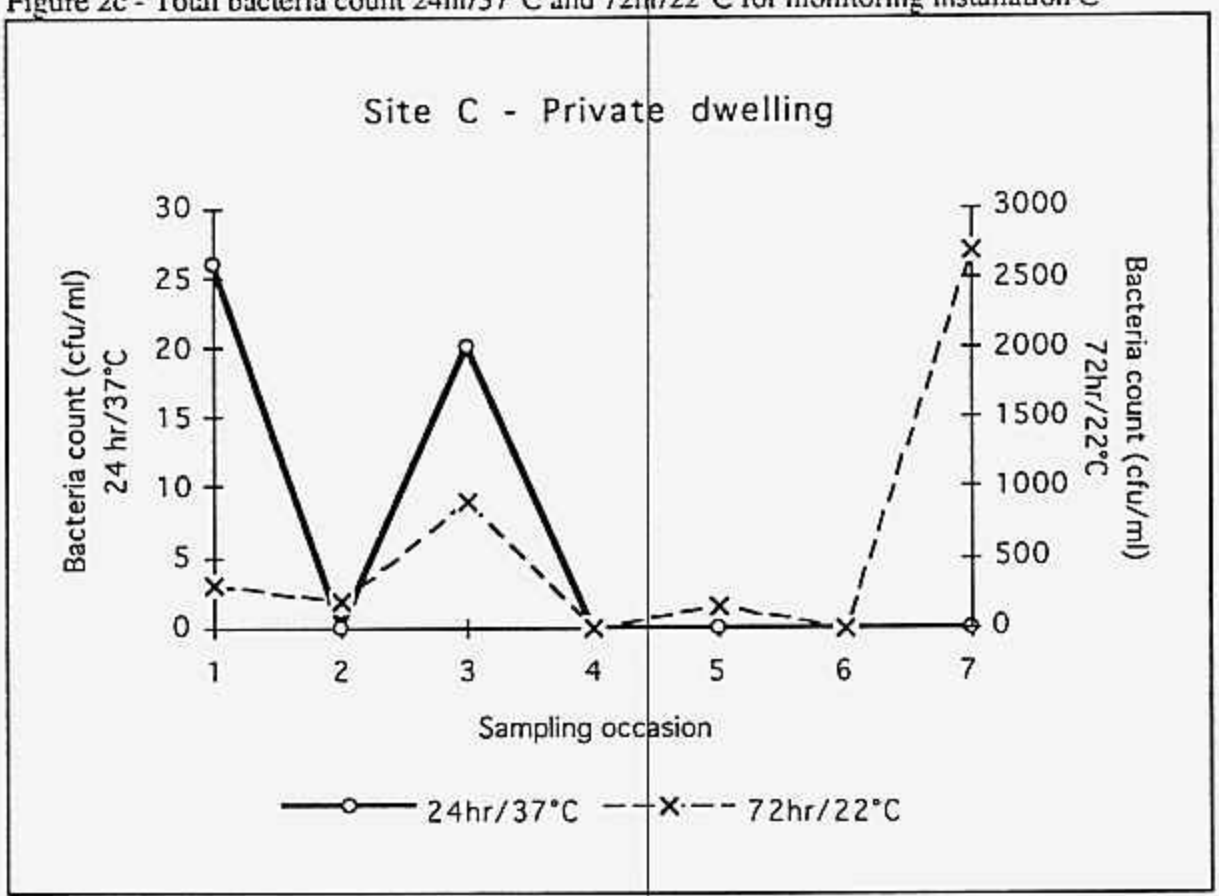


Figure 2d - Total bacteria count 24hr/37°C and 72hr/22°C for monitoring installation D

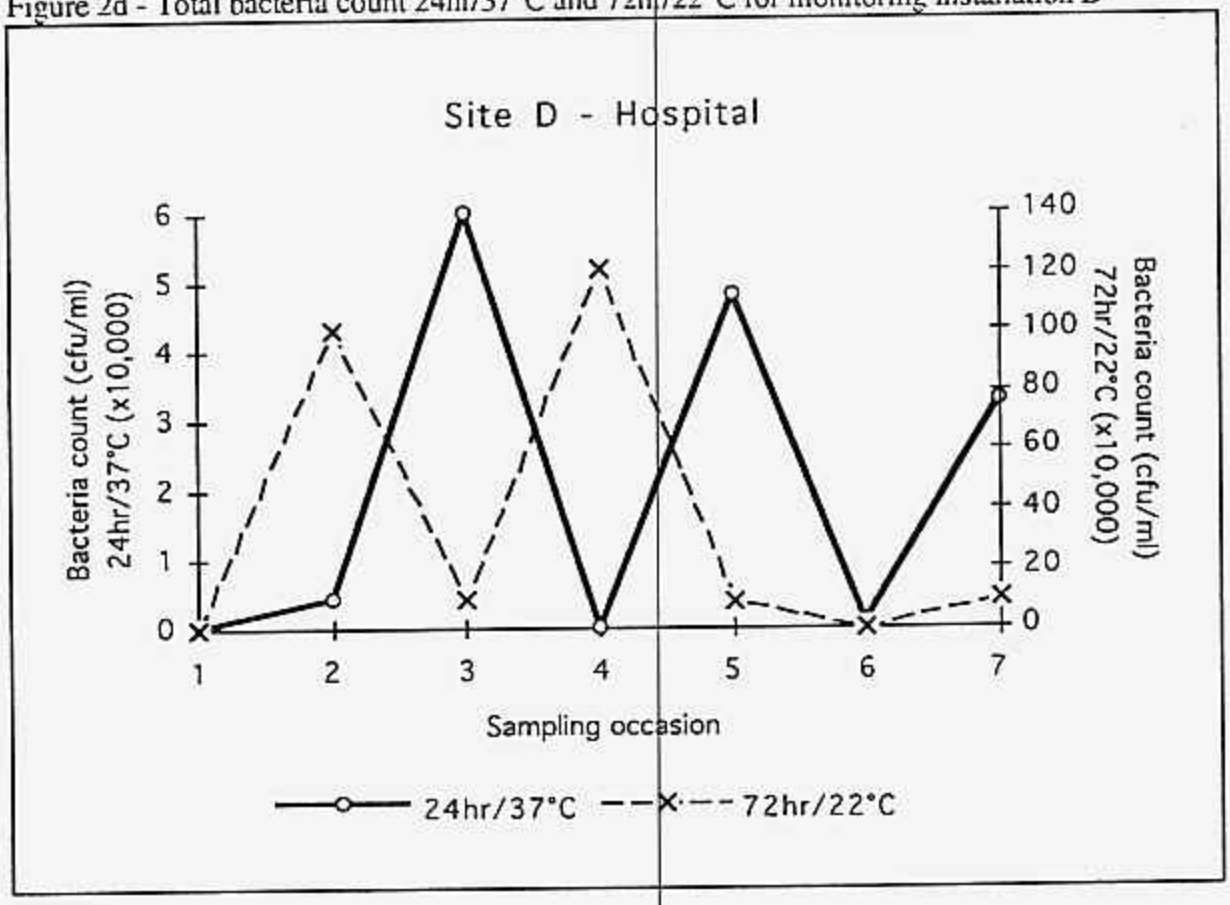



Table 3 - Maximum total bacteria count at long-term monitoring sites

| Installation | 24hr at 37°C (cfu/ml) | 72hr at 22°C (cfu/ml) |
|---|---|---|
| Site A | 45 | 1,100 |
| Site B | 127 | 3,600 |
| Site C | 26 | 2,700 |
| Site D | 60,000 | 1,210,000 |

*cfu: colony forming units*

### 6.2 Legionella

One expansion vessel contained legionella. A count greater than 25,000 colony forming units per litre of L. pneumophila serogroup 8 was determined. The system, with a replacement expansion vessel in place, was sampled at the hot and cold water taps after a period two weeks. The subsequent analyses did not detect legionella. Water from the replacement expansion vessel was not sampled due to the short period of use.

## 7 Risk assessment summary

To assist in the understanding and interpretation of the results of the microbiological survey, a risk assessment was carried out for each of the 35 installations. The risk assessment was based on the Guide to Risk Assessment[5] and examined the following:

a) Quality of the cold water feeding the water supply system

i) water temperatures,

ii) contamination that may lead to micro-organism proliferation,

iii) stagnation of stored or distributed water,

iv) materials and fittings meeting the requirements of the Water Byelaws. This was assessed by reference to The Water Fittings and Materials Directory[6]*, and

v) monitoring of water conditions, eg tanks.

b) Hot water system

i) hot water temperatures within the water system,

ii) any temperatures that fall within the range 20 - 50°C,

iii) potential to collect pockets of sludge within calorifiers, eg unvented hot water storage systems,

iv) any site programmes for cleaning and/or disinfection,

v) stagnation within the unvented hot water storage systems, and

vi) other associated factors, such as vulnerable users who may inhale bacteria whilst showering.

*Note: The Water Fittings and Materials Directory is published by the Water Research Centre. It has the Water Byelaws Scheme list which is consulted by UK Water Byelaw inspectors of the water industry to enable compliance with the Water Byelaws to be ascertained. It also contains a list of substances, products, and processes for use in connection with the supply of water for drinking, washing, cooking, or food production purposes and is published by the Department of the Environment's Drinking Water Inspectorate in the UK.

The condition of unvented hot water storage systems and the charges in the expansion vessels were investigated on site. Tables 4a, 4b, and 4c give a summary of the assessed risk assessment (RA)

based on all the above criteria. The levels of hazard 0, 1, 2, and 3 relate to the possibility of the water system harbouring and transmitting bacteria to the occupants of the building. The definitions of hazard used for this work are based on UK's COSHH Regulations[7] and defined as:

Hazard level 0: risk insignificant now - no reasonably foreseeable increase in the future.

Hazard level 1: identified risks are present, they are controlled but could foreseeably increase in the future.

Hazard level 2: risks are known, if control measures are not implemented the risk will increase in the future unless control measures are implemented, maintained, and reviewed.

Hazard level 3: uncertain about the risks, insufficient information, uncertain about degree and extent of exposure, additional information and monitoring required.

In general, the water systems in the dwellings were assessed as having lower assessed hazard levels than the other building types, although no correlation was identified between the assessed hazard levels and the high bacteria counts. High bacteria counts at a particular installation could not be attributed to a single installation condition (eg age of expansion vessel) or set of conditions. The installation with the expansion vessel in which L. pneumophila serogroup 8 was detected had no features that indicated that it would be more liable to contain the bacteria than the other installations examined.

Table 4a - Summary of risk assessment - expansion vessel long-term monitoring installations

| Ref No | Use of building | Cyl | EV age yrs | Dir/ Ind | Insul | Water S/M/H | Stag. | Water temp. ℃ | | EV Charge | Hi TVC | Haz |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Cold | Hot | | | |
| A | School | G/S | 2-3 | Dir | N | H | P | 13 | 45 | Y | Y | 2 |
| B | Dwelling | Cu | 3-4 | Ind | Y | S | N | 6 | 58 | Y | N | 0 |
| C | Dwelling | Cu | 3-4 | Ind | N | M | N | 10 | 76 | Y | N | 0 |
| D | Hospital | G/S | 3-4 | Dir* | Y | S | Y | 14 | 70 | Y | Y | 3 |

Table 4b - Summary of risk assessment - expansion vessel replacement installations

| Ref No | Use of building | Cyl | EV age yrs | Dir/ Ind | Insul | Water S/M/H | Stag. | Water temp. ℃ | | EV Charge | Hi TVC | Haz |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Cold | Hot | | | |
| 1 | Uni accom | Cu | 1-2 | Ind | N | S | P | 13 | 44 | X | Y | 2 |
| 2 | Uni accom | Cu | 1-2 | Ind* | Y | S | P | 9 | 66 | Y | Y | 1 |
| 3 | Hospital | G/S | 1-2 | Dir | Y | S | N | 13 | 53 | Y | Y | 1 |
| 4 | Dwelling | | 2-3 | Ind | Y | S | N | 11 | 58 | Y | Y | 0 |
| 5 | Restaurant | G/S | 2-3 | Dir* | N | H | N | 9 | 63 | Y | Y | 2 |
| 6 | Commercial | S | 2-3 | Ind* | N | H | P | 10 | 62 | Y | Y | 1 |
| 7 | Golf club | G/S | 2-3 | Dir | Y | H | N | 10 | 53 | X | Y | 2 |
| 8 | Commercial | G/S | 1-2 | Dir | Y | S | P | 9 | 45 | Y | NIL | 1 |
| 9 | Uni accom | Cu | 2-3 | Ind | Y | S | P | 9 | 69 | Y | Y | 1 |
| 10 | Uni accom | S | 2-3 | Ind* | Y | S | P | 10 | 70 | Y | N | 1 |
| 11 | Dwelling | S | 3-4 | Ind* | N | M | N | 10 | 65 | Y | Y | 0 |
| 12 | Dwelling | S | 7+ | Ind* | N | S | N | 8 | 68 | Y | N | 0 |
| 13 | Dwelling | Cu | 9+ | Ind* | Y | S | N | 9 | 72 | X | N | 0 |
| 14 | Nursing hm | G/S | 1-2 | Dir* | Y | M | N | 10 | 42 | Y | NIL | 1 |
| 15 | School | G/S | 3-4 | Dir | Y | S | P | 8 | 48 | Y | Y | 1 |
| 16 | Commercial | Cu | 1-2 | Ind | N | M | Y | 11 | 18 | Y | Y | 2 |
| 17 | Hospital | G/S | 1-2 | Dir | Y | S | P | 14 | 59 | Y | Y | 1 |
| 18 | Commercial | Cu | 4-5 | Ind | N | S | P | 8 | 52 | Y | N | 2 |
| 19 | Dwelling | Cu | 6-7 | Ind | N | S | N | 9 | 55 | Y | N | 0 |
| 20 | Dwelling | Cu | 3-4 | Ind | N | S | N | 10 | 61 | Y | N | 0 |
| 21 | Dwelling | Cu | 4-5 | Ind | N | S | N | 9 | 60 | X | N | 0 |
| 22 | Comm. ctre | G/S† | 4-5 | Dir | Y | S | N | 8 | 67 | Y | NIL | 2 |
| 23 | Commercial | S | 6+ | Ind* | N | S | Y | 12 | 12 | Y | Y | 2 |
| 24 | Hospital | G/S | 3-4 | Dir | Y | S | N | 12 | 52 | X | Y | 0 |

Table 4c - Summary of risk assessment - installations additional to the requirement of the programme

| Ref No | Use of building | Cyl | EV age yrs | Dir/ Ind | Insul | Water S/M/H | Stag. | Water temp. ℃ | | EV Charge | Hi TVC | Haz |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Cold | Hot | | | |
| i | Dwelling | Cu | 3-4 | Ind | N | M | N | 10 | 65 | Y | Y | 0 |
| ii | Dwelling | Cu | 2-3 | Ind | N | M | N | 12 | 73 | Y | N | 1 |
| iii | Dwelling | Cu | 2-3 | Dir | N | M | P | 9 | 76 | X | Y | 1 |
| iv | Medical ctr | Cu | 2-3 | Ind | Y | M | N | 11 | 62 | Y | NIL | 0 |
| v | Nursing hm | G/S | 1-2 | Dir* | N | S | N | 10 | 66 | Y | N | 0 |
| vi | Nursing hm | G/S | 1-2 | Dir* | Y | S | N | 11 | 69 | Y | Y | 0 |
| vii | Shop | Cu | 1-2 | Dir* | N | S | Y | 9 | 62 | Y | Y | 2 |

Key: Cylinder: Cu - copper, S - steel, G/S - glass lined steel,
† - non-Water Byelaws Scheme (WBS) listed materials
Dir/Ind: Direct fired/indirect fired, *possible heat transfer to expansion vessel
Insul: Insulation on pipework adjacent to expansion vessel
Water S/M/H: Water hardness: S < 100 < M < 200 < H ppm.
Stag: Stagnation of water in system P: possibility, N: no.
EV charge: X - low expansion vessel charge pressure, Y - pressure correct
Hi TVC: High total viable bacteria count Y: yes, N: no
Haz: Hazard level 0 - 3

8 Water services

Traditionally, in the UK, domestic hot water has been supplied from a water cistern positioned in the roof space of a house and a vent pipe from the hot water cylinder terminates over the cistern and is open to atmospheric pressure: these systems are known as 'vented' systems. Therefore, the system produces a low pressure (the pressure available is created by the height of the cistern above the outlets) at the cylinder which is generally constructed from copper. The water can be either heated directly (eg by an immersion heater) or indirectly (eg by a primary coil from a boiler).

Since 1985 Building Regulations[8] in England and Wales have controlled the installation, with regard to over-temperature, of unvented hot water storage systems and since 1987 UK Water Byelaws have allowed the connection of mains fed systems of all capacities. Unvented hot water storage systems do not have a vent pipe to atmosphere. Most are fed directly from the mains water supply, although they can be supplied from a tank and a boosting pump, if needed.

A study in the USA[9] showed that in raw water sources counts of legionella can be between $10^4$ and $10^5$ colony forming units per litre. After chlorination at treatment works, in water distribution networks, the counts drop to between $10^2$ and $10^3$ cfu/litre. In cold drinking water services studies have shown a proportion of between 7 and 25% of all water outlets as being determined positive for legionella; these were ad hoc studies not associated with outbreaks[10]. A number of factors effect the likelihood of the presence of legionella in a water system. They are temperature, materials used in construction and installation, and debris contaminating the water. Legionella multiply most in water conditions at temperatures between 20 and 46°C. There is a relationship between the temperature of the water at the outlet and the possibility that the water will contain legionella; see appendix V.

Previous studies have found a lower frequency of legionella in systems less than 300 litre capacity. A number of reasons for this could be that:

i. in small systems the through-put of water is usually high, normally with a complete change of water daily,

ii. in small systems the pipes are purged frequently as taps are used often,

iii. in small systems the pipe runs are short and there are few deadlegs, and

iv. rust at the bottom of large cylinders has been found to have a high legionella content, although rust in smaller cylinders could harbour legionella.

## 9 UK legislation and guidance

UK legislative requirements for reducing the risk of infection by legionellosis are listed in appendix VI, including requirements on persons responsible for the design of water supply systems and equipment. The Health and Safety Commission's Approved Code of Practice (ACoP) - The prevention or control of legionellosis (including Legionnaires' disease)[11] covers any work activity where water is used or stored and where there is the possibility of inhalation of water droplets which could give rise to a risk of exposure to the legionella bacteria. The ACoP gives practical guidance on the requirements of the Health and Safety at Work etc Act 1974[12] and the Control of Substances Hazardous to Health Regulations 1994, with regard to the risk of legionellosis. In particular, it gives guidance on sections 2, 3, 4, and 6 (as amended by the Consumer Protection Act 1987) of the Health and Safety at Work etc Act 1974 and Regulations 6, 7, 8, 9, and 12 of the Control of Substances Hazardous to Health Regulations 1994. It identifies a number of areas at risk, which include:

- cooling towers,
- evaporative condensers,
- hot water services (storage capacity greater than 300 litre),
- hot and cold water services with persons at a high level of susceptibility,
- humidifiers and air washers,
- spa baths and pools, and
- generally systems or equipment where there is a risk that water may exceed 20°C and where there is the possibility that aerosols may develop.

The ACoP outlines the requirements that employers and others should undertake in order to comply with their legal duties:

- identify and assess sources of risk,
- prepare a scheme for preventing or controlling the risk,
- implement and manage precautions,

- keep records of the precautions implemented, and
- appoint a person to be managerially responsible.

The ACoP does not include detailed methods of minimising the risk of infection. It gives guidance on appropriate good practice, the need for a detailed plan of risk avoidance, records of use, and maintenance to be compiled. The legislative requirement of the ACoP is that 'reasonably practicable' precautions and measures should be taken. A detailed cost-risk analysis should be carried out which will determine the limit to which preventive measures should be taken.

The Health and Safety Executive's document, 'The control of legionellosis including legionnaires' disease' HS(G)70[13] gives further technical guidance on minimising the risk of legionella. The document outlines the competence and responsibilities of personnel managing and operating systems that are at risk from colonisation of legionella. The responsibilities of manufacturers, importers, suppliers and installers are outlined. Examples of these responsibilities include:

- manufacturers should ensure that their products comply with water byelaws, that they do not use products which support the growth of micro-organisms and that plant can be readily drained and cleaned, and that adequate information is supplied on correct operation and means of controlling the risk,
- system installer should ensure there are no unnecessary deadlegs and other areas of stagnation, and
- the installer or consultant should ensure that the system is properly designed, installed and commissioned and will work safely.

The Chartered Institution of Building Services Engineers' (CIBSE) Technical Memorandum: 'Minimising the risk of legionnaires' disease TM13: 1991'[14]. This document complements the Health and Safety Executive Guidance Note, HS(G)70, giving further practical advice. This includes the design , operation, and maintenance of hot and cold water services.

## 10 Discussion

This work has shown a low occurrence of legionella in the systems examined, with only one positive result from the 35 expansion vessels examined. Studies carried out in countries other than the UK on domestic hot water systems have produced differing results. A Canadian study (1991)[15] has shown the presence of legionella in 69 of the 211 unvented hot water systems where water

samples drawn from hot water taps were examined. The results suggested a strong link between the method of water heating, oil fired burner or gas fired burner, or electric immersion heater, and the presence of legionella. Legionella only occurred in systems with electric storage water heaters. This may be due to the fact regions of water are not heated to the desired thermostatically controlled temperature. This contrasts with the findings of a similar study[16] conducted in the UK in 1992, in which legionella was detected in only 2 of 40 vented domestic hot water storage vessels examined. In this case the legionella were in systems that had water heated directly by gas-fired burners.

Work carried out in Germany[17] on expansion vessels of a larger size than that commonly used in the UK, gave a higher rate of legionella colonisation than found in the current study. Two 80 litre 'flow-through' type expansion vessels fitted on 1000 litre water heaters, providing hot water for a building occupied by 50 people, were examined. 'Flow-through' system expansion vessels do not produce a quiescent zone in which water can stagnate, even when the gas charge is lost. Legionella were not found in the cold water supply to the system, although legionella were present in the water flowing from the expansion vessels. One of the expansion vessels was removed for analysis, which showed the presence of a biofilm containing legionella.

In the present study, the high bacteria counts at long-term monitoring site D, a hospital, may be linked to two installation factors. The expansion vessel was situated close to the top of a direct gas fired unvented hot water storage vessel, see figures 3a and 3b, and so the temperature was raised, by radiant heat transfer, on one side from the flue pipe which took hot gases away from the burner. This gave rise to a temperature gradient across the expansion vessel which meant that the water contained in the expansion vessel would be at a higher temperature than the incoming mains water. Therefore, it is possible that water temperature within the vessel are favourable to the multiplication of legionella. Also, the system had a pumped secondary return, controlled by a timer, which could cause prolonged periods of stagnation in the return to the water heater when the pump was switched off.

Figure 3a - Unvented hot water storage system - Site D

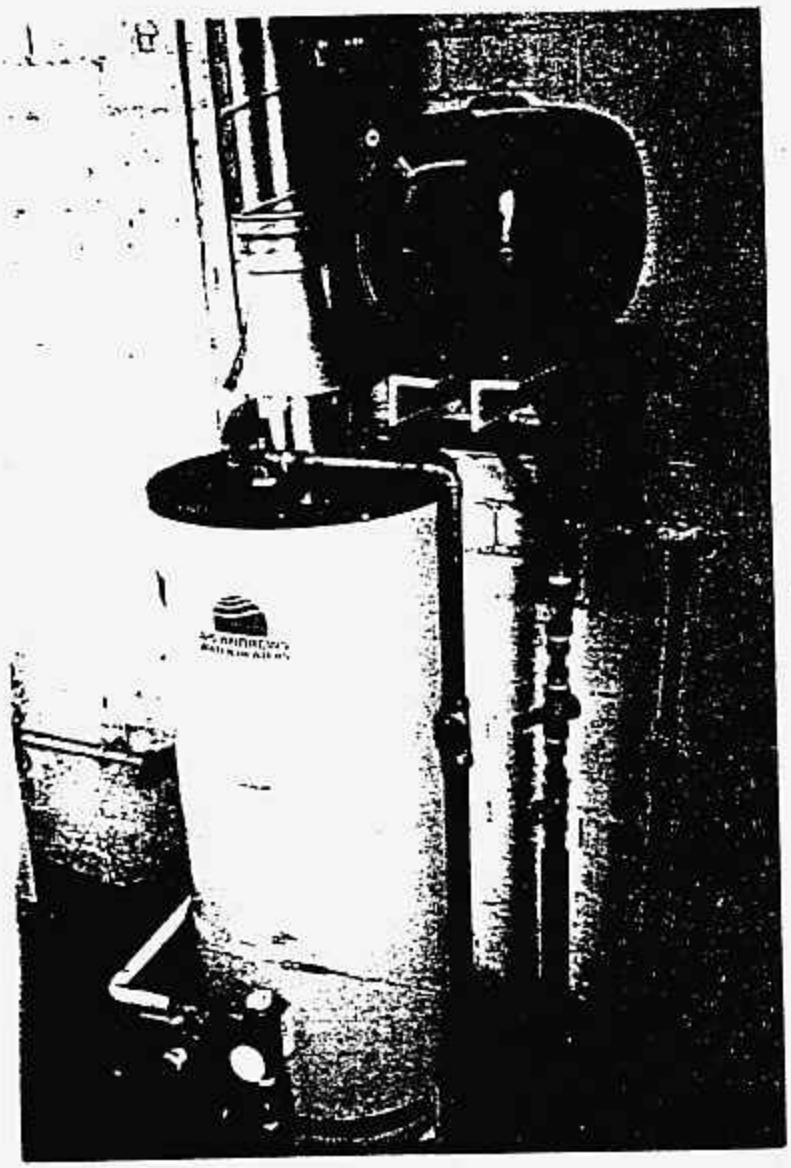
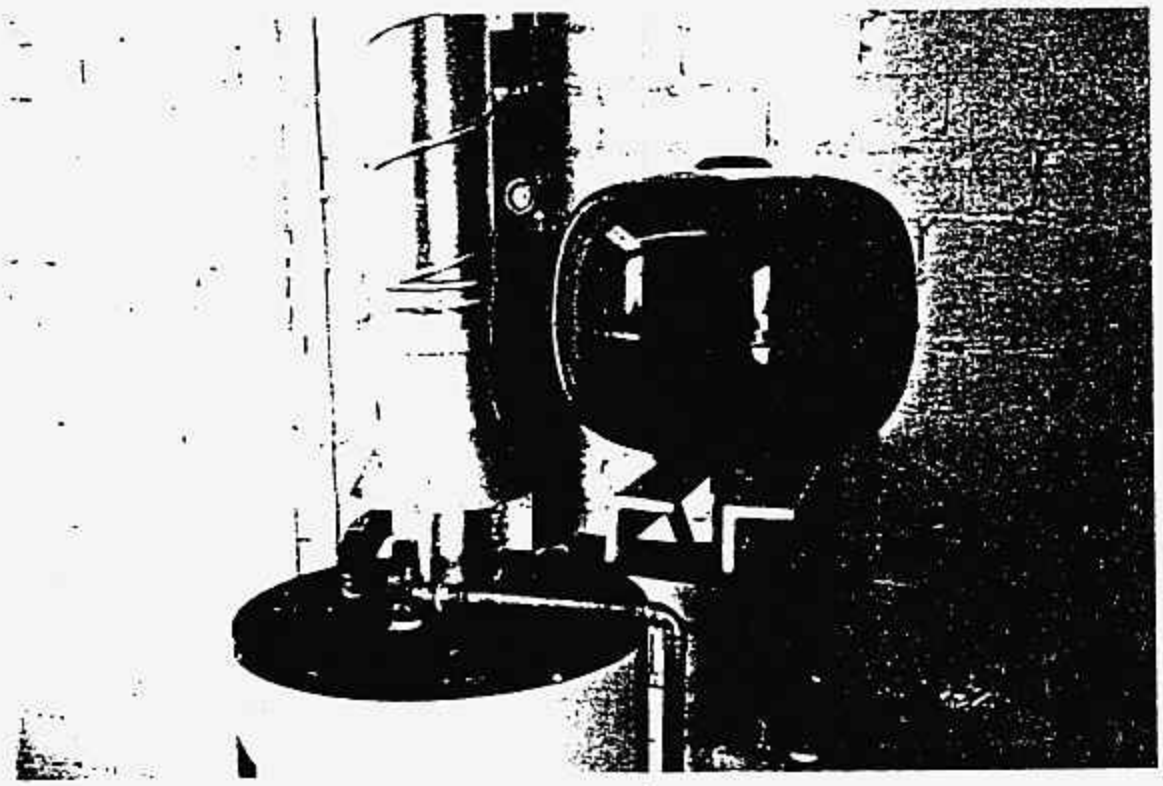


Figure 3b - Close up of expansion vessel positioned near the flue pipe - Site D



Although British Standard, BS 6144: 1990, for expansion vessels requires that the effect of the material used in its construction should 'not support microbial growth' and the UK Water Byelaws Scheme requires this to be by compliance with BS 6290, there is evidence from this study that the majority of vessels contained a biofilm on membranes. The type of expansion vessel commonly used in the UK has a single entry connection. Water can remain in the vessel in contact with its membrane for long periods of time. In fact, the vessel can become a deadleg if its gas charge has become depleted, containing water which will not undergo frequent exchange with water in the system. In this study, it was found that 6 of the 35 expansion vessels had low, or zero, internal pressure. There was no exclusive correlation between an expansion vessel losing its charge and a high bacteria count, although there is a reasonable probability that a depleted expansion vessel may encourage the multiplication of bacteria.

## 11 Design considerations

The design of a hot water supply system is an important aspect in reducing the risk of bacteria growth. Poor design and maintenance of water services can lead to conditions where legionella can

multiply and become aerosolised. British Standard BS 6700[18] gives guidance on the good design of water services for buildings to reduce the risk. For example, if hot and cold water pipes are to be run together, cold pipes should be run below to minimise unwanted heat transfer and long pipe runs should be insulated, if necessary.

In a water system it is undesirable to allow the following:

conditions that can cause stagnation, eg deadlegs,

- conditions that allow a biofilm to form, eg materials that allow colonisation by bacteria,
- conditions that allow the multiplication of bacteria (especially legionella), eg temperature, and
- the formation of aerosols where water is between 20°C and 46°C, eg spray taps.

Stagnation can be caused by deadlegs from poorly designed systems, from subsequent modification of the system, and from oversizing water storage tanks. Stagnant water could be heated by the local environment, encouraging the growth of micro-organisms, or biofilms.

The formation of aerosols can convey water-borne bacteria which may be inhaled by persons in and around a building. Aerosol formation should be avoided wherever reasonably practicable.

The following should be considered when designing and installing a water system:

- 1. deadlegs formed when piping is remote from the main flow of the system should be avoided. This may occur when pipe runs and terminal fittings become disused, especially in large buildings. Deadlegs should be minimised;
- 2. the use of aerosol forming terminal fittings, such as showers and spray taps, should be avoided in buildings used by immuno-suppressed persons;
- 3. the maintenance of the correct pressure charge in expansion vessels to ensure that a stagnation zone cannot be created;
- 4. heat transfer to the expansion vessel from other parts of the system and the surrounding environment should be minimised or eliminated. Heat transfer can occur by conduction through the connecting pipework and water and radiant heat transfer from hot

surfaces, such as flues. Such conditions may lead to a temperature gradient across the expansion vessel which could give rise to temperature favourable to the multiplication of bacteria;

- 5. the method of heating the water in the cylinder should be such that the temperature of stored water cannot create favourable conditions for the multiplication of bacteria; legionella multiplies most at temperatures between 20°C and 46°C;
- 6. cylinders should be designed so as not to encourage debris retention. For example, cylinders with domed bases allow the accumulation of debris, such as rust, which cannot be drawn through the cylinder with the normal flow of water. This debris can build up and produce conditions which are favourable to the multiplication of bacteria;
- 7. materials in contact with water should not support microbial growth. The materials used in the construction of water systems should be carefully chosen. Certain materials support the growth of micro-organisms. Natural rubber sealing washers and gaskets or non-suitable materials should be avoided as they may aid the multiplication of legionella. In the UK, the materials used must be suitable for the application, eg meet the requirements of BS 6920 and the Water Byelaws Scheme, ie be listed in the Water Byelaws Fittings and Materials Directory;
- 8. the oversizing of the hot water storage vessel and the water supply cistern (if installed) can create conditions in which water may not be flushed through the system, but may be retained in quiescent zones. Careful consideration should be given to the amount of hot water required from a hot water storage system in order that it may be sized correctly;
- 9. in the UK, the cold water cistern for new installations should meet the requirements of Water Byelaw 30;
- 10. infrequently used systems will have water which is stagnant for long periods. Examples include emergency showers and systems in holiday homes. The temperature of the water in emergency showers should be maintained at below 20°C;
- 11. water conditioners, such as water softeners, require regular cleaning and maintenance to ensure that their ion exchange resin beds are free from debris and organic material. If not, they may produce conditions favourable to the multiplication of bacteria;

- 12. filters used to remove debris from the water supply to protect valves, eg pressure reducing valves, should be cleaned regularly;
- 13. cracked water mains below-ground can result in infiltration of debris and bacteria.
- 14. cross contamination and backflow should be eliminated;
- 15. a programme of maintenance, cleaning and disinfection should be undertaken, where appropriate, as specified in BS 6700 for the UK; and
- 16. the disinfection of water systems on commissioning, as specified in BS 6700 for the UK.

## 12 Conclusions

This study has shown that bacteria, including legionella may be present in expansion vessels, at levels higher than the incoming cold water supply. 85% of the 35 expansion vessel examined contained bacteria, with one vessel containing legionella. Bacteria counts were lower at the hot water delivery taps than those determined in the expansion vessel; there is a risk to health associated with certain bacteria in water.

The following points should be considered with regard to the use of expansion vessels for drinking water systems:

1. Although no positive link has been made between the detection of bacteria in expansion vessels and the depletion of its internal pressure charge, regular maintenance (every year, for example) would be appropriate practice in, for example, healthcare premises. This would be appropriate action to prevent the stagnation of water in the expansion vessel in all cases.
2. An alternative construction of expansion vessels could reduce the risk of having stagnant water observed in the conventional design of vessel. A 'flow-through' design, in which there is an exchange of water in the vessel with the incoming water supply as water is drawn for use, could be used.
3. The position of the expansion vessel, with regard to local heating sources, is a factor that can affect the rate of multiplication of bacteria. This hazard could be reduced by positioning the expansion vessel on the cold water supply to the system away from heating sources. This is especially important when the expansion vessel is used in conjunction with gas or oil fired water heaters where hot flue gases are produced. The positioning of expansion vessels could be incorporated in future revisions of British Standard BS 6700, test house specifications, and other appropriate specifications and standards.
4. The design considerations given in section 11 should be considered for use in an appropriate document dealing with the design and installation of hot drinking water systems specifying expansion vessels.

## 13 Future work

1. Other methods of accommodating expanded water in unvented hot water systems should be examined. The 'flow-through' type of device, which has an exchange of water with the incoming mains supply, as water is drawn should be investigated, under service conditions. Another device available in Germany[19], similar to the expansion vessels used in the UK, allows a quantity of water to divert from the main flow into the water heater to pass in and out of the expansion vessel. In effect, the single connection to the vessel contains inlet and outlet flow ways. This means that there is an exchange of water in the expansion vessel with the incoming mains water, even if the expansion vessel charge pressure becomes depleted.

2. The use of the 'bubble top' expansion accommodation should be examined as the interface between the air bubble and the heated water could be a place favourable to the multiplication of bacteria.

## Appendix I - Procedures carried out on site

### Procedure for installing sampling valve

1. Isolate the system from the mains water supply by closing stop valve.

2. Remove pressure from system by opening hot tap until water flow ceases, then close hot tap.

3. Clean thoroughly, with methylated spirits, 'tee and drain' fitting.

4. Fit 'tee and drain' fitting.

5. Recommission system (eg. open stop valve, etc.).

### Procedure for taking water samples from expansion vessel at monitoring sites

1. Isolate the system from the mains water supply by closing stop valve.

2. Completely deplete the charge from the expansion vessel by depressing the shraeder valve.

3. Remove pressure from system by opening hot tap until water flow ceases, then close hot tap.

4. Connect sterile tubing to drain port in order to facilitate draining.

5. Open drain valve and collect the water sample in a sterile container whilst pressurising the expansion vessel (to force water from expansion vessel).

6. Close drain valve and remove tubing.

7. Recharge new expansion vessel to manufacturer's specifications.

8. Recommission system (eg. open stop valve, etc.).

Note: Water samples are to be taken from the hot and cold taps at the beginning and at the end of the monitoring.

### Procedure for removing and replacing expansion vessel

1. Deplete the charge from the expansion vessel by depressing the shraeder valve.

2. Isolate the system from the mains water supply by closing stop valve.

3. Remove pressure from system by opening hot tap until water flow ceases, then close hot tap.

4. Remove expansion vessel and fit with sterile cap (cleaned with methylated spirits).

5. Refit replacement expansion vessel.

6. Recharge new expansion vessel to manufacturer's specifications.

7. Recommission system (eg. open stop valve, etc.).

## Appendix II - Microbiological procedure

The following procedure was used to obtain water/biofilm samples from the expansion vessels. The expansion vessels were delivered to the laboratory with amounts of water inside them. The metal flange plate connecting the expansion vessel to the water system was unbolted, levered open, and removed. This exposed the interior of the rubber membrane. The water volume was adjusted so that the expansion vessels all contained 500ml (any additional water was taken from a sample removed, at the time of removal of the expansion vessel, from the connecting pipe). The inner wall of the membrane was then scrubbed vigorously with a sterile brush to dislodge adherent biofilm which became suspended in the 500ml of water contained in the expansion vessel. The latter was then processed as a water sample with counts being quoted per ml or 100ml of water.

The tests for Coliform Organisms and Escherichia Coli, Pseudomonads and Pseudomonas aeruginosa counts were performed by the methods quoted in Report 71[20] using the membrane filtration method. Total viable counts at both 22°C and 37°C were carried out by the Pour-Plate method (carried out in accordance with Report 71) using yeast extract agar.

Aeromonas bacteria were tested as follows. Quantitation was carried out by membrane filtration of 100ml of water. The filter was then incubated on bile salt Irgasan Brilliant green agar for 24 hours at 37°C. Yellow coloured colonies (1.5 - 2.0 mm diameter) were counted and tested for oxidase production. Oxidase positive colonies (presumptive Aeromonads) were further tested for resistance to 0129, the ability to ferment dextrin and mannitol, and failure to grow in the presence of 6% NaCl.

Legionella isolation was carried out according to the BSI DD211: 1992[21] using the centrifugation method for concentration of the water sample.

# Appendix III - Microbiological results

## First sampling occasion

Date of sample : 17/1/95 Date received : 17/1/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site A** | | | | | | | | |
| Mains cold | 0 | 17 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| E.V. water | 2 | >300 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site B** | | | | | | | | |
| Mains cold | 1 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic hot | 22 | 43 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| E.V. water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site C** | | | | | | | | |
| Mains cold | 2 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic hot | 1 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| E.V. water | 26 | >300 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site D** | | | | | | | | |
| Mains cold | 0 | 14 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic hot | 61 | 56 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| E.V. water | 0 | 4 | 0 | 0 | 0 | 0 | 0 | Not Detected |

*E.V. water: water sampled from the expansion vessel*
*Limit of legionella detection: 100 cfu/litre*

## Second sampling occasion

Date of sample : 30/1/95 Date received : 31/1/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site A** | | | | | | | | |
| E.V. water | 0 | $1.1x10^3$ | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site B** | | | | | | | | |
| E.V. water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site C** | | | | | | | | |
| E.V. water | 0 | 186 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site D** | | | | | | | | |
| E.V. water | 4210 | $>1x10^6$ | 0 | 0 | 0 | 0 | 0 | Not Detected |

## Third sampling occasion

Date of sample : 13-14/2/95 Date received : 14/2/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site A** | | | | | | | | |
| Mains cold | 2 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| E.V. water | 45 | 1100 | 0 | 0 | >600 | 0 | 0 | Not Detected |
| **Site B** | | | | | | | | |
| E.V. water | 127 | 68 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site C** | | | | | | | | |
| E.V. water | 20 | 900 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site D** | | | | | | | | |
| E.V. water | $6x10^4$ | $1.0x10^5$ | 0 | 0 | 0 | 0 | 0 | Not Detected |

*E.V. water: water sampled from the expansion vessel*
*Limit of legionella detection: 100 cfu/litre*

## Fourth sampling occasion

Date of sample : 28/2/95 Date received : 28/2/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site A** | | | | | | | | |
| E.V. water | 0 | 624 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site B** | | | | | | | | |
| E.V. water | 0 | 528 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site C** | | | | | | | | |
| E.V. water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site D** | | | | | | | | |
| E.V. water | 0 | $1.21 \times 10^6$ | 0 | 0 | 0 | 0 | 0 | Not Detected |

## Fifth sampling occasion

Date of sample : 13/3/95 Date received : 14/3/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site A** | | | | | | | | |
| E.V. water | 0 | 732 | 0 | 0 | 850 | 0 | 0 | Not Detected |
| **Site B** | | | | | | | | |
| E.V. water | 0 | 127 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site C** | | | | | | | | |
| E.V. water | 0 | 138 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site D** | | | | | | | | |
| E.V. water | $4.8 \times 10^4$ | $9 \times 10^4$ | 0 | 0 | 0 | 0 | 0 | Not Detected |

*E.V. water: water sampled from the expansion vessel*
*Limit of legionella detection: 100 cfu/litre*

## Sixth sampling occasion

**Date of sample : 27/3/95** **Date received : 28/3/95**

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site A** | | | | | | | | |
| E.V. water | 0 | 41 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site B** | | | | | | | | |
| E.V. water | 0 | 7 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site C** | | | | | | | | |
| E.V. water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site D** | | | | | | | | |
| E.V. water | 800 | 900 | 0 | 0 | 0 | 0 | 0 | Not Detected |

*E.V. water: water sampled from the expansion vessel*
*Limit of legionella detection: 100 cfu/litre*

## Seventh sampling occasion

Date of sample : 18/4/95 Date received : 18/4/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site A** | | | | | | | | |
| Mains Cold | 0 | 36 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic Hot | 0 | 1 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | 8 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site B** | | | | | | | | |
| Mains Cold | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic Hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | 3,600 | 0 | 0 | 60 | 0 | 0 | Not Detected |
| **Site C** | | | | | | | | |
| Mains Cold | 0 | 80 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic Hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | 2,700 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site D** | | | | | | | | |
| Mains Cold | 43,600 | 33,500 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic Hot | 44,00 | 88,400 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 32,400 | 92,800 | 0 | 0 | 0 | 0 | 0 | Not Detected |

*Limit of legionella detection: 100 cfu/litre*

## Expansion vessel removal sites

Date of sample : 30/1/95 Date received : 31/1/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas | | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | spp. 100ml | aerug 100ml | 100ml | cfu / litre |
| **Site (i)** | | | | | | | | |
| Expansion Vessel | 144 | 2448 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site (ii)** | | | | | | | | **L.pneumophila** |
| Expansion Vessel | 50 | 218 | 0 | 0 | 0 | 0 | 0 | **sg 8>25,000 cfu / litre** |
| **Site (iii)** | | | | | | | | |
| Expansion Vessel | 1260 | 5340 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site (iv)** | | | | | | | | |
| Expansion Vessel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site (v)** | | | | | | | | |
| Expansion Vessel | 0 | 35 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site (vi)** | | | | | | | | |
| Expansion Vessel | 0 | 2736 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site (vii)** | | | | | | | | |
| Expansion Vessel | 3250 | 3808 | 0 | 0 | 0 | 0 | 0 | Not Detected |

**sg 8 : seragroup 8**

**Note: hot and cold water samples were not analysed at sites (i) - (vii)*

Date of sample : 13-14/2/95 Date received : 14/2/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas | | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | spp. 100ml | aerug 100ml | 100ml | cfu / litre |
| **Site (ii) (re-test)** | | | | | | | | |
| Mains cold | 200 | 9 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic hot | 700 | 151 | 0 | 0 | 0 | 0 | 0 | Not Detected |

*Limit of legionella detection: 100 cfu/litre*

Date of sample : 13-14/2/95 Date received : 14/2/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site 1** | | | | | | | | |
| Domestic hot | 107 | 100 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 7 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | $2.44x10^6$ | $8.4x10^5$ | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 2** | | | | | | | | |
| Domestic hot | 86 | 8 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 84 | 428 | 0 | 0 | 126 | 0 | 0 | Not Detected |
| Expansion Vessel | 4,900 | 300 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 3** | | | | | | | | |
| Domestic Hot | 900 | 1,800 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 10 | 33 | 0 | 0 | 2 | 0 | 0 | Not Detected |
| Expansion Vessel | $1.08x10^6$ | $1.9x10^5$ | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 4** | | | | | | | | |
| Domestic hot | 64 | 730 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 232 | 305 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | $7.2x10^5$ | $2.9x10^5$ | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 5** | | | | | | | | |
| Domestic hot | 444 | 545 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 790 | 210 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | $7.20x10^5$ | $2.1x10^5$ | 0 | 0 | >600 | >600 | 0 | Not Detected |
| **Site 6** | | | | | | | | |
| Domestic hot | 200 | 1,100 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 428 | 42 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 1,700 | $1.2x10^5$ | 0 | 0 | 0 | 0 | 0 | Not Detected |

*Limit of legionella detection: 100 cfu/litre*

Date of sample : 13-14/2/95 Date received : 14/2/95 (continued)

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. 100ml | Pseudomonas aerug 100ml | Aeromonas 100ml | Legionella cfu / litre |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | | | | |
| **Site 7** | | | | | | | | |
| Domestic hot | 361 | 423 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 849 | 1,000 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | $1.6x10^6$ | $8.1x10^5$ | 0 | 0 | 102 | 80 | | Not Detected |

*Limit of legionella detection: 100 cfu/litre*

Date of sample : 28/2/95 Date received : 28/2/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas | | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | | | | | spp. | aerug | | |
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site 8** | | | | | | | | |
| Domestic hot | 0 | 37 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 9** | | | | | | | | |
| Domestic hot | 0 | 5 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 852 | 0 | 0 | u/c | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | 424 | 0 | 0 | 36 | 0 | 0 | Not Detected |
| **Site 10** | | | | | | | | |
| Domestic hot | 0 | 1 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 85 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | 0 | 0 | 0 | 26 | 0 | 0 | Not Detected |
| **Site 11** | | | | | | | | |
| Domestic hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 588 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 1 | 624 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 12** | | | | | | | | |
| Domestic hot | 0 | 4 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 104 | 0 | 0 | 14 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | 204 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 13** | | | | | | | | |
| Domestic hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 2 | 70 | 0 | 0 | u/c | 0 | 0 | Not Detected |
| **Site 14** | | | | | | | | |
| Domestic hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 5 | 60 | 0 | 0 | 14 | 14 | 0 | Not Detected |
| Expansion Vessel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |

*u/c - uncountable spreading colonies*
*Limit of legionella detection: 100 cfu/litre*

Date of sample : 13/3/95 Date received : 14/3/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site 15** | | | | | | | | |
| Domestic hot | 448 | 8,900 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 5 | 16 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | $2 \times 10^5$ | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 16** | | | | | | | | |
| Domestic hot | 0 | 79 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 7 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 3 | 1,300 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 17** | | | | | | | | |
| Domestic hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 21 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | $7.8 \times 10^4$ | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 18** | | | | | | | | |
| Domestic hot | 1 | 17 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 115 | 0 | 0 | 6 | 0 | 0 | Not Detected |
| Expansion Vessel | 3,500 | 3,300 | 0 | 0 | 0 | 0 | 0 | Not Detected |

*Limit of legionella detection: 100 cfu/litre*

Date of sample : 27/3/95 Date received : 28/3/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Site 19** | | | | | | | | |
| Domestic hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 32 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 43 | 500 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 20** | | | | | | | | |
| Domestic hot | 0 | 1 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 6 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 23 | 42 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 21** | | | | | | | | |
| Domestic hot | 2 | 13 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 5 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 43 | 67 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 22** | | | | | | | | |
| Domestic hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Mains cold | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |

Date of sample : 18/4/95 Date received : 18/4/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas spp. | Pseudomonas aerug | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | 100ml | 100ml | 100ml | cfu / litre |
| **Training vessel*** | | | | | | | | |
| Mains cold | 0 | 3,500 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | 19,200 | 0 | 0 | 0 | 0 | 0 | Not Detected |

** This installation has not been included in the analysis as its age and use are unknown*
*Limit of legionella detection 100: cfu/litre*

Date of sample : 2/5/95 Date received : 2/5/95

| Sample | Total bacteria cfu / ml | | Coliform count / 100ml | | Pseudomonas | | Aeromonas | Legionella |
|---|---|---|---|---|---|---|---|---|
| | 24 hr / 37 °C | 72 hr / 22 °C | total | faecal | spp. 100ml | aerug 100ml | 100ml | cfu / litre |
| **Site 23** | | | | | | | | |
| Mains cold | 0 | 14 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic hot | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 6 | 300 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| **Site 24** | | | | | | | | |
| Mains Cold | 0 | 74 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Domestic Hot | 0 | 7 | 0 | 0 | 0 | 0 | 0 | Not Detected |
| Expansion Vessel | 0 | 90,000 | 0 | 0 | 0 | 0 | 0 | Not Detected |

*Limit of legionella detection: 100 cfu/litre*

## Appendix IV - Questionnaire

# Health risks associated with expansion vessels

**Please return to:** Martin Shouler,
Public Health Engineering Section,
Environmental Systems Division,
Building Research Establishment,
Garston, Watford, WD2 7JR,
UK.

- Does the practice in your country permit the use of expansion vessels?

  Yes/No*

  -What are their applications?†

  -What, if any, regulations, codes of practice and/or standards apply?†

- Are you aware of any health risks associated with expansion vessels, eg legionella, E coli, pseudomonads, acromonads?

  Yes/No*

  -If yes, please can you give details, or send reports and papers, or give references to appropriate reports or papers.†

- Do you have any further information about expansion vessels, eg faults, failures, materials and other details of their use?†

* Delete, as appropriate.
† Please give details in the space provided, if appropriate, and continue on an additional page, if necessary.

**Thank you for your co-operation.**

## Appendix V - Health effects of legionella

### Legionella

Legionnaires' disease was first reported after a large outbreak of illness in Philadelphia, USA in July 1976. One hundred and eighty-two members of the Pennsylvania American Legion were infected. Subsequently, a bacterium was identified as the cause and it was named Legionella pneumophila. Since then the disease has claimed hundreds of lives throughout the world and there have been a number of outbreaks in the UK. Legionella pneumophila is a member of the legionella family which is found worldwide in a range of aquatic habitats where it forms part of the biofilm. In the built environment it is particularly associated with building services where the conditions to support its growth can be present.

### Effect on Man

Many species of legionella have been isolated, the most virulent is Legionella pneumophila. In this species there are at least fourteen serogroups of which serogroup 1 causes the most illnesses.

On entering the lungs either by aspiration (ie accidental' swallowing' down the trachea instead of the oesophagus) or as an aerosol (a fine mist of water particles) the bacteria can cause illness. Legionella bacteria can cause two distinct illnesses: Pontiac Fever and the more serious Legionnaires' disease.

**i. Pontiac Fever**

The symptoms of Pontiac Fever are flu-like; infected people experience muscle pains, headache, fever and some have a cough. The illness is not fatal. The incubation period is commonly 36-48 hours and the attack rate approaches 100% of those exposed. It was named after an outbreak of flu-like illness in a County Health Department in Pontiac, Michigan, USA.

ii. **Legionnaires' disease.**

The attack rate of Legionnaires' disease is less than 5%. Those infected are typically more susceptible due to underlying ill health, eg smoking, chronic alcoholism, emphysema immunosuppression and following surgery. Mortality rates up to 25% have been recorded. However, if the infection is diagnosed and treated within 48 hours the mortality rate is reduced considerably.

After an incubation period of 2-10 days a pneumonic illness occurs. The disease is more common in men than women by a ratio of approximately 2 to 1. Hospitals are an area where many people are at risk from the illness because people who have other illnesses or have their immune systems depressed are more likely to catch the disease. Legionnaires' disease can be treated using antibiotics such as Azithromycin, Erythromycin, Rifampicin and Ciprofloxacin.

Studies in the UK and the USA have shown that there is a seasonal variation in the number of occurrences of Legionnaires' disease with a peak during the summer months. This is partly due to an increase in travel at that time of the year.

**Sequence of events leading to infection**

To cause infections, legionella pneumophila must have suitable conditions for multiplication and transmission:

i. the organism must gain entry to a water system,

ii. the strain that has gained entry must be harmful to man,

iii. it must multiply to a quantity sufficient to present a risk, and

iv. to gain entry into the lungs it must be in an aerosolised form (see below) or be aspirated.

All the above can occur with water supply systems, especially hot water. The multiplication process is optimised when a number of factors coincide.

**Aerosolisation**

Aerosolisation is one of the ways in which a person may contract Legionellosis. This may occur under a number of different mechanisms[22]:

i. waves are generated if air is blown across a water film. If waves are of sufficient power aerosolisation may occur;

ii. free falling water may break up, causing smaller droplets to be formed;

iii. if saturated air meets cooler air, water vapour will be condensed out onto small particles present in the air. An example of this may occur at the outlet of cooling towers.

iv. droplets of water impacting on a surface form a thin film crown which breaks up causing minute water droplets to be formed; and

v. bubbles bursting through a liquid film can also have a similar effect causing aerosolisation. Another consideration with bubbles bursting is that the concentration of bacteria or other contaminants increases at the air liquid interface, as compared with the liquid as a whole, due to particulates in the liquid adhering to the bubble as it rises.

To reduce the effect of aerosolisation the disturbance of the water interface should be avoided or contained.

To reach the lungs, air must travel through the nose and along the bronchi to the alveoli. A coarse filtration (particles above 10 μm) occurs in the nose. The mucus linings in the bronchi trap other particulates in the air stream. Water droplets, containing legionella, in the order of 2 - 5 μm are the most dangerous because particles of this size can reach the alveoli.

**Occurrences in England and Wales**

Although not a notifiable disease, in the UK the Public Health Laboratory Service (PHLS) compiles a central database on the number of outbreaks (two or more cases) together with information on where the outbreak occurred.

Confirmed outbreaks of Legionnaires' disease reported to Communicable Disease Surveillance Centre (CDSC) England and Wales 1979-88

Case Clusters - two or more cases

| | Hotel | Hospital | Industrial site | Other | Total |
|---|---|---|---|---|---|
| UK | 4 (32) | 12 (112) | 4 (47) | 13 (158) | 33 (349) |
| Overseas | 63 (182) | - | - | - | 63 (182) |
| Total | 67 (214) | 12 (112) | 4 (47) | 13 (158) | 96 (531) |

*(Numbers in brackets represent total number of people infected)*

It can be seen from the table that in England and Wales there is a high rate of outbreaks in hospitals. This could be due to the high susceptibility of patients who may be immuno-suppressed. A higher level of vigilance may be appropriate for water systems serving healthcare buildings, eg the regular sampling of water outlets.

**Methods of controlling legionella**

The control of this bacterium must tackle the conditions in which legionella multiplies and also prevent aerosol formation. These situations involve both design and maintenance.

**Temperature**

The population growth of legionella is highly dependant upon temperature. Between a temperature of 35 to 45°C legionella can double in population daily. This reduces markedly at below 25°C and above 45°C. At temperatures below 25°C legionella in tap water will become dormant, although they can exist in water for up to four months. To kill legionella the temperature of the water must be raised above 46°C.

The rate at which the population is destroyed is a function of the temperature to which it is exposed, i.e. the higher the temperature is raised, the shorter is the time to kill the legionella. Hospitals have used the technique of raising the water temperature to 70°C and flushing the hot water taps. However, it is important to note that in the biofilm, bacteria are partially protected from sudden

excesses of temperature. Legionella can also exist inside amoebae which can also protect the bacteria from heat.

### Biocides

Biocides are chemicals which kill bacteria in a variety of different ways. The concentration of the biocide in the water is the most important factor as to how effective its kill rate will be. The temperature and pH of the water will also effect the process. The higher the temperature, the greater the effect the biocide will have. The cleanliness of the water is also important. In the presence of organic matter many biocides are either completely or partially inactivated. Again legionella in a biofilm are protected from biocides. Another form of protection is within amoebae. These host amoebae are far more resistant to biocides than legionella on its own and legionella can multiply inside and subsequently be released.

Biocides may be used at the pre-commissioning stage of a hot water supply system. They are also routinely used in maintaince programmes for cooling towers.

### Ultraviolet Radiation

All bacteria are susceptible to irradication by ultraviolet radiation. The effect of UV on legionella is dependant on the intensity of the UV and the exposure time. A UV lamp can be installed to destroy legionella and other bacteria present in the circulating water. The effect of UV on the biofilm is at best modest and indirect. UV transmission is reduced by turbidity (suspended solids in the water) and high flowrates past the UV source will diminish residence time and therefore UV effect.

### Silver/copper ion treatment

Releasing Ag/Cu ions into a water system[23] at levels below those permitted by European Standards has an effect on legionella and has been used to treat hot water systems. Also, the ions are trapped by the biofilm allowing them to act at that site as well as in the circulating water.

## Appendix VI - UK Legislation

Specific UK legislation is covered in a number of Acts of Parliament. The most relevant Acts regarding the health risks presented by water services are as follows:

- Occupiers Liability Act, 1957

  This confirms that the occupier of a building has the responsibility of care for the visitors.

- Defective Premises Act, 1972

  The landlord has the responsibility for the safety of visitors, neighbours and passers-by. It obliges a landlord to show that he has taken all precautions to ensure their safety. The landlord should declare his policy on health and safety and have a named person responsible for it.

- Health and Safety at Work etc Act, 1974

  The employer has a direct responsibility to ensure, as reasonably practicable, the health, safety and welfare of all his employees. A cost benefit risk analysis should be assessed to compare the cost of implementing work against a risk to employees.

- Control of Substances Hazardous to Health, COSHH, 1988

  This addition to The Health and Safety at Work etc Act, 1974, makes an employer responsible for the exposure of employees to dangerous substances which can cause a health hazard. Certain biocides and other chemical treatments of building services are covered, as is legionella itself.

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# Topic A3

## Study on Plumbing Systems for Ground Food Waste Recycling

S. Koshimizu and Dr. F. Kiya, Japan

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Abstract

Development of a food waste recycling systems utilizing food waste disposal units has been underway for almost three years now, since 1994. This research and development have been carried out as a joint study involving the Construction Research Institute, 17 private companies, and 3 related private organizations.

## 1. Introduction

The Ministry of Construction look over integrated technology development projects, and then changed its focus to items affecting people's daily lives.
As a part of the integrated technology development project, the development of a food waste recycling systems utilizing food waste disposal units has been underway for almost three years now, since 1994.

To promote this project, a new experimental facility was constructed (including wastewater treatment plant) where studies on plumbing systems could be conducted. This experimental facility was built on the Construction Research Institute ( CRI ) of the Ministry of Construction ( M of C ).

This research and development ( R&D) has been carried out as a joint study involving the Construction Research Institute, 17 private companies, and 3 related private organizations.

The purpose of this R&D is to establish food waste recycling systems, which prompt the reuse of wastewater and reduce the generation of food waste by grinding food wastes generated in kitchens by food waste grinders; thereafter the ground food waste is carried through waste pipes and processed by a food waste composting plant.

The two requirements governing the development of systems are as follows:

(1) Both the waste-water load (i.e. the load to public water areas and sewerage) and the actual waste amounts generated, must not be greater than those generated by conventional systems.
(2) The demands for both compost and recycled water (both in quality and quantity) must be acceptable.

## 2. System configuration

A food waste recycling system is made up of the following three components--all of which are integrated into a single system:

(1) A component which grinds food waste
(2) A component which grinds food waste is transported (drainage system)
(3) A component which grinds food waste is processed and composted .

treated water is created ( food waste composting plant )

This R&D considers the standards required for the performance of each component based on the systems shown in Figures 1 and 2 as the "Standard system".

Standard system 1 is a system which collects all household wastewater and treats it by a food waste composting plant and creates compost while purifying the wastewater.

When compost is not created in this system, any losses in excess sludge volume should be reduced.

When Standard system 1 is constructed with a purifier (food waste grinder support type can be used) which can process both household wastewater as well as waste water from the food waste grinder is required.

Standard system 2 is a system which processes food waste grinder wastewater + kitchen wastewater by a food waste composting plant and creates compost while discharge the treated water either to the sewer system or to a purifier.

In case compost is not created in this system, excess sludge volume should also be reduced.

3. Progress in the current state of R&D

In 1994 information, regarding the existing technology about food waste grinders, characteristics and amounts of food waste, effects of food waste on sewer systems and purifiers, etc. through the available documents and data, was compiled.

Although systems are currently subject to legal regulation in our country, it was found that their bad influence on both sewer systems and purifiers can be.

In 1995, author undertook a series of overseas investigations to ascertain what regulations ( if any ) governed food waste grinders and other treatment of food waste, including sewer systems, and food waste composters in both European and North-American countries. As a result, the regulations governing the use of food waste grinder were collected.

(1) Rationale behind the regulation of food waste grinder use

① Effects (on waste pipes) of grease which are likely to be contained in large amounts in wastewater

The grease content of food waste grinder wastewater is little higher than that found in the household wastewater generally; furthermore, in the past 30 years, there have been few blockage accidents in sewer pipes despite the use of some 50 million disposal units in the United States.

② Increased load effects on sewage treatment facilities

Although some both BOD and SS are increased slightly, significant changes in conventional sewage treatment processes in sewage-treatment plants are not required.

③ Increases in water usage

Water usage necessary for disposal units amounts to only 2.6% of total water usage; therefore water consumption increase due to food waste grinders will be slight.

④ Deterioration of water quality in rivers and harbors due to the overflow of combined sewer systems at the time of heavy rains

The overflow of combined sewer systems is a most serious problem; both New York City and the City of Toronto ( in Canada ) have prohibited the use of food waste grinder (from the viewpoint of sewer systems) even today. However, in older cities such as Boston, Chicago, and Philadelphia, all of which have combined sewer systems, the municipal authorities have improved existing sewer systems, and at the same time, have recommended the use of food waste grinder systems, commenting that the environmental benefits of food waste grinder outweigh their drawbacks. Perhaps, as a result, the installation rate of food waste grinders has reached some 28 to 30% in these cities.

In the U. S., the increasing rate of the installation of disposal units has remained stable -- at an approximate annual rate of 1% or so -- and any effects on the water quality of rivers and harbors due to this overflow is insignificant, especially when accompanied with the improvement of sewer systems.

(2) Current statistics on food waste grinders in the U. S. and other countries

The installation rate of food waste grinders in the U. S. is approx. 51% (as of 1991); each year it has continued to increase by approximately 1%. As of January 1995, the installation of food waste grinders became mandatory for new home construction in 98 cities in U.S.; in some cities, installation of disposal units is mandatory when a house is renovated.

Usage statistics for disposal units -- in other countries other than U. S. -- are shown in Table 1.

This table shows the summaries of the questionnaire results on food waste grinder usage which were filled out by the participants in CIB W62 (held in 1994 Brighton ) and also by us who participated in the overseas investigation.

As can be seen from the table, there is no country which recommends the installation of food waste grinders; however, on the other hand, food waste grinder imported from the U. S. have been widely used (some even in countries which have prohibited the use of food waste grinders.)

Countries in which the installation of food waste grinders has been prohibited by law are: Germany, South Korea, Singapore, and Chile. Countries which have regulations governing their use are: Holland, France, Switzerland, Scandinavia, and Japan. All other countries seem to have no regulations.

Also, in 1995, we the Garbage Disposal and Composting Committee (GDCC) was established in the Japan Society of Plumbing Engineers (JSPE), and a working group was also established for to begin an experimental study and the collection of preliminary data based on the study theme.

In 1996, the experimental study is under continuance from 1995, in order to create design guidelines for this system, and apply the system to a housing development.

## 4. Experiments carried out as part of the integrated technology development project

### 4.1 Purpose of experiments

The experiments carried out are mainly divided into two categories: first, the food waste grinder, and second, the waste pipe which transports ground food waste.

The experiment on the food waste grind is carried out to know about grinding characteristics, noise and vibration characteristics, appropriate water supply flow rate, discharge and duration, and finally, the water quality characteristics of marketing food waste grinders effluent.

The aim of the waste pipe experiment is to gather information about the amount (and quality) of scale and sediment inside existing building drain with food waste grinders. At the same time, the flow characteristics of wastewater (containing ground food waste) in the waste pipe will be observed. The results obtained will be used to create indexes to assist in the design, construction and maintenance of waste pipes for food waste grinders.

### 4.2 Experimental Subjects

The specific experimental subjects, for experiments carried out in 1995 were as follows:

(1) Measurements on the establishment of an appropriate water supply
(2) Measurements of grinding time and performance
(3) Measurements of grinding water quantity
(4) Measurements of grinding classification (grain size, particle size, grit) and decreasing rate
(5) Measurements of food waste grinder effluent water quality
(6) Confirmation of amount of debris remaining inside the food waste grinder after grinding
(7) Experiment to establish test methods for sound and vibration performance
(8) Sound and vibration experiment based on the above test methods
(9) Measurements of sound and vibration at a light-weight steel framed existing building

(10) Measurements of drainage characteristics of food waste grinder based on the HASS 206 "Plumbing Code" of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan.

(11) Experiments on the flow characteristics of ground food wastewater in waste pipes

(12) Experiments on the flow characteristics of ground food wastewater at the experimental facility of CRI

(13) Confirmation of the amount of slime and the state of deposits inside the food waste grinder waste pipe

This time we report on items (4), (10), (11), (12), and (13) above.

Following experiments are planning to be carried out in 1996:

(1) Sound and vibration measurements at a steel framed concrete building

(2) Experiments to determine whether a single food waste or a substitute test body will be used in performance evaluation tests

(3) Performance test for to decide the kind of waste inhibited for food waste grinders

(4) Experiments regarding to determine methods for decreasing generated sound and vibration

(5) Experiments with regards to measures for prevention of noise and vibration in the food waste grinder waste pipe

4.3 Ground food waste flow in drainage stacks and horizontal drains

(1) Purpose of experiment

It is necessary to confirm the behavior of ground food wastewater inside the waste piping itself, from the standpoint of determining the ideal characteristics (from a design, construction, and maintenance) of waste piping which accepts water from a food waste grinder. For this purpose, so we conducted a gravity-fed experiment with ground food wastewater with food waste grinders connected to test piping mainly constructed from transparent hard vinyl chloride pipe (VP).

Also, when considering the cleaning frequency of waste piping connected to food

waste grinders, it is necessary to verify the amounts of slime and other deposits generated inside the piping. This is impossible in a short-term experiment, so we checked the existing waste pipes from kitchen sinks in the Fapartment of T company, in which a food waste grinder has been installed in a single sink, being 1 year and 4 months after high-pressure cleaning.

(2) Experimental Facility

A four-story steel-framed experimental tower (inside the existing experimental facility building) in the construction laboratory of CRI was constructed and an experimental piping system consisting of transparent VP pipes and ovate pipes is installed.

(3) Food waste used in the experiment

The composition of food waste used in the experiment was determined as shown in Table-2 based on data from various documents about the composition of food waste.

(4) Drain trap size

A preliminary experiment on Ptraps with nominal diameter of 40 (outer dia. 49 mm ×inner dia. 44 mm) and a nominal diameter 32 (outer dia. 38 mm×inner dia. 34 mm) for the drain trap for food waste grinders was carried out in a laboratory. As a result, ground food waste in the trap with the nominal diameter 32 disapeared in a shorter time, so the Ptrap of nominal diameter 32 was chosen for the following experiments.

(5) Experimental items and methods

We observed the flow down characteristics of ground food waste in a vertical drain pipe 50 VP(main branch 75 VP) and vertical drain pipe 75 VP(main branch 100 VPand 100 mm oval pipe) in the following states: an independent drain from 1 single unit, a simultaneous drain from 2 to 4 units, and three-time continuous drain of standard food waste.

The water supply flow rates are tested at three levels: 8 L/ min., 6 L/ min., and 4 L/min., with a water supply duration from the start time of grinding to the completion of grinding of food waste grinders. In the case where the ground food waste was retained into the main pipe, we continued the supply of water (flushing water) for 10 to 30 seconds and repeated several times until the retained ground food waste is thoroughly discharged. Thegrade of the main pipe was installed to be between 1/100

and 1/150; 1/200 was also tested partially. The experiment (with the same water supply flow rate) was carried out twice in principle.

Measuring points -1 and -2 are video taped. As for the flow characteristics of main horizontal pipe, we measured the flow velocity and wetted perimeter length from the video screen. We determined the flow velocity from the number of frames required for the representative item (flowing close to the water surface) to pass a 200 mm interval, and further, measured the wetted perimeter length by attaching a 10 mm-square monochrome ruled tape to the bottom of the external surface of the pipe (for a transparent pipe) and to the inner bottom of the cutout part of the oval pipe.

(6) Experimental Results

One part (the first flow of the independent drain at the measuring point - 1) of the experimental results is shown in Table -3.

① Differences in drain flow characteristics by food waste grinder model

There is a difference in the inner diameters between the transparent VP and the stopper of the transparent joints used this time (the inner diameter of the joint stopper is larger by 3 mm with 100 VP pipe, and by 1 mm with 75 VP pipe). The entire inner face of the piping was not even, but when imperfections in the insertion state of straight pipe at the actual installation is taken into consideration, it may be considered to be at the same level as in actual pipe installation.

In the drain from the food waste grinder with rough-grained grinding, temporary retention of ground food waste was observed at the previously mentioned joints, but if the water supply flow rate is sufficient ( 8 L/min or more), the so-called block was not created, and the wastewater flowed away freely. As indicated in Table-2, the rough ground food waste in the oval pipe demonstrates poor flow characteristics as compared with the circular pipe.

When drained simultaneously in models 2 to 4, there were a few cases where ground food waste was temporary retained.

When standard food waste was discharged from rough-grained disposers with less water flow rate and gentle grade, there were cases where flushing water is necessary.

② Relation between the flow rate of the water supply and the maximum flow rate of wastewater in the main horizontal pipe

As mentioned in ①, since the inner face of the piping is not even, the relationship between water supply flow rate and the maximum flow rate of wastewater in the main horizontal drain pipe was not clarified. However, when a constant flow was generated in the main horizontal pipe in case of models with fine-grained grinding, the maximum flow rate in the main horizontal pipe was less than one-half of the flow rate of the water supply. As the slope becomes more gentle, the ratio of the maximum wastewater flow rate to the flow rate of the water supply in the main horizontal pipe becomes greater.

In the case where ground food waste flows while it is making a weir at the head of the wastewater, the ground food waste being carried down by the water following, so the maximum flow rate in the main horizontal pipe assumes several times that of the water supply flow rate.

③ Friction coefficient between ground food waste, wastewater, and the inner piping face

The coefficient of roughness in the Manning formula has been treated as a fixed piping value; however, its value is in inverse proportion to the velocity, and it is considered as a friction coefficient between the down-flowing fluid and the inner surface of the piping.

Accordingly, when seeking this value from the experimental case, when the flow is smooth, it was approx. 0.005 to 0.008 in 100 VP pipe and 100 mm oval pipe, and approx. 0.008 to 0.02 in 75 VP pipe; it tends to slightly increase when the slope became gentler.

However, in cases where the ground food waste flows while it is forming a weir, for example, when the standard food waste is flow three times in succession through a 100 mm oval pipe with grade 1/150 and flushing water of 4 L/min is discharged five times, this value closely approached 0.2.

④ Flow in vertical waste pipe

The flow characteristics of ground food waste in vertical pipes were almost the same as the those observed in the general drain. An sanitary tee (ST) joints are used for the connection of the horizontal and vertical pipes, and there were cases where the drain from the upper floor invaded the pipe in the lower floor. This phenomena were also seen in the other drain experiments.

⑤ Other phenomena

The clean outs of the main horizontal pipe were installed as in the general drain pipe, but when the wastewater flows down, the water level in the pipe rises, and the wastewater invade the lower part of the clean outs. The ground food waste remained there after the wastewater had been drained. This phenomenon has already been known in the U. S. and is the reason why loop vent pipes should be taken out from the branch immediately after the fixture waste pipe furthest upstream.

However, even if the invasion of waste water is repeated, remaining solid matter is unlikely to accumulate in succession and also it is very difficult to install a cleaning hole on the top of the piping where the wastewater flows constantly, so cleaning of pipes is the only solution.

(7) Slime and deposit in the waste pipe

The state of slime and deposit in the waste piping of kitchen sink system with food waste grinder installed with a single sink 1 year and 4 months after high pressure cleaning is shown in Figure 2 and the characteristics of these deposits in the pipe are shown in Table 4.

The proportion of organic matter of slime in the vertical pipe is more than that in the horizontal pipe, and from the deposition state of microbe, it is assumed that much protein and sugar are present. The grease of organic matter in the slime in the vertical pipe is as high as 30% and that in the sediment in the main horizontal pipe is a low value like 12%.

The diameter of the main horizontal pipe is larger compared to the load so the wastewater passes only on the lower part ; 1/4 of pipe cross section. There was also a sediment in this part but no sediment was seen in the top air passage part. The sediment in the main horizontal pipe was mainly consisted of egg shells and sea shells and when they were scraped out, there was hydrogen sulfide odor and the sediment is under the anaerobic condition.

From these result, tew inside of the ground food waste piping of the food waste grinder need to be cleaned at least once a year.

(8) Conclusion

The following facts were obtained from the experiment this time:

① The food waste from a food waste grinder with a rough grinding grain size tends to get trapped in the main horizontal pipe.

② When the wastewater only from a food waste grinder is drained, approx. 8 L/min. of water supply flow rate is needed to be run for longer than the operation time of the food waste grinder, but generally as the sink drain which drains general wastewater for cooking and dish washing, great problems are not expected. Furthermore, bulk-draining the sink is an effective way to prevent sediment build-up.

③ The food waste for a day should be treated each time when it is generated instead of grinding it all at one time.

④ As for the joint that connects the horizontal and vertical pipes, tee wye (TY) lets waste water flow in a vertical pipe twice as much as ST, so it has been said ST should be used, but when the capacity of the vertical pipe is large enough, it is better to use TY.

⑤ Horizontal pipes should be so installed that there is no step difference on the inner surface of the waste pipe and joint.

⑥ The clean outs on the horizontal pipes, if possible, should be installed from the top of pipes where wastewater always runs.

⑦ The drain pipe for a food waste grinder should be cleaned with high pressure at least once a year.

## 4.4 Drain characteristics on food waste grinder

(1) Purpose of experiment

Prior to considering the introduction of food waste grinders, one must take into account its effects on waste pipe clogging and wastewater treatment. Therefore, drain characteristics of disposer should be grasped. In this report, particular notes: first, the ground grain size distribution for each model of food waste grinder, and second, any relevant measurements affecting equipment drain characteristics are reported.

(2) Selection of food waste grinder used for the experimentation

8 models (some imported, some domestic) were selected as typical food waste

grinders, each of which at present are commonly available on the domestic market. Three units of each model were provided on the assumption that there would be variations inproduct performance by testing to identify the each performance, and the individual units were ranked accordingly. The units with the best performance were chosen as food waste grinders for tests.
The models and specifications of the tested food waste grinders are outlined in Table 5.

(3) Distribution of ground grain size for each food waste grinder model

The ground grain size serves as an important index when considering the effects of ground food waste on both the transportation of wastewater in the waste pipe, and the overall water treatment facility load. Therefore, a measurement of the ground grain size for each test model is required.

① Experimental method

The measurement of the distribution of ground grain sizes was carried out using six sizes of "analytical screen". At the time of measurement, the screens overlapped, with the larger ones on top and the smaller ones further down. The shredded food waste water was flowed downward. At this time, the food waste grinder was operated in the same manner as during the measurement of grinding time. With only this water flow, however, smaller grains might still remain on the upper screen, so shower flushing was used to assist the procedure. Residual matter on each "screen" was placed on a cotton cloth for dehydration (the residual matter was showered out onto the cotton cloth) after which it was dehydrated in a centrifugal dehydrator for three minutes. And then, the weight was measured.

The charged amount of "standard food waste" was three times that of the standard amount (250 g) to make the dispersion smaller. The water supply (momentary flow rate) was 8 L/min.

The measurement diagram is shown in Figure 5.

Used "analytical screen" (sieve opening dimensions specified in JIS Z 8801 "test screen")

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Wire dia. standard dimensions | (mm) | 1.25 | 0.90 | 0.80 | 0.56 | 0.45 | 0.40 |
| Sieve opening standard dimensions | (mm) | 3.35 | 2.00 | 1.70 | 1.00 | 0.71 | 1.60 |

② Experimental Results

The results (ground grain size) of the standard food waste for each model are given in Table 6 and Figure 6.

The proportion of the residue larger than the sieve openings 3.35 mm and 2.0 mm was remarkable. Food waste grinders were divided into three major groups; models A to D are 47.6 to 42.6%, models E and F are 34.6 to 37.5%, and model H is 30%. It can be seen that the ratio of ground waste which permeated the sieve opening of 0.60 mm becomes larger in these group order.

It can be seen it seems that the grinding mechanism of the food waste grinders has been designed with a sieve opening 2.0 mm or more in mind.

(4) Fixture drain characteristics of food waste grinders

Plumbing Fixtures, such as food waste grinders, need to have precisely measured drain load characteristics in advance of the waste piping design.

① Experimental method

The measurement of fixture drain characteristics was carried out in accordance with HASS 206 "Plumbing code-its commentary". The fixture drain characteristics refers to drain characteristics such as: the drain flow rate and time change of drain flow rate when draining from the fixture, as well as information on the fixture drain for example, equipment drain capacity, average fixture drain flow rate, required time for drainage, etc. All of these values can be determined experimentally. The diagram related to this measurement is given in Figure 7 and the detail of measuring device is given in Figure 8.

A trap with an inner diameter of 34 mm was installed with the nozzle of food waste grinder, where a transparent waste pipe was connected to the measuring device at the end.

In the measurement of drain flow rates from the food waste grinders, data was recorded by the measuring device as a series of voltage changes, recorded on digital audio taperecorder (DAT). These voltage changes were later translated back to water volumes based on a series of pre-determined voltage/water readings.

② Experimental Results

At the calculation of instantaneous drain values from the recorded data, to eliminate extraneous figures, AD conversion was carried out and the results smoothed by averaging-out. Measurements were carried out three times for each model, however, the measurement frequency was added for models C, F, and H to observe their dispersion.

The results on fixture drain amounts and fixture average drain flow rates are given in Table 7; the flow rate - time characteristics of models A to H are given in Figure 9. The 0 second of the time axis in Figure 9 was set to the starting time of water input to the weighing tank.

In Figure 9, flow rate-time characteristics, the maximum value of instantaneous drain flow rates are approx. 0.18 to 0.20 L/sec. and fixture average drain flow rates are approx. 0.13 to 0.15 L/sec., so the difference between the models was insignificant. Fixture drain amounts between models were large and 6.7 liters (Model C) was the minimum value, while 17.4 liters (Model H) was the maximum.

In Figure 9, flow rate-time characteristics, the maximum flow rate was achieved at about 10 seconds after the start of draining, while from around 20-second to the completion time of grinding, it showed a slight fall with time in the flow characteristics. It can be guessed that mixture the ground waste was affecting the slower flow rate.

## 5. Future consideration

All aspects of this project have proven favorable--the food waste grinder and waste piping, the standard wastewater treatment systems 1 and 2, and the development of technology for the food waste composting plant.

A field test installing disposers and wastewater treatment plants with or without composter is being planned for implementation in a housing system from 1996 through to 1997. The results from this project will also be coordinated as "Design Guidelines for Food Waste Recycling Systems Using Food Waste Grinders" and the "Food Waste Recycling System with Food Waste Grinders" will be introduced along with the

construction of multiple-residence housing units, etc. under the administration's control.

The importance of establishing a people-friendly social environment has been well established, as we approach the 21st century. In particular, it is very important to deal with this matter of food waste treatment, without which current lifestyles are not sustainable, while retaining our understanding of the current situation and having an appropriate vision for the future.

On the part of the Japanese plumbing industry, it is appropriate for us to take advantage of the current environmental awareness by drawing up and implementing our plans aggressively.

[Address of Gratitude]

The Building Research Institute of the Ministry of Construction, as well as all the members of the Japan Society of Plumbing GDCC (Garbage Disposal and Composting Committee) for their great cooperation and guidance in compiling this report are much appreciated.

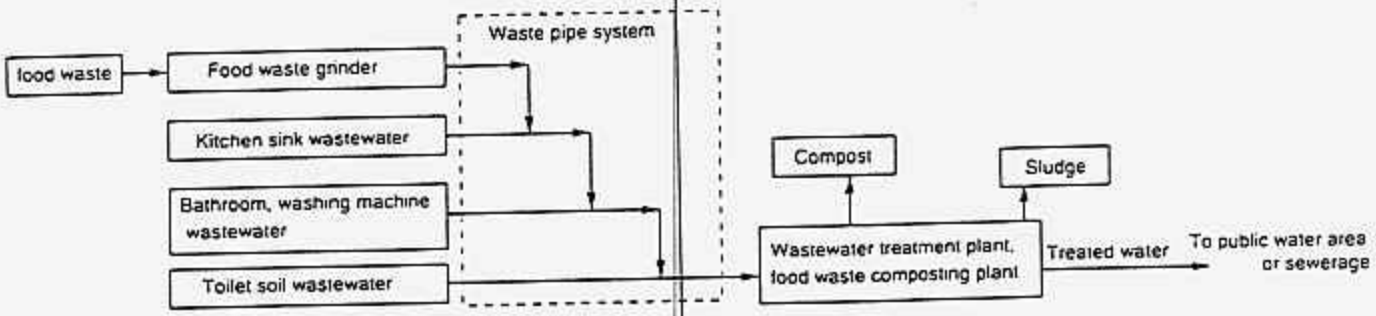



Figure 1 Standard system 1 (all wastewater combined system)

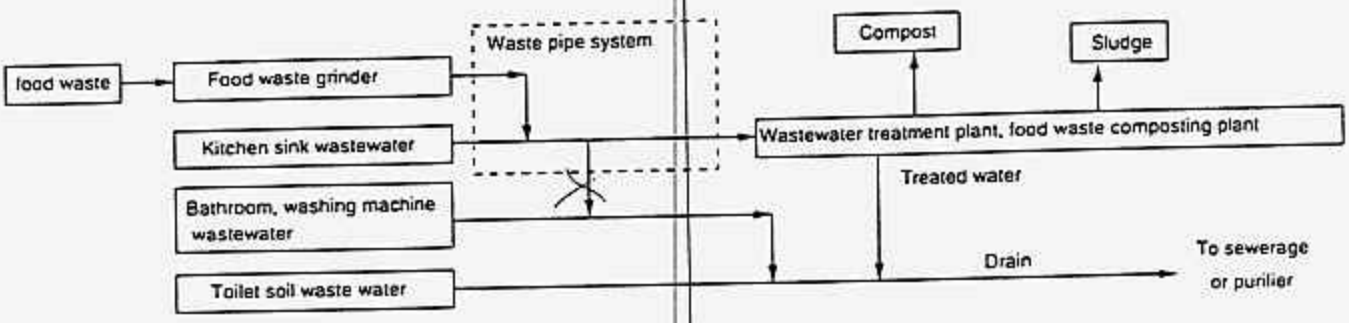



Figure 2 Standard system 2 (Kitchen wastewater separated system)

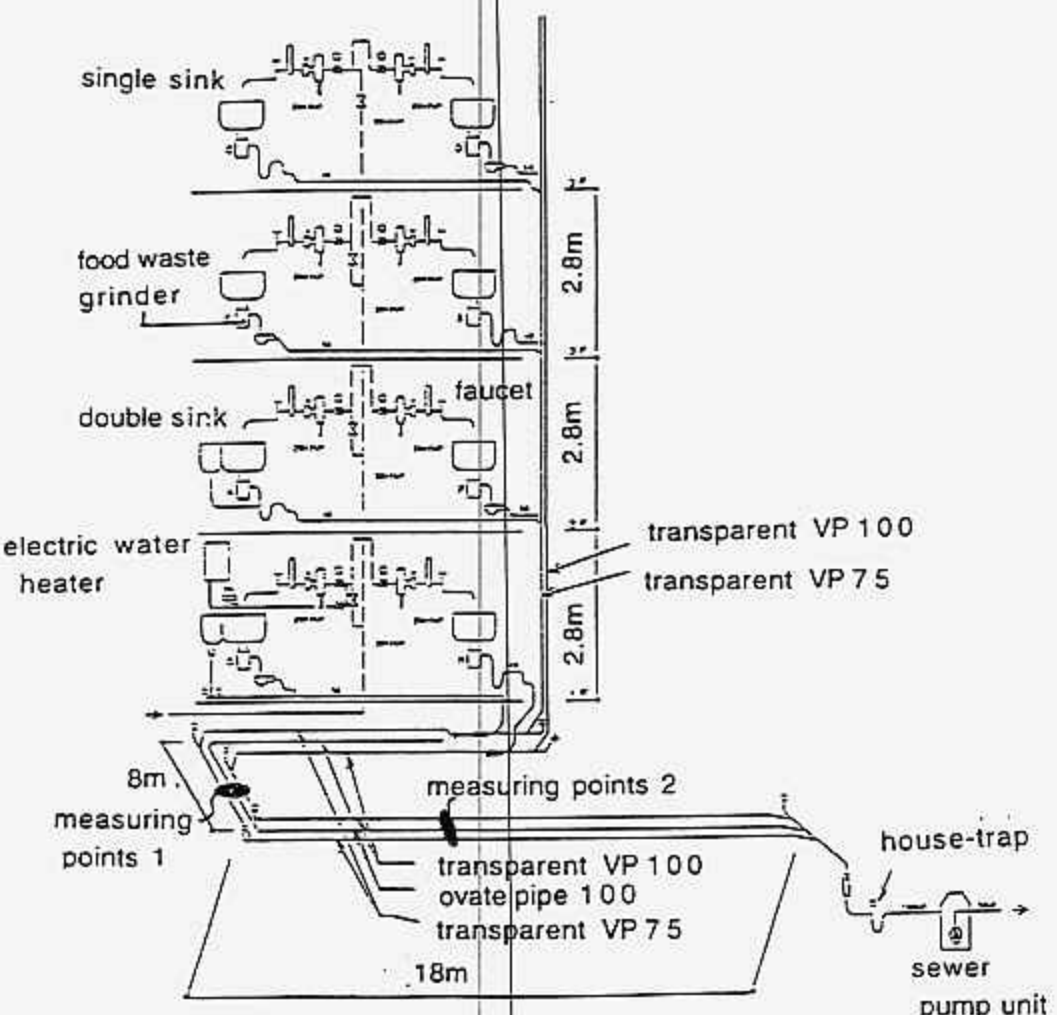



Figure-3 Experimental piping system




Drain vertical pipe 75 VP
(for 4 housing units)

Main horizontal pipe 125 VP (grade : 1/100)
(for 12 housing units)

Figure 4 Deposit in ground food waste piping

Table 4 Characteristics of deposit in pipe in Figure 4

| Deposit | vertical pipe | main horizontal pipe |
|---|---|---|
| Dry deposit amount ($g/m^2$) | 113 | 782 (2653)* |
| Organic matter ratio (wt%) | 15.6 | 1.7 |
| Inorganic matter ratio (wt%) | 84.4 | 98.3 |
| Oils and fats/organic amount (wt%) | 30.2 | 12.4 |

* Percentage per unit sediment surface

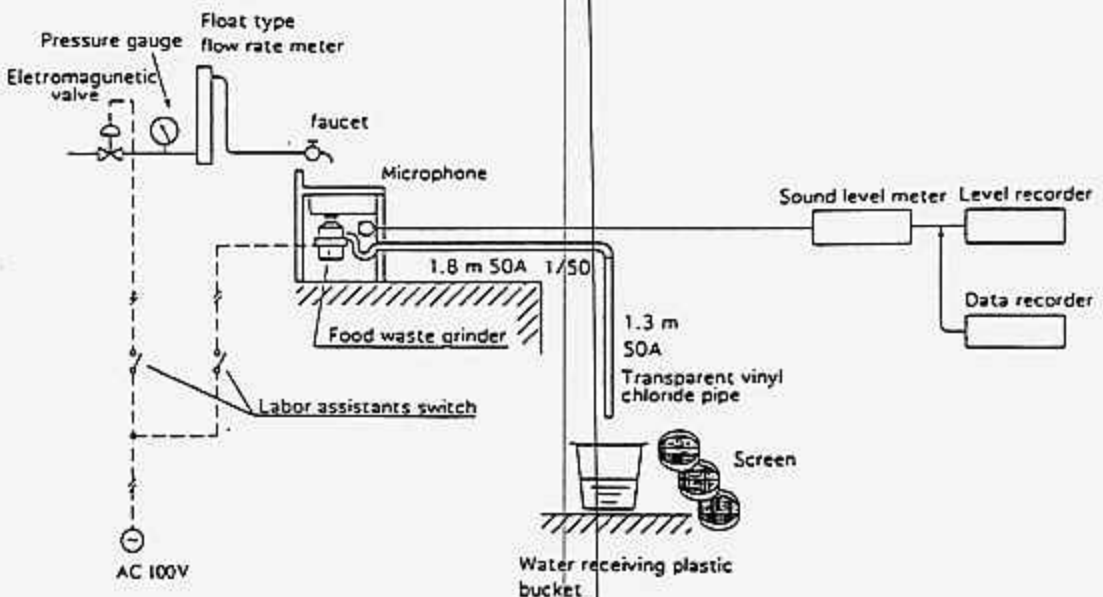



Figure 5 Block diagram of measurement on grain size distribution of ground waste

Table 6 List of shredded grain size test results on "standard food waste" with food waste grinder used

| Nominal dimensions of screen / Model | Weight (g) | | | | | | | Total weight (g) |
|---|---|---|---|---|---|---|---|---|
| | 3.35 | 2.00 | 1.70 | 1.00 | 0.71 | 0.61 | Less than 0.60 not including 0.60 | |
| A | 162 | 173 | 28 | 50 | 22 | 9 | 288 | 732 |
| B | 186 | 159 | 31 | 57 | 21 | 12 | 269 | 735 |
| C | 165 | 192 | 28 | 55 | 22 | 9 | 279 | 750 |
| D | 150 | 169 | 29 | 55 | 21 | 13 | 311 | 748 |
| E | 77 | 204 | 37 | 64 | 23 | 14 | 330 | 749 |
| F | 77 | 199 | 46 | 71 | 31 | 12 | 328 | 764 |
| G | 81 | 178 | 33 | 85 | 38 | 17 | 317 | 749 |
| H | 24 | 201 | 34 | 76 | 31 | 11 | 382 | 759 |

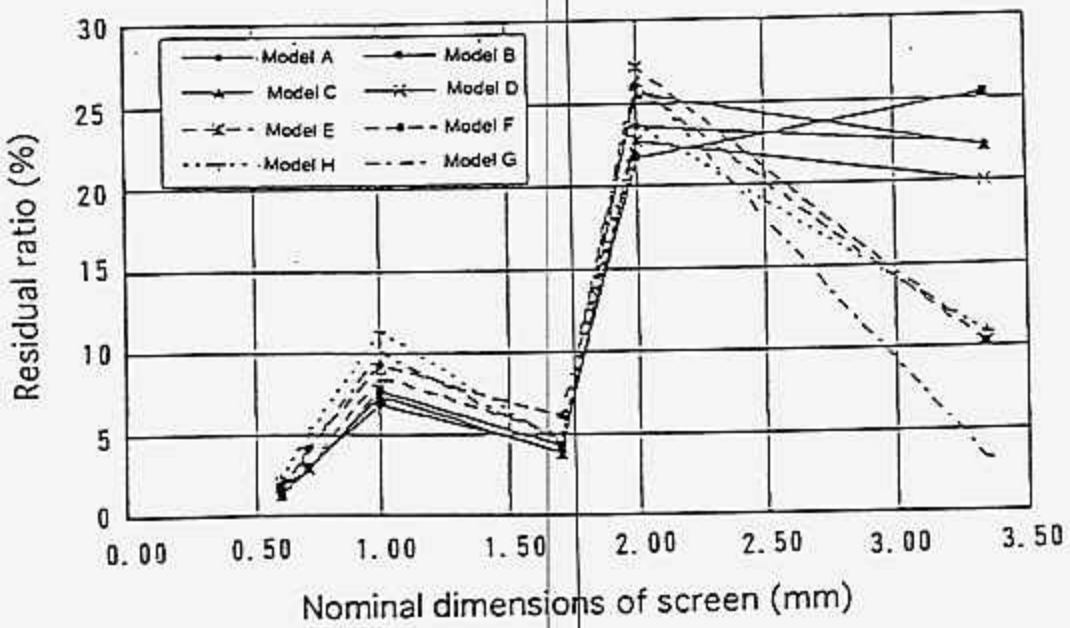



Figure 6 Distribution of ground grain size of " standard food " with food waste grinders unite

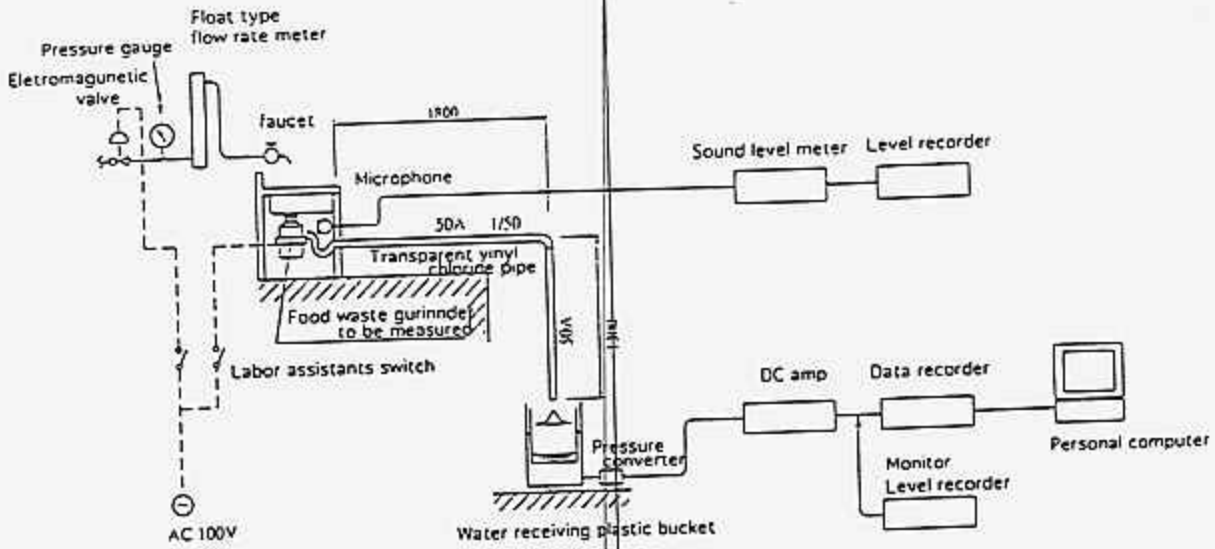



Figure 7 Block diagram of measurement on fixture drain characteristics

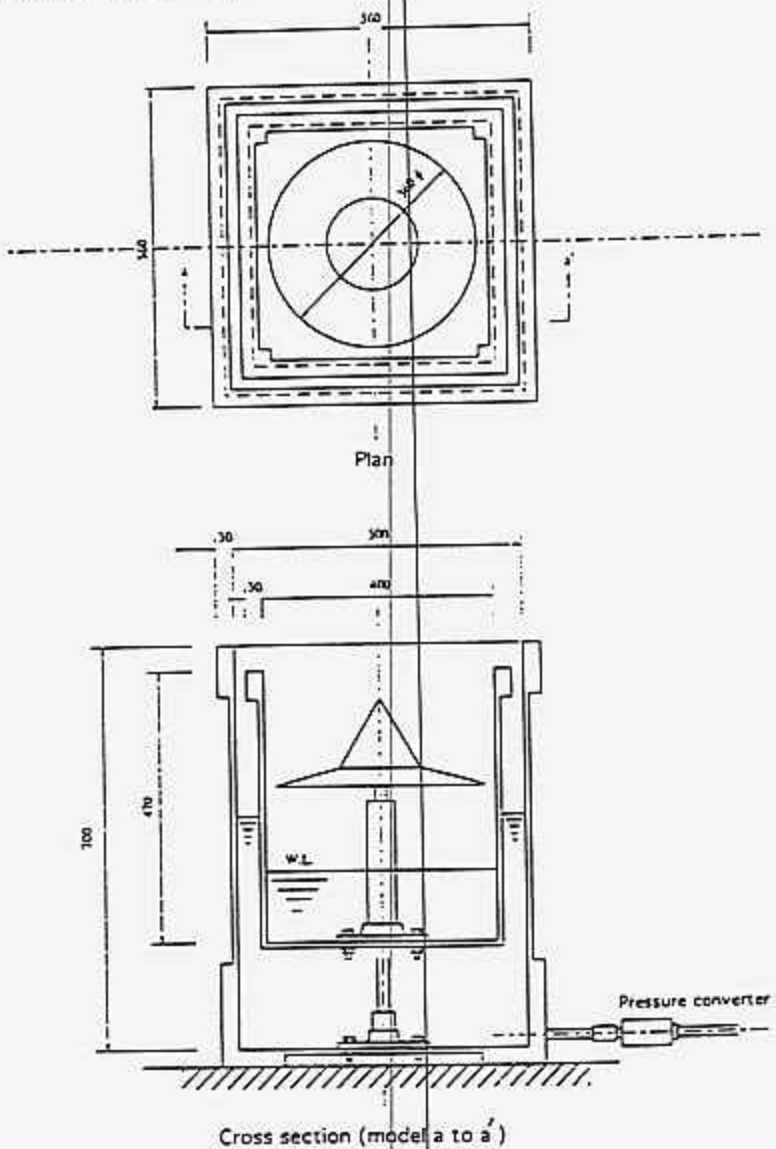



Figure 8 Detailed drawing of water-meter measurements on flow rate variation

Table 7 Resuite of equipmente drain characterristics of dispoosal unite

| | Model A | Model B | Model C | Model D | Model E | Model F | Model G | Model H |
|---|---|---|---|---|---|---|---|---|
| Equipment drain amount (L) | 10.75 | 8.57 | 8.41 | 9.06 | 12.69 | 8.23 | 6.74 | 17.43 |
| Equipment average drain flow rate (L/sec) | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.15 | 0.13 |

Equipment drain amount : Entire water amount drained by disposal unit at one-time drain

Equipment average drain flow rate : Average flow rate between 20% and 80% of the drain amount is drained in the drain of disposal

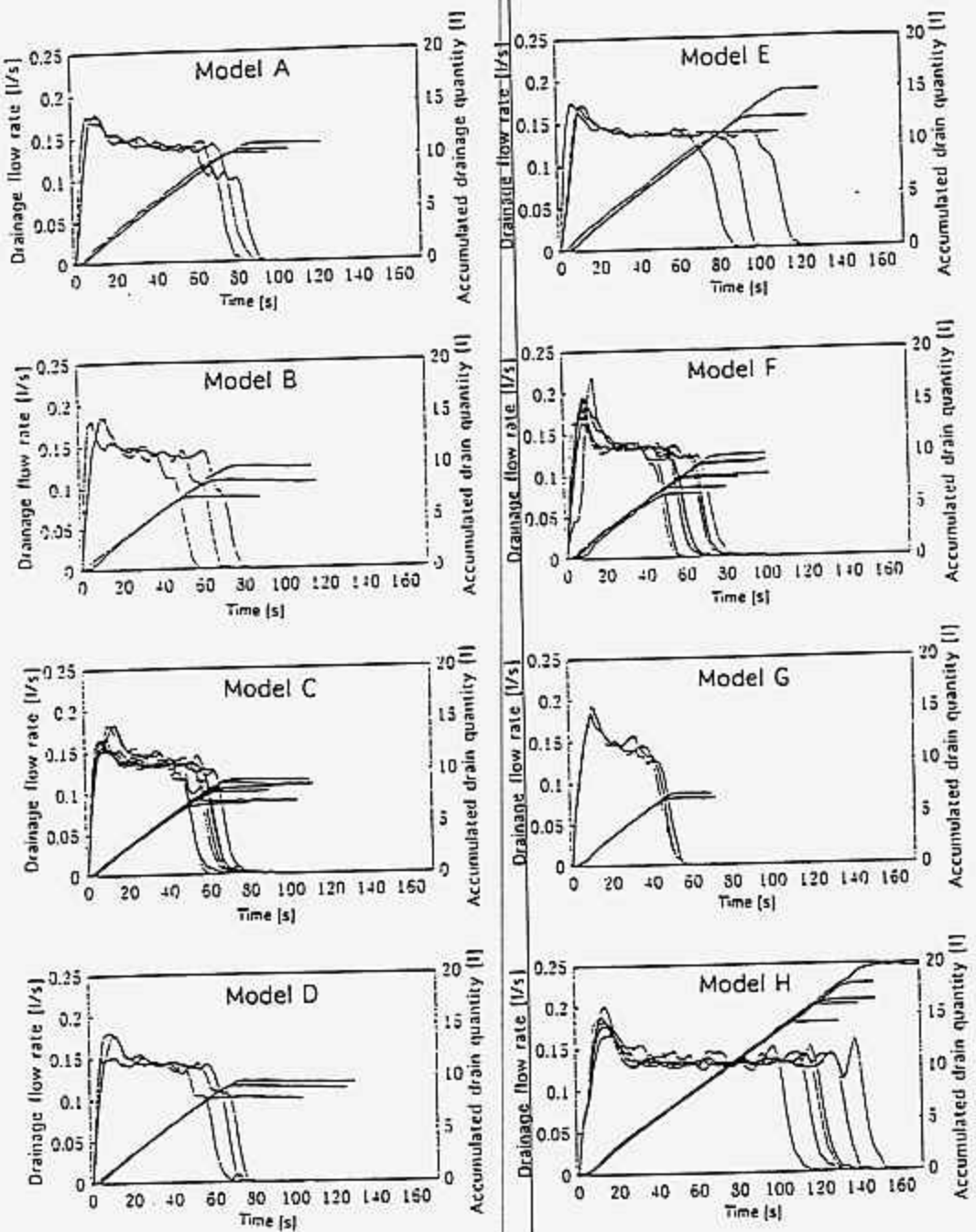



Figure 9 Fixture drain characteristics of food waste grinders

Table 1 Usage statistics on food waste grinders in countries other than the U.S.

| Country | Usage of food waste grinders | | | Import condition of food waste grinders |
|---|---|---|---|---|
| | Recommended | Not recommended but being used | Prohibited | |
| England | | ○ | | ○ |
| Malta | | ○ | | ○ |
| Australia | | ○ | | ○ |
| France | | | ○ | ○ |
| Switzerland | | | ○ | ○ |
| Austria | | | ○ | ○ |
| Germany | | | ○ | ○ |
| Denmark | | ○ | | |
| Belgium | | | ○ | ○ |
| Finland | | | ○ | |
| Norway | | | ○ | ○ |
| Canada | | ○*2 | | ○ |
| Brazil | | ○*2 | | ○ |
| Italy | | ○*2 | | ○ |
| Spain | | ○*2 | | ○ |
| Republic of South korea | | | ○*2 | |
| Singapore | | | ○*2 | |

*1 Questionnaires distributed at the CIB-W62-1994 ( Brighton )

*2 Based on GDCC overseas investigation

Table 2 Composition of food waste used in the experiment

| | Material | Specification | Wetting weight | Standard weight |
|---|---|---|---|---|
| Vegetables | Carrots | Cut by approx.2cm | 18 % | 45 g |
| | Cabbages | Cut roughly | 18 | 45 |
| | Subtotal | | 36 | 90 |
| Fruits | Banana peels | | 30 | 25 |
| | Apple or pear | Cut roughly | | 25 |
| | Grapefruit peels | Half cut after squeezing | | 25 |
| | Subtotal | | 30 | 75 |
| Others | Chicken bones | Leg bones or wing bones ( after cooking ) | 8 | 20 |
| | Fishes | Dried, with bones ( after heating ) | 10 | 25 |
| | Egg shell | | 2 | 5 |
| | Rice | | 10 | 25 |
| | Tea leaves | After draining | 4 | 10 |
| | Subtotal | | 34 | 85 |
| Total | | | 100 % | 250 g |

Table-3 Flow characteristics of ground food wastewater at measuring point-1 of the 1 model independent drain .

| Model | Pipe diameter | Grade of main horizontal pipe | Water supply flow rate (L/min.) | Flow velocity of main horizontal pipe (m/s) | Flow rate of main horizontal pipe (L/min.) | Friction coefficient | Remarks |
|---|---|---|---|---|---|---|---|
| C(4F) | 100mm | 1/100 | 8 | 0.33 | 21.8 | 0.0158 | Flow forming a weir at the measuring point-1 |
| | | | 6 | 0.43 | 26.5 | 0.0118 | |
| | | | 4 | 0.43 | 12.5 | 0.00854 | |
| | | 1/150 | 8 | 0.27 | 14.4 | 0.0144 | |
| | | | 6 | 0.46 | 30.4 | 0.00923 | |
| | | | 4 | 0.50 | 30.8 | 0.00826 | Flusing water of 4 L/min x 30 sec. Â~two times required |
| F(3F) | 100mm | 1/100 | 8 | 0.40 | 3.42 | 0.00538 | |
| | | | 6 | 0.33 | 2.31 | 0.00598 | |
| | | | 4 | 0.25 | 1.51 | 0.00455 | |
| | | 1/150 | 8 | 0.30 | 4.87 | 0.00776 | |
| | | | 6 | 0.30 | 4.23 | 0.0073 | |
| | | | 4 | 0.16 | 4.67 | 0.0187 | Flow forming a weir at the measuring point-1 |
| D(4F) | 75mm | 1/100 | 8 | 0.35 | 16.4 | 0.0135 | Flow forming a weir at the measuring point-2 |
| | | | 6 | 0.20 | 16.2 | 0.0294 | Flow forming a weir at the measuring point-1 |
| | | | 4 | 0.29 | 18.3 | 0.0294 | Flow forming a weir at the measuring point-1 |
| | | 1/150 | 8 | 0.33 | 13.0 | 0.0109 | |
| | | | 6 | 0.27 | 11.6 | 0.0138 | Flow forming a weir at the measuring point-2 |
| | | | 4 | 0.22 | 8.67 | 0.0141 | |
| E(2F) | 75mm | 1/100 | 8 | 0.30 | 12.9 | 0.0152 | Flow forming a weir at the measuring point-2 |
| | | | 6 | 0.30 | 12.9 | 0.0152 | Flow forming a weir at the measuring point-2 |
| | | | 4 | 0.26 | 8.50 | 0.0156 | |
| | | 1/150 | 8 | 0.33 | 9.74 | 0.00962 | |
| | | | 6 | 0.30 | 7.95 | 0.0101 | |
| | | | 4 | 0.19 | 8.17 | 0.0196 | |
| C(4F) | 100mm oval pipe | 1/100 | 8 | 0.46 | 24.3 | 0.0111 | Flow forming a weir at the measuring point-2 |
| | | | 6 | 0.35 | 33.3 | 0.0178 | Flow forming a weir at the measuring point-1 |
| | | | 4 | 0.35 | 38.6 | 0.0187 | Flusing water of 4L/min. x 10 sec. Â~ four times required |
| | | 1/150 | 8 | 0.22 | 12.9 | 0.0197 | Flow forming a weir at the measuring point-1 |
| | | | 6 | 0.17 | 16.8 | 0.0303 | Flow forming a weir at the measuring point-1 |
| | | | 4 | 0.16 | 14.7 | 0.0314 | Flow forming a weir at the measuring point-1 |
| F(3F) | 100mm oval pipe | 1/100 | 8 | 0.55 | 6.79 | 0.00542 | |
| | | | 6 | 0.50 | 4.65 | 0.0053 | |
| | | | 4 | 0.46 | 4.28 | 0.00576 | |
| | | 1/150 | 8 | 0.46 | 9.81 | 0.00656 | |
| | | | 6 | 0.46 | 7.24 | 0.00539 | |
| | | | 4 | 0.32 | 7.47 | 0.00845 | |

Note 1 : Friction coefficient is a value corresponding to the roughness coefficient in the manning formula

Note 2 : The wetted perimeter length of the round pipe was measured at the outer face of the pipe, then it was corrected to the value at the inner face, after flow rates and friction coefficients were caculated.

Table 5 Measurements on food waste grinder specifications

| | Model | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|
| | Disposal method | Continuous system | Continuous system | Continuous system | Batch system | Continuous system | Batch system | Continuous system | Continuous system |
| Motor | Motor type | Capacitor sart-up type induction motor | Capacitor sart-up type induction motor | Capacitor sart-up type induction motor | Capacitor sart-up type induction motor | Permanent magnet type motor | Permanent magnet type motor | Universal | Capacitor sart-up type induction motor |
| | Nominal rated output (HP) | 3/4 | 3/4 | 3/4 | 3/4 | 1/2 | 3/4 | 3/4 | 0.65 |
| | Nominal rotational frequency (rpm) | 1,425 | 1,425 | 1,425 | 1,425 | 2,600 | 2,700 | 8,000 | – |
| | Maximum load outpit (A) | 8.1 | 8.1 | 8.0 | 8.5 | 4.8 | 5.4 | 7.9 | ( 8.2 ) |
| | Non-load current (A) | 7.7 | 7.6 | 7.6 | 7.8 | 1.8 | 1.8 | 2.9 | ( 6.4 ) |
| Dimensions | Inlet diameter (mm) | 85 | 85 | 85 | 85 | 80 | 80 | 80 | 80 |
| | Effective inner diameter for sprash guard input port (mm) | 78 | 78 | 75 | – | 63 | – | | |
| | Scupper outer diameter (mm) | 38.2 | 38.2 | 38.2 | 38.2 | 38.0 | 38.2 | 38.2 | 32.0 |
| | Depth of grinding chamber (mm) | 155 | 155 | 155 | 220 | 170 | 230 | 160 | 180 |
| | capacity of grindng chamber (L) | 1.0 | 1.2 | 1.3 | 1.8 | 0.9 | 1.2 | 0.9 | 1.7 |
| | Weight (kg) | 7.2 | 7.7 | 9.0 | 9.5 | 5.4 | 6.0 | 3.8 | 13.0 |

Notes :

1 For load and no-load, the current is the average of measured value of 3 units (AC 100V 50Hz)

2 The depth of the grinding chamber is the depth from the edge of the sink inlet to the rotor shredder board.

3 The capacity of the grinding chamber is the capacity from the rotor grinder board to the position of the stopper of the splash gurd for continuous system models, and to the presser lid stopper position for batch system models.

# Topic A4

## Aerosol Generation by Taps

W. Carson, Scotland



UNIVERSITY
*of*
GLASGOW

# AEROSOL GENERATION BY TAPS AND THE RESULTANT EXPOSURE OF HUMANS TO LEGIONELLA BACTERIA

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# AEROSOL GENERATION BY TAPS AND THE RESULTANT EXPOSURE OF HUMANS TO LEGIONELLA BACTERIA

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## 1. Summary

It is widely believed that infection by Legionella bacteria results from the inhalation of the bacteria in aerosols of water which contains the bacteria. In this paper an experimental method for measuring aerosol production rates from taps is described. Factors influencing the rate of production are investigated and some qualitative results are presented.

The exposure of people to the bacteria is affected by their respiration rate, the duration of their exposure and the ventilation rate of the room concerned as well as the rate of production of the aerosols and the concentration of bacteria in the water. The relationships between these factors is examined in the paper.

## 2. Acknowledgements

This paper is based on project work by four final year students of Mechanical Engineering in the University of Glasgow.

| | |
|---|---|
| 1991-92 | Ian Dick |
| 1992-93 | Richard A. Nelson |
| 1994-95 | Roderick W. McDonald |
| 1995-96 | John Van der Stighelen. |

The first project was very much "a shot in the dark" or "suck it and see" exercise. There was little idea initially of where the project would lead and only very broad objectives were defined. During the subsequent projects the objectives became more specific while the experimental apparatus and methods were developed and refined.

The present paper is a statement of the current understanding of the subject. There is no attempt to trace its development. In several cases results can be presented only as comparisons because errors and inconsistencies make the numerical values unreliable.

## 3. Introduction

Bacterial infections always involve the transfer of bacteria from a source to a susceptible host. In the case of Legionella infections the source is usually contaminated water. It is widely believed that transfer takes place in aerosol droplets of this water which are inhaled. These are small enough to penetrate deep into the lungs of the host. Here, if the host is susceptible, they react with the lung tissue to cause Legionellosis. There is however some doubt about this transmission route. Stout and Yu,[1] state that the mode of transmission is uncertain and, that although evidence exists to support aerosolization, there is also evidence to support aspiration of contaminated water or oropharyngeal secretions. It does not seem unreasonable to suggest that contaminated aerosols could be a cause of the intermediate infection of the oropharynx, though drinking contaminated water could be another.

Elimination of the Legionella pneumophila bacteria from water distribution systems would clearly be an effective means of reducing the risk of infection. Much work has been done on methods of sterilization and on the contamination levels found in installations. Karl De Cuyper's paper for this seminar is the latest in a series going back at least to Ovesen's paper in 1989 [2].

While elimination remains the main thrust of precautions against Legionella it has proven to be an elusive target. Some attention is given to aerosol production within the context of risk assessment in Health and Safety legislation and guidance [3] & [4]. No publications have been found which deal with aerosol generation by hot and cold water supply fixtures though one manufacturer at least has offered shower heads "researched and designed to reduce aerosols and minimise the inhalation of Legionella bacteria".[5] Some work has been done[6] on the inhalation of volatile organic compounds and radon released from tap water but this seems to consider mass transfer by evaporation rather than the formation of aerosols.

This paper is intended to provide a basis for the assessment of aerosol generation and of the resultant exposure by inhalation. An experimental method of measuring aerosol production rates will be described and used to investigate the factors which influence the production rate. The interaction between aerosol production and room ventilation will be examined to enable exposure doses to be estimated. Unfortunately the relationship between

exposure and probability of infection is not known so that the final (medical) link in the assessment of the risk of infection is still missing. The process for risk assessment is summarised in the flow chart shown in Figure 1.

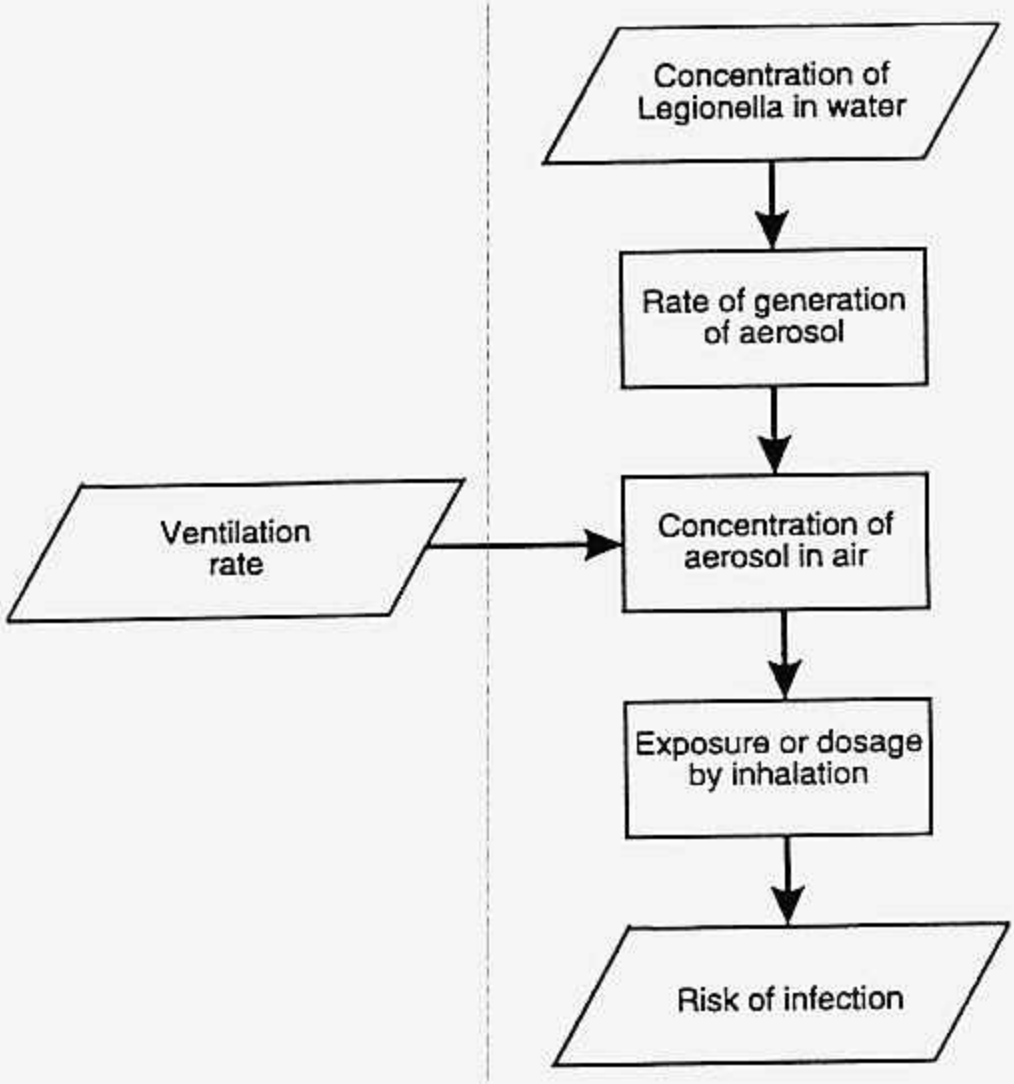



Figure 1: Flow chart for assessment of risk of infection from Legionella in water distribution systems

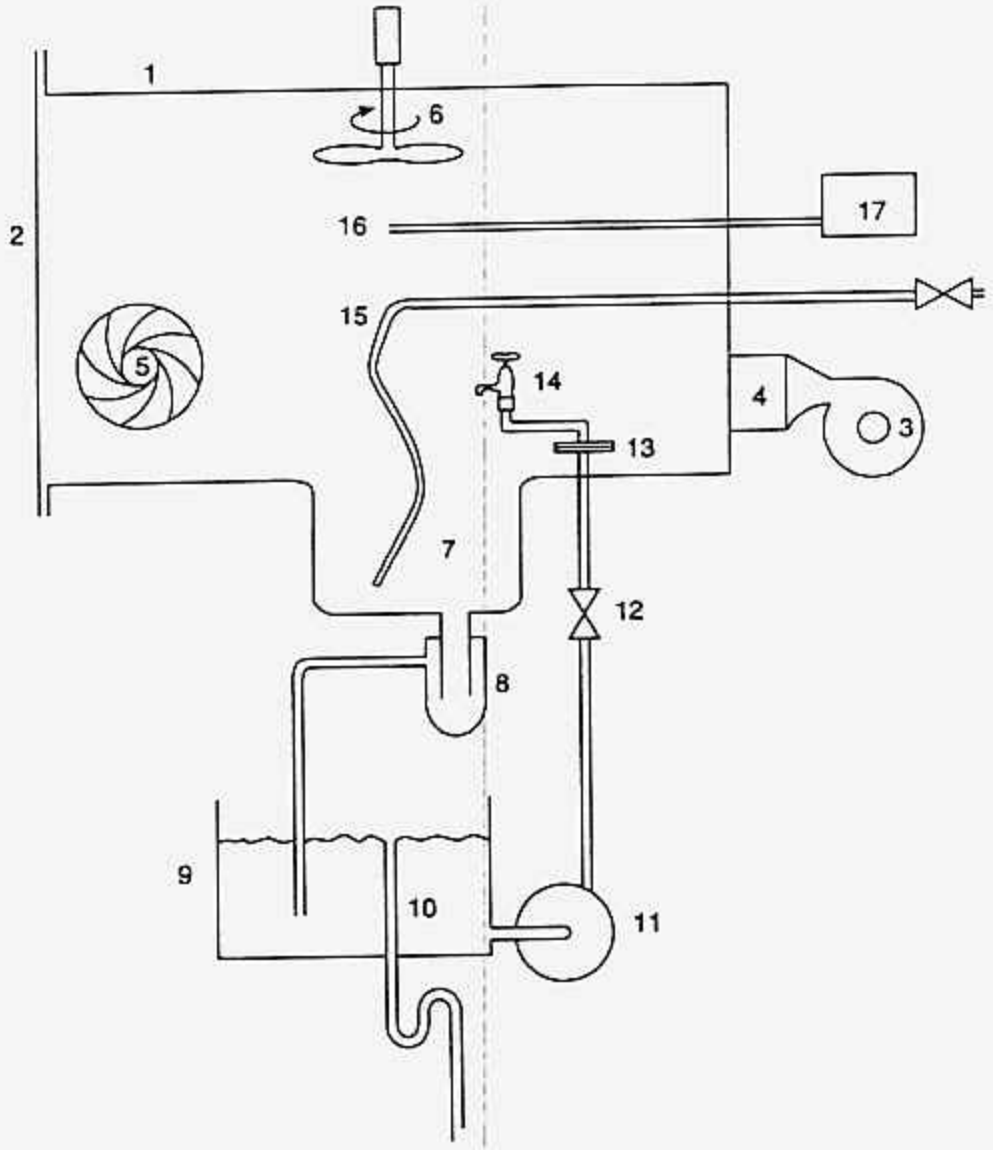
## 4. Experimental Apparatus and Methods

Aerosols are formed when small droplets of water evaporate leaving any dissolved or suspended solids as solid airborne particles. If these are small enough they will remain in the air for significant lengths of time. For obvious reasons it would have been unacceptable to use live bacteria in experiments to be conducted by engineering students. Some simulant had therefore to be used and after some consideration common salt was chosen. This had no health risks and was cheap and readily available.

There is an important assumption here which has not been tested. This is that the mechanisms of droplet formation and evaporation are not affected by the presence of salt instead of naturally occurring contaminants.

A glove box, as used in the nuclear industry, was used as the basic enclosure for the experiments. The box was modified by fitting a laboratory pattern sink into the base and providing a particle free air supply. This provided a closed environment where all the airborne particles could be considered to have been generated by a tap discharging into the sink. A diagram of the apparatus is shown in Figure 2 with some detailed information. By using distilled water, extraneous dissolved contaminants should have been eliminated. The filter upstream of the tap was fitted to trap any particulate contaminants in the water. These two precautions enabled us to be reasonably confident that the majority of the aerosol particles generated were derived from the salt deliberately introduced into the system.

Four different taps were used in the tests. There was no particular reason for their selection other than they were examples of different styles of tap and happened to be available. Tap 1 (Figure 3) is an old pattern of household hand-basin tap, many of which are still in use, while Tap 2 (Figure 4) is a more modern version. Tap 3 (Figure 5) is a quarter turn tap with an aerated nozzle. Tap 4 (Figure 6) is a fairly old pattern of hose tap. When used with no fitting attached it is referred to as Tap 4A. When a fitting with a 37 mm long piece of 15 mm pipe was in place it is referred to as Tap 4B. A rose for a garden watering can was fixed to this fitting to represent a shower for a few tests.




1. Glove Box 1.53 x 0.84 x 0.935 m 1.202 $m^3$
2. Removable end for access
3. Variable speed fan:air supply
4. HEPA filter (99.999% efficient against particles > 0.3 µm dia.)
5. Iris damper fitted to glove port as air outlet
6. Air stirrer with external motor
7. Sink 0.4 x 0.33 x 0.17 m, 0.022 $m^3$
8. Bottle trap
9. Reservoir tank
10. Overflow plug to drain
11. Variable speed water pump
12. Quick action valve
13. Water filter (pore size 0.45 µm)
14. Tap being tested
15. Mains water supply with flexible delivery pipe
16. Air sampling probe
17. Airborne particle counter

NB. Other glove ports not shown on diagram are fitted with gloves for manipulating items inside box or blanked off

Figure 2: Schematic diagram of experimental apparatus

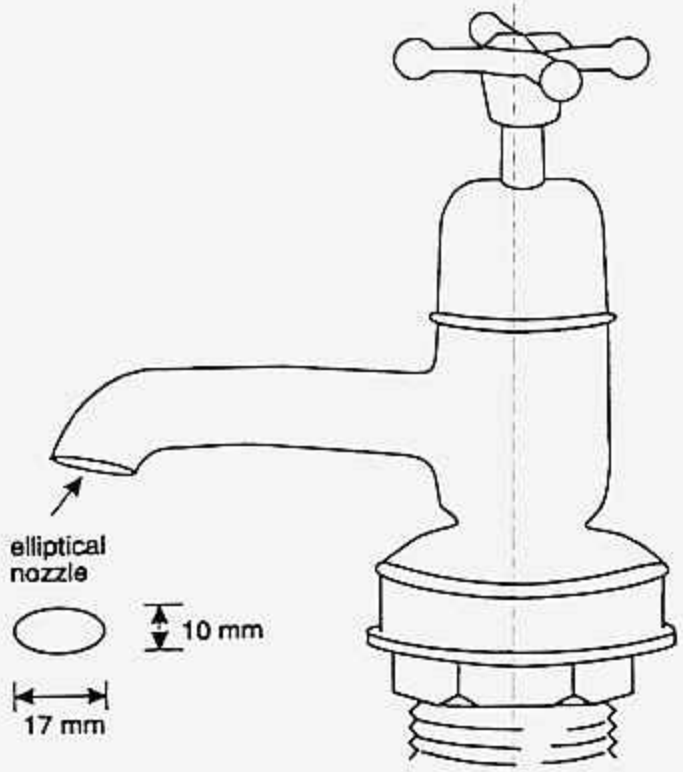



Figure 3: Tap 1 - Old style chromed hand-basin tap

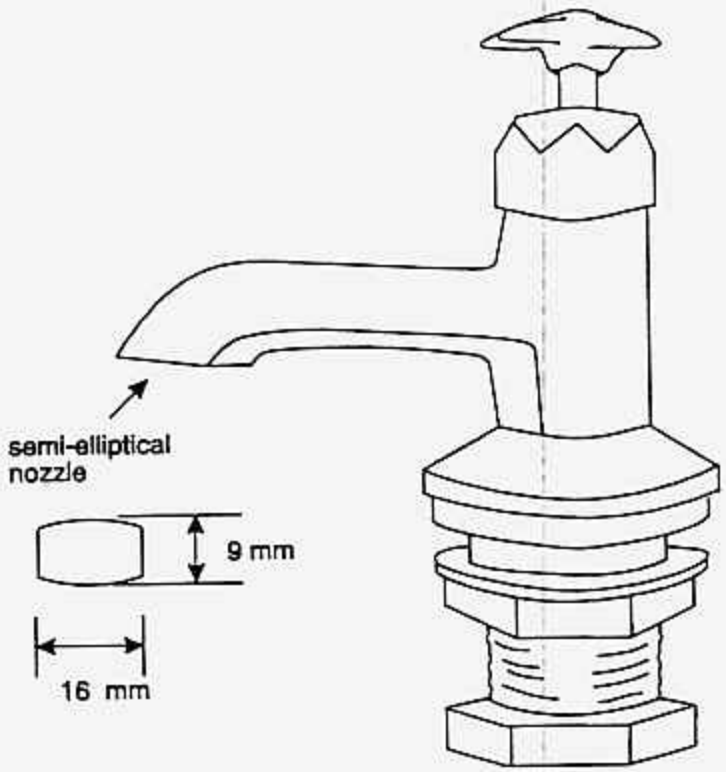



Figure 4 : Tap 2 - More modern chromed hand-basin tap

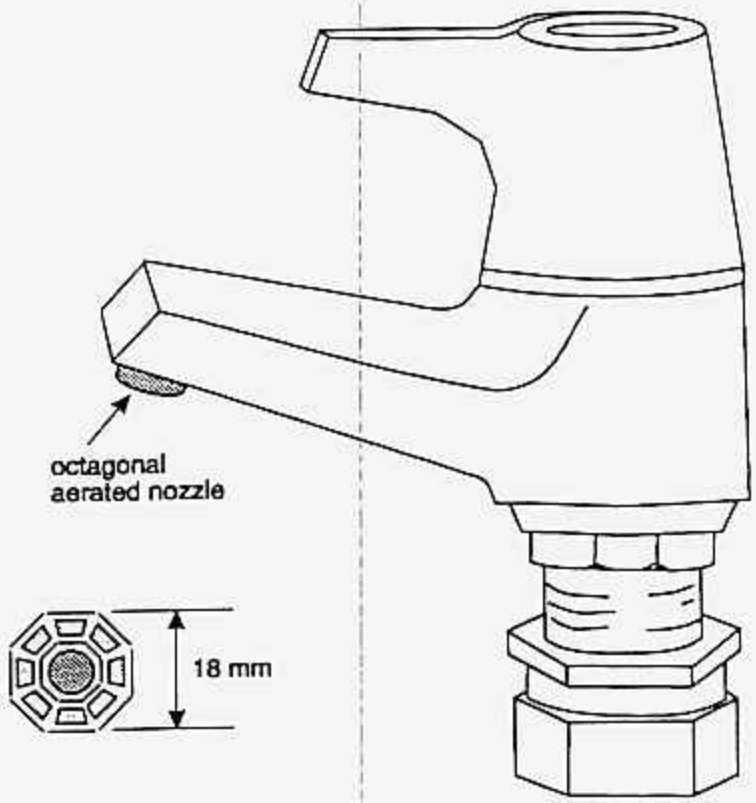



Figure 5 : Tap 3 - Modern 1/4 turn chromed hand basin tap

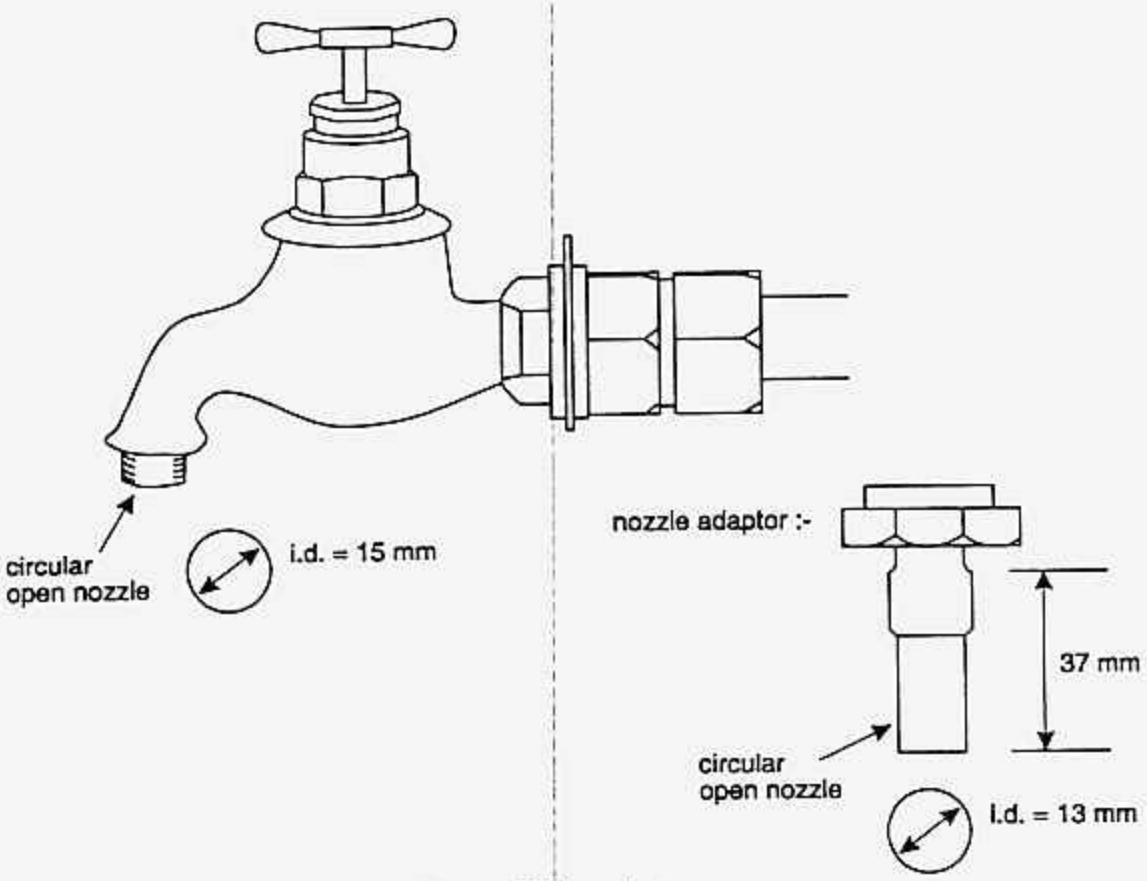



Figure 6 : Tap 4 - Old hose tap

The airborne particle counter used in this work was a rather elderly light scattering counter manufactured by Royco. The model 225 monitor sampled 0.1 cubic feet of air per minute. The model 264 display unit counted the number of particles larger than 0.5 μm diameter and the number larger than 5 μm detected during one minute periods. A model 503 recorder module had a variable size threshold which could be set to 0.5, 0.7, 1.4, 3 or 5 μm. Because of its age this counter could not be relied on to give unvarying accuracy. It was recalibrated by the manufacturer's agents from time to time and we were confident about its relative accuracy over short periods.

It was intended to measure the velocity of the air entering the box at the face of the HEPA filter and hence obtain the air flow rate. The results the students obtained this way did not always agree well with the rate of increase in particle counts. No good explanation for this discrepancy was found so in this report ventilation rates have been derived from the rate of increase in particle counts as explained in the following section.

## 5.0 Theory

### 5.1 Measurement of Particle Generation Rate

For an enclosure with perfect mixing the build up of contaminant from zero, with no contamination in the air supply, is described by the equation

$$N_t = \frac{n}{Q}\left[1 - e^{-\left(\frac{Qt}{V}\right)}\right] \qquad (1)$$

where $N_t$ = concentration of contaminant at time t, number of particles/$m^3$.

$n$ = Rate of release of contaminant, number of particles/s.

$Q$ = ventilation rate, $m^3/s$.

$V$ = volume of enclosure, $m^3$.

$t$ = time from start of release of contaminant, s.

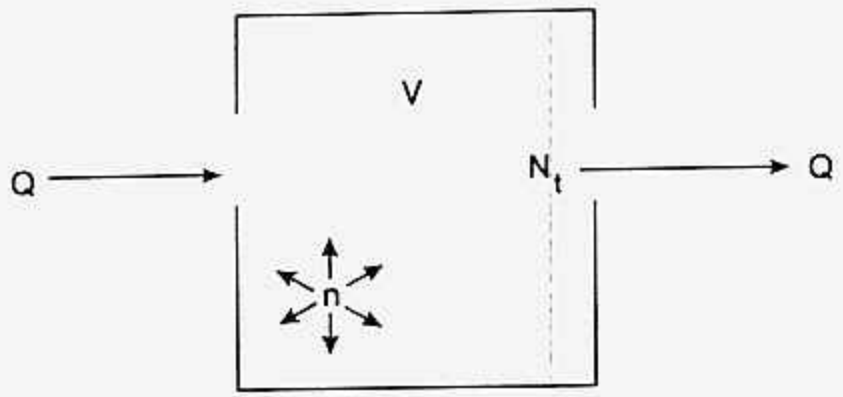



Figure 7 : Enclosure with perfect mixing

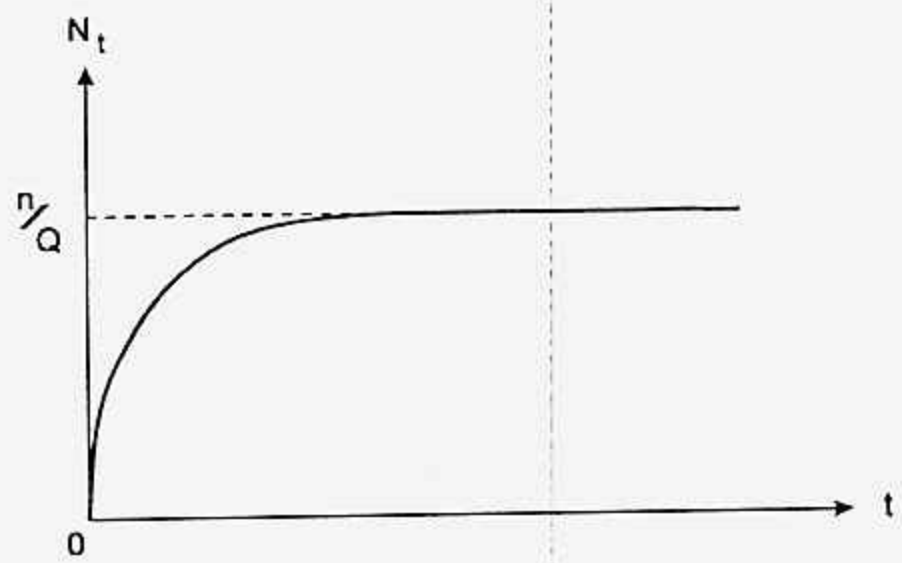



Figure 8 : Build up of concentration of contaminant

When the steady state condition is reached, theoretically when $t = \infty$, then

$$N_t = N_s = n/Q$$

$$\therefore n = Q N_s \text{ droplets/s} \qquad (2)$$

We can measure $N_s$ and can therefore obtain n if we know Q.

Calculation of Q

If the ventilation rate Q cannot be readily measured directly then it can be calculated from the relationship between contaminant concentration and time. In other words by evaluating the term Q/V in the exponential in equation (1).

Dividing equation (1) by the steady state concentration $N_s$, ie n/Q, we get:

$$\frac{N_t}{N_s} = 1 - e^{-\left(\frac{Qt}{V}\right)}$$

$$\therefore 1 - \frac{N_t}{N_s} = e^{-\left(\frac{Qt}{V}\right)} \qquad (3)$$

If the values obtained experimentally for the left hand side of this equation are plotted on Log-Linear graph paper then a straight line relationship should be seen,

i.e. $\text{Log } Y = a - bt$ (4)

Where $Y = 1 - \frac{N_t}{N_s}$

$a = \text{Log } 1$

$b = \frac{Q}{V} \log e$

The value of b can be estimated from the slope of the line but it is probably easier and more accurate to use a scientific calculator to carry out a linear regression of $\text{Log}_e Y$ on t. If this is done then the slope coefficient $b = \frac{Q}{V}$ because conveniently $\text{Log}_e e = 1$.

Q can now be obtained easily from

$Q = bV.$ (5)

As well as the assumption of perfect mixing mentioned initially, this analysis relies on two further assumptions; that 1) the ventilation rate in the enclosure and 2) the rate of aerosol generation remain constant.

EXAMPLE

Raw experimental data are shown in columns (1) and (2) of table 1. A linear plot of the data is shown in figure 9. From this it was decided to average the last eight values to give a value for the steady state concentration $N_s$ (column 3). Columns (4) and (5) of table 1 were then calculated and figure 10 drawn to illustrate the straight line relationship.

The regression equation obtained was

$$y = -0.937 - 0.0097\,t$$

with a correlation coefficient $r = 0.976$.

Now $Q = bV$.

The volume of the experimental enclosure was $1.224\ m^3$

$$\therefore\ Q = 0.0097 \times 1.224$$

$$= 0.0119\ m^3/s$$

Now $n = Q N_s$

$$= 0.0119 \times 19{,}713 \times 10^3$$

$$= 234 \times 10^3 \text{ Particles/sec.}$$

The fitted curve shown in figure 9 was obtained by substituting the above numerical values into equation (1).

A quick estimate of the flow rate, or a check on the regression arithmetic, can be made using the relationship,

$$N_t = 63.2\% \text{ of } N_s$$

after 1 air change has occurred; that is when

$$Qt = V$$

or $$Q = \frac{V}{t}$$

In this example 63.2% of $N_s = 12{,}460 \times 10^3$ Particles/$m^3$.

which occurs at approximately $t = 105$ secs

$$\therefore\ Q = \frac{1.224}{105} = 0.0117\ m^3/s.$$

| (1) Time t (s) | (2) Concentration $N_t$ (k Particles/$m^3$) | (3) Steady State Concentration $N_s$ (k Particles/$m^3$) | (4) $\frac{N_t}{N_s}$ | (5) $1 - \frac{N_t}{N_s}$ |
|---|---|---|---|---|
| 0 | 0 | | 0 | 1 |
| 60 | 6,758 | | 0.3335 | 0.6665 |
| 130 | 15,714 | | 0.7972 | 0.2028 |
| 200 | 17,868 | | 0.9064 | 0.0936 |
| 270 | 18,539 | | 0.9405 | 0.0595 |
| 340 | 18,774 | | 0.9524 | 0.0476 |
| 410 | 19,730 | | | |
| 480 | 19,687 | | | |
| 550 | 19,150 | | | |
| 620 | 19,016 | 19,713 | | |
| 690 | 19,023 | | | |
| 760 | 19,052 | | | |
| 830 | 20,907 | | | |
| 900 | 21,135 | | | |

**Table 1: Example calculation of ventilation rate**

### 5.2 Contamination Carried by Airborne Particles

The number of Legionella carried by the aerosol particles will be directly related to the volume of the wet droplets which are their precursors, and of the concentration of Legionella in the original water. The wet droplet volume was estimated experimentally from the measured dry particles size as follows.

SALT SOLUTION

Concentration of salt in water C g/$m^3$

Wet droplet size diameter D m

$$\text{Wet droplet volume} = \frac{4}{3}\pi\left(\frac{D}{2}\right)^3 \text{ m}^3$$

$$= \frac{\pi}{6} D^3 \text{ m}^3$$

$\therefore$ Mass of salt in one droplet $= \frac{\pi}{6} D^3 \times C$ g

Density of salt $= \sigma$ kg/m$^3$

$= \sigma \times 10^3$ g/m$^3$

$\therefore$ Volume of dry salt particle $= \frac{\pi D^3 C}{6 \sigma \times 10^3}$ m$^3$

If diameter of dry salt particle is d m

$$\frac{\pi}{6} d^3 = \frac{\pi D^3 C}{6 \sigma \times 10^3}$$

$$\therefore D^3 = \frac{d^3 \sigma \times 10^3}{C}$$

$$\therefore D = 10\, d \left(\frac{\sigma}{C}\right)^{\frac{1}{3}} \text{ m} \qquad (6)$$

Note. This equation can be rearranged to give,

$$d^3 = \frac{D^3 C}{\sigma \times 10^3}$$

If D is constant, since $\sigma$ is constant

$$d^3 = k C \qquad \text{where } k = \frac{D^3}{\sigma \times 10^3}$$

This relationship could be tested experimentally by varying C and measuring the dry particle size.

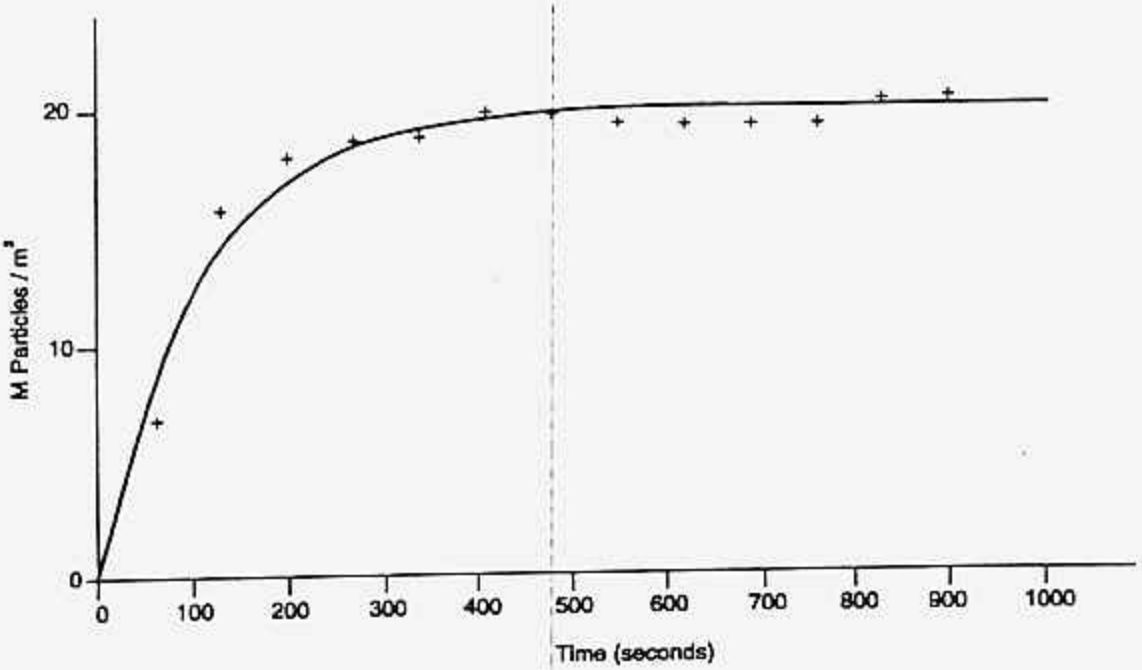



Figure 9 : Example linear plot of data with fitted curve

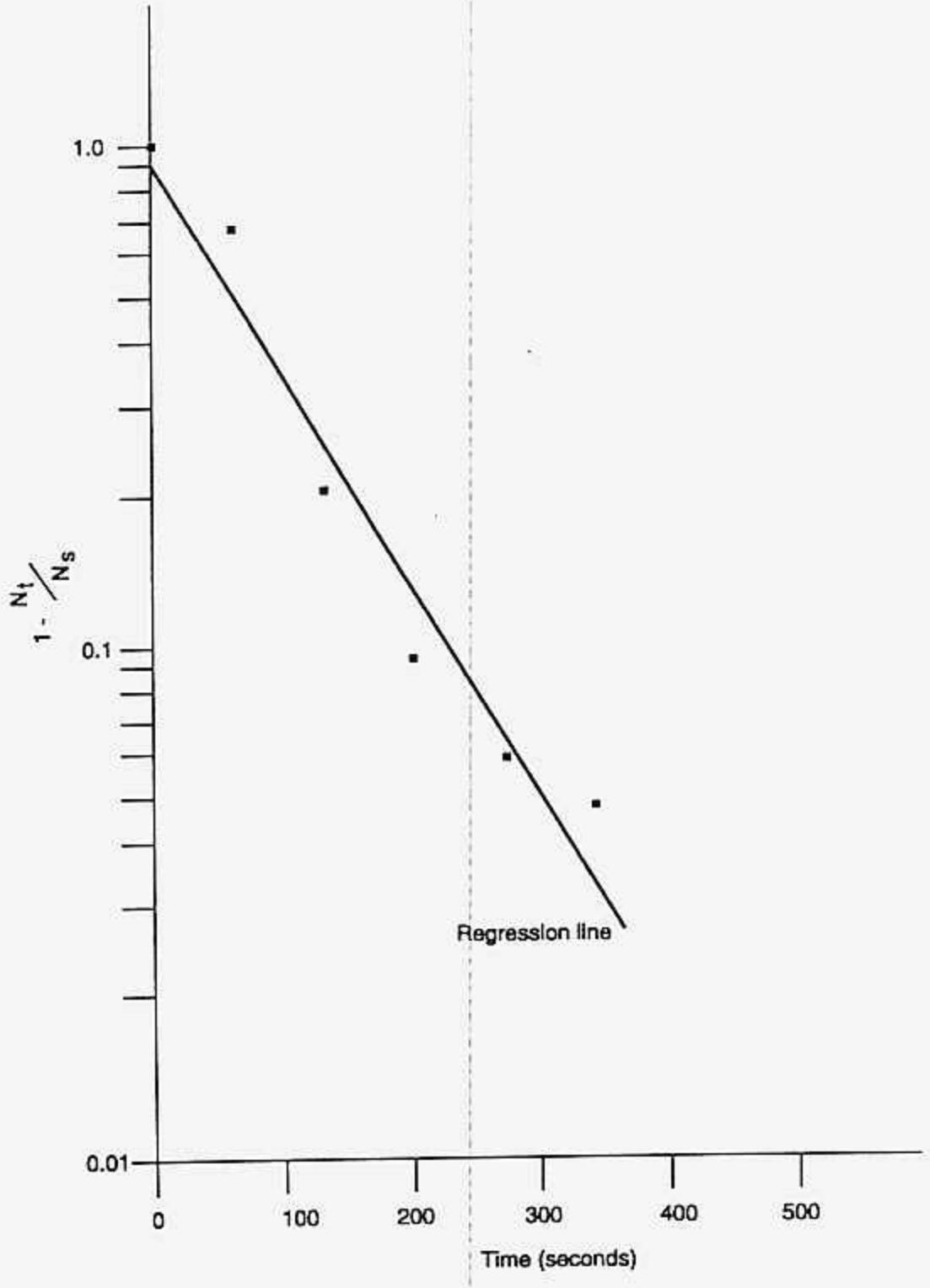



Figure 10 : Log-linear plot

BACTERIAL SUSPENSION

Concentration of bacteria in water

= B colony forming units/$m^3$

Wet droplet volume = $\frac{\pi}{6} D^3$ $m^3$

c.f.u. in one drop = $\frac{\pi}{6} D^3 B$ c.f.u. (7)

If > 1 average cfu/droplet

If < 1 proportion of droplets with 1 cfu.

If we assume that for both salt and bacteria the properties of water ie density, viscosity, surface tension, etc, are the same, then it is reasonable to assume that droplet production is not effected for any particular combination of the experimental variables; ie tap, flow rate, impact surface etc. We therefore assume that for both salt and bacteria D and n, the number of wet droplets generated per second, are the same.

EXAMPLE

This calculation should be carried out separately for each band of dry particle sizes for which data is available. Ideally the particle size bands should reflect any variation in their potential for causing infection. While such variations are probable, at present we are not aware of any specific information.

For this example we will assume that approximately half of the dry particles being generated in the previous example are in a band with a mean diameter d of 1.0 μm, ie 100 x $10^3$ Particles/second.

The concentration of salt used by the students was in the order of 18,000 g/$m^3$. (375 g salt to 20.8 litres water). The density of salt is 2.165 kg/$m^3$.

For this example we will assume a concentration of Legionella in the water of 1 colony forming unit (c.f.u.) per millilitre or $10^6$ c.f.u./$m^3$.

$$\text{Now } D = 10d\left(\frac{\sigma}{C}\right)^{\frac{1}{3}} \qquad (6)$$

$$= 10 \times 1.0 \times \left(\frac{2,165}{18,000}\right)^{\frac{1}{3}}$$

$$= 4.94\ \mu m$$

$$\text{Now c.f.u./droplet} = \frac{\pi}{6}(D)^3 B \qquad (7)$$

$$= \frac{\pi}{6}(4.94 \times 10^{-3})^3 \times 10^6$$

$$= 0.0474 \text{ c.f.u./droplet.}$$

∴ Rate of production of Legionella aerosol

= c.f.u./droplet x droplet generation rate

$= 0.0474 \times 100 \times 10^3$ c.f.u./sec.

= 4,740 c.f.u./sec.

This calculation would be repeated for each size band for which data was available.

### 5.3. Concentration of Contamination in Air

We are now considering the concentration of Legionella in the air within a room, probably a bathroom or a kitchen. Theoretically speaking we are again considering an enclosure with an internal source of contamination, a supply of presumably uncontaminated air and perfect mixing within the room as in Figure 7. Equation (1) therefore applies during the period of release of the Legionella into the room. When release has stopped then the decay in concentration is described by the equation:

$$N_t = N_o\, e^{-\left(\frac{Qt}{V}\right)} \qquad (8)$$

where $N_t$ = concentration of contaminant at time, t, number of particles/$m^3$.

$N_o$ = concentration of contaminant at time t = 0, number of particles/$m^3$.

Q = ventilation rate, $m^3/s$.

V = volume of enclosure, $m^3$.

t = time from an arbitrarily defined zero time during the decay period, s.

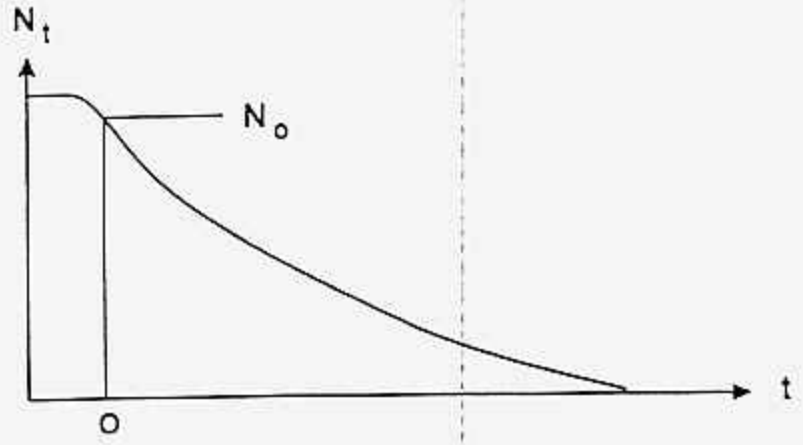



Figure 11 : Decay of concentration of contaminant

EXAMPLE

Consider a bathroom with a volume of 20 $m^3$ and a ventilation rate of 60 $m^3$/hr as required by the Building Regulations in the UK. We will use the production rate as calculated in the previous example for one size band (4740 c.f.u./s) and specify that the tap is open for 10 minutes.

It was noted in section 5.1 that after 1 air change the concentration will rise to 63% of its steady state value. In this example only ½ an air change will have taken place when the tap is turned off. The contamination level will therefore start to decay well before the steady state level of concentration has been reached.

Substitution of the appropriate values in equations (1) and (8) gives the build up and decay curves shown in figure 12.

## 5.4 Human Exposure to Contaminant

Exposure to an airborne contaminant is dependent on the following three factors:

Concentration of contaminant

The rate of respiration

The duration of exposure.

The risk of any ill effects resulting from this exposure is dependent on many other variables such as the toxicity or virulence of the contaminant, the susceptibility of the recipient, the size of the particles and the proportion of the inhaled contaminant which is trapped in the respiratory system[5]. The assessment of this risk is beyond the scope of this paper and may well be impossible until the clinical microbiologists establish a dose - response relationship.

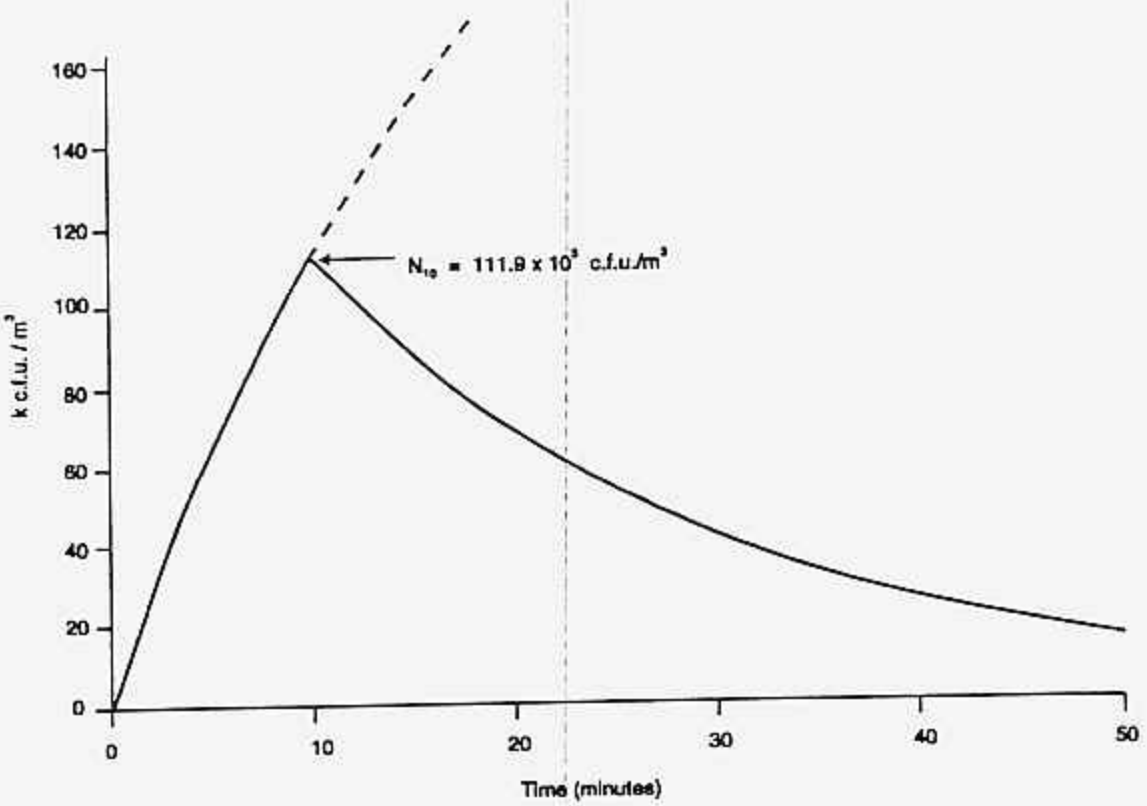



Figure 12 : Example Build-up and decay of contamination in a room

The quantity of a contaminant inhaled by an individual during a period $t_1$ to $t_2$ when the concentration in the air is constant and equal to $N_s$ will be simply the product:

$$N_s R (t_2 - t_1)$$

where R is the respiratory rate of the individual. Where the concentration is varying this quantity, the dose D, will be given by the integral of the concentration equation multiplied by the respiratory rate

$$D = R \int_{t_1}^{t_2} N_t \, dt$$

We are concerned with exposure during build up, steady state, and decay of a contaminant as shown in Figure 13.

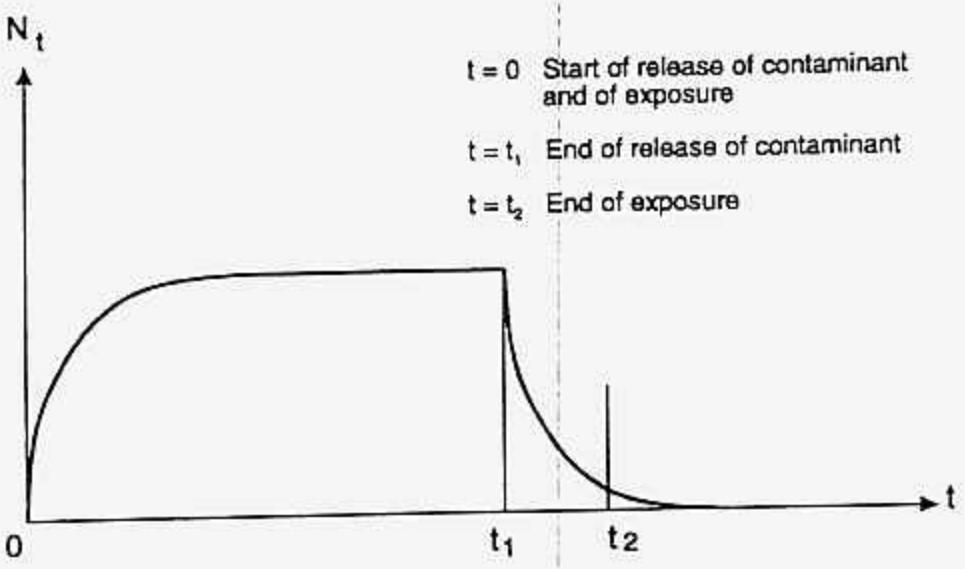



Figure 13 : Build-up and decay of contamination during a period of exposure

$t = 0$ Start of release of contaminant and of exposure

$t = t_1$ End of release of contaminant

$t = t_2$ End of exposure.

The dosage equation can now be written:

$$D = R\int_0^{t_1} \frac{n}{Q}\left[1 - e^{-\left(\frac{Qt}{V}\right)}\right] dt + R\int_{t_1}^{t_2} N_{t1}\, e^{-\left(\frac{Q(t-t_1)}{V}\right)} dt \qquad (9)$$

It can be shown that

$$\int \frac{n}{Q}\left[1 - e^{-\left(\frac{Qt}{V}\right)}\right] dt = \frac{n}{Q}t - \frac{nV}{Q^2}\left[1 - e^{-\left(\frac{Qt}{V}\right)}\right]$$

and

$$\int N_{t1}\, e^{-\left(\frac{Q(t-t_1)}{V}\right)} dt = \frac{N_{t1}V}{Q}\left[1 - e^{-\left(\frac{Q(t-t_1)}{V}\right)}\right]$$

Hence

$$D = R\left\{\frac{nt_1}{Q} - \frac{nV}{Q^2}\left[1 - e^{-\left(\frac{Qt}{V}\right)}\right] + \frac{N_{t1}V}{Q}\left[1 - e^{-\left(\frac{Q(t_2-t_1)}{V}\right)}\right]\right\} \qquad (10)$$

EXAMPLE

We will use the same figures as in the preceding worked examples. It is worth reiterating the values used.

Room volume 20 $m^3$.

Room ventilation rate 60 $m^3$/hr (1 $m^3$/min).

Aerosol production rate 4740 c.f.u./s (284.4 x $10^3$ c.f.u./min)

Tap open for 10 minutes.

Maximum concentration (at t = 10 minutes) 111.9 x $10^3$ c.f.u./$m^3$.

Exposure for 50 minutes starting from time tap opened.

Respiration rate 7.5 litres/minute (0.0075 $m^3$/min).

Substitution of these values in equation (10) gives the total number of colony forming units inhaled as 19 x $10^3$.

## 6. Results

The results quoted here are drawn from the work of the most recent three students mentioned in the acknowledgements. As stated there, many of their results are unreliable in any absolute sense. There was however fairly good consistency within each individual's work. Their data can therefore be used with reasonable confidence to make comparisons within each set of data.

Tap number 2 will be used as a datum in most of the results which follow to ease comparisons, ie a particle production rate of 100% is the rate of generation from tap 2 flowing at 10 litres/minute in the sink before any attempts to reduce the production rate.

### 6.1 Comparison between Taps

A comparison of the rates of production of particles from the various taps and the shower is shown in figure 14. The water flow rate in each case is nominally 10 litre/minute. Similar differences were found at a range of flow rates and one could associate the higher production rates with the more irregular and "splashy" jets. The shower was included in this test to give an indication of the relative rates of generation of showers and taps. The test arrangement is very different to a practical shower installation so the comparison must be treated circumspectly.

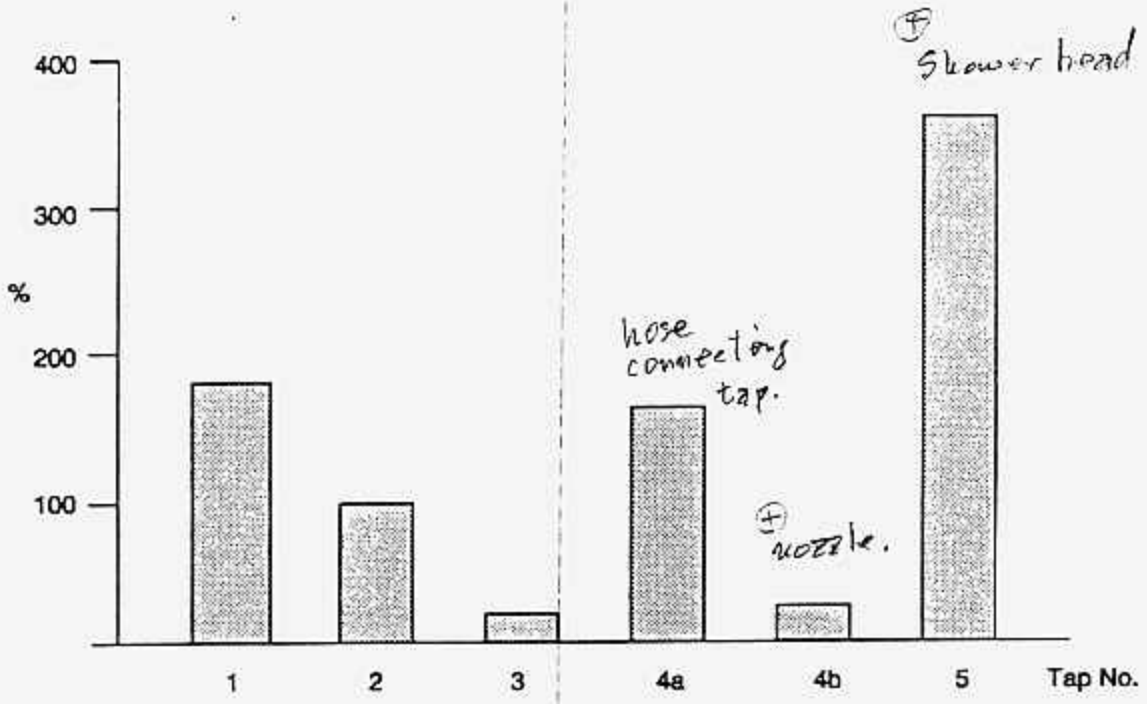



Figure 14 : Particle production rates at 10 litres/min

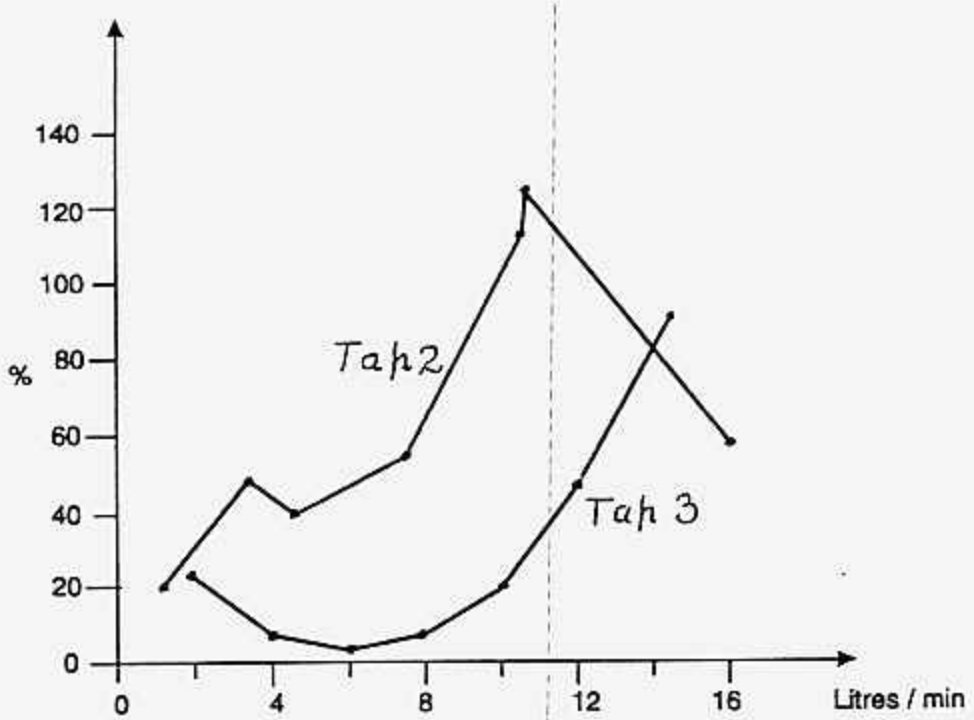



Figure 15 : Particle production rates v water flow rates

## 6.2 Variation with Flow Rate

Although the mechanisms of droplet formation were not known, it was expected that the rate of production of aerosol particles would increase with the rate of flow of water from any particular tap. It was therefore with some surprise that results such as those shown in Figure 15 were obtained. All the taps tested, except 4B, showed a minimum particle production rate at an intermediate flow rate. The relationship for tap 2 shown in Figure 15 is the least convincing example where one might easily attribute the apparent minimum to experimental error. However, this effect was found by all three students who examined the variation of particle production rates so that overall the evidence is convincing. Observation of the flow from the taps suggested that the particle production rate was linked to the smoothness of the flow stream. The aerated tap (No.3) and the tap with the nozzle fitted (No.4B) both had very smooth streams at a wide range of flow rates. While the former was aerated the latter was homogeneous and showed a steady rise in particle production as the flow rate increased. At low flows the streams from the other taps tended to be broken and disorganised. As the flow rate increased the stream would become more continuous and smoother. Increasing the flow further tended to increase the velocity of the stream and its turbulence. There were clearly also big variations in the amount of splashing where the stream hit the sink or water lying in the sink.

## 6.3 Source of Particles

An experiment was devised to quantify the relative importance of the falling stream of water and of its final impact as sources of particles. This was done by sealing a cover over the sink with a hole in the cover just big enough to allow the water stream from the tap to pass through without touching the cover. Air was extracted from the sink, through the cover, via flexible vacuum cleaner hose by a fan outside the glove box. This air flow was adjusted to ensure downward air flow around the water stream to prevent any particles generated by the final impact escaping into the glove box. At the same time it had to be less than the air supply to the glove box to maintain the pressurization and prevent ingress of extraneous airborne particles.

Experiments on tap 1 showed that less than 10% of the particles generated were released from the water stream at flow rates of 12 and 15 litres/minute. At lower flow rates production from the water stream was a smaller proportion of the total. Taps 2, 3, 4A and 4B all gave similar results. Subsequent work on the reduction of particle generation was therefore concentrated on the impact of the stream on the sink or on water in the sink.

## 6.4 Modification of Impact

The rate of generation of particles from the final impact was expected to depend on features such as the angle of incidence of the stream to the surface, whether this surface was water or was the wall or the bottom of the sink; and if the latter, if it was well drained or flooded. The initial investigation of these effects was carried out using a ramp which could give an impact surface sloping at either $30^0$ or $60^0$ to the horizontal and two overflow plugs giving water depths of approximately 15 mm or 80 mm. (Details in Appendix).

The results obtained from tap 1 are shown in Figure 16 where it can be seen that all four modifications reduced the production rates at the higher flows but tended to be less effective at lower flows. Similar tests on Tap 2 showed no significant effect with either ramp, an increase in production with the shallow plug but the deep plug gave a reduction in production by a factor of 2.5 at least. Tap 4B, which had a very smooth jet, showed no benefits from any of the modifications at flow rates less than 10 litres/minute with useful reductions at higher flow rates.

It was difficult to draw any very secure conclusions from these tests but it did appear that cushioning of the impact by hitting fairly deep water rather than the hard surface of the sink was beneficial. A smooth transition from the free falling stream to flow at reduced velocity within the sink also reduced particle generation.

The last student to work on this topic tested these ideas further to attempt to develop some guidance for designers. "Diffusers" were used to cushion the impact of the stream. These were two different types of scouring pad. One was fairly dense stiff labyrinthine mesh, the other was softer, more open, knitted nylon. These both showed some benefit comparable with that from the deep overflow plug shown in Figure 16 when used with Tap 2. When used with Tap 3 with its inherent low production rate there was an increase in particle production.

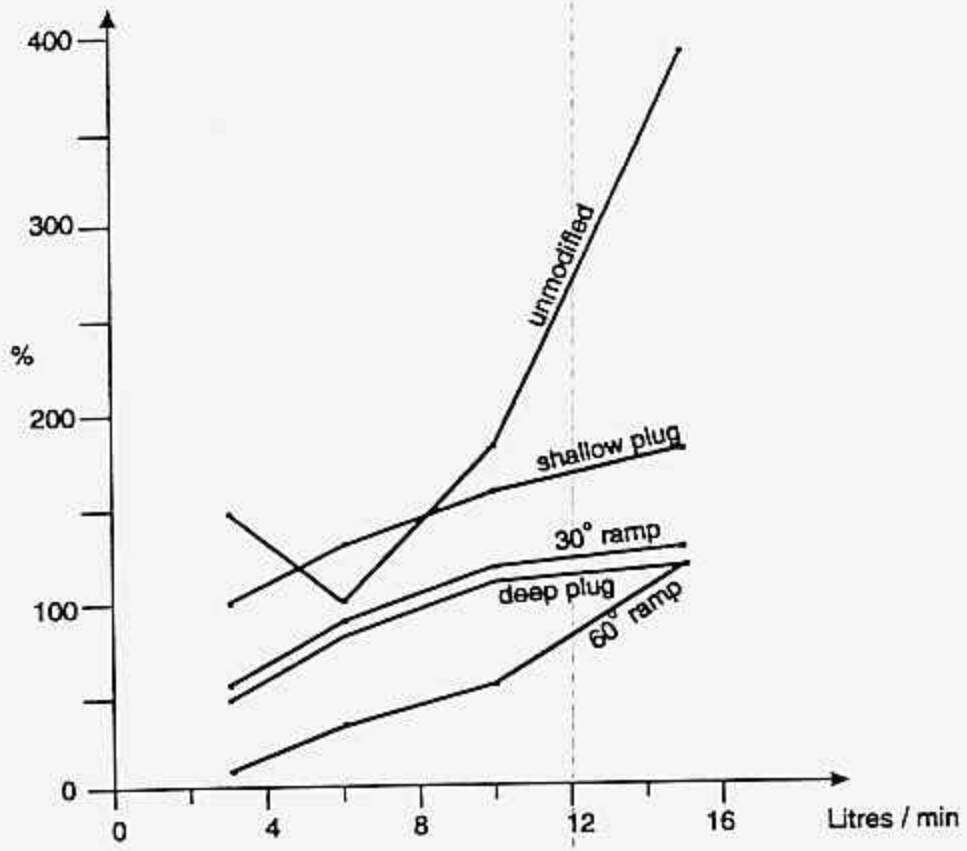



Figure 16 : Effects of modifications to impact of stream on particle production rate from Tap 1 at various flow rates

The final tests were of the effects of placing an elliptical cone in the water stream to gently disperse the water flow and divert it from near vertical to almost horizontal (Figure 17). Though obviously not very practical, this device proved to be effective in reducing the particle production rate from both Taps 2 and 3 over a wide range of flow rates provided the water could leave the cone freely. Similar reductions in particle production had been noticed when an angled water stream hit the wall of the sink with smooth flow over the sink surface.

### 6.5 Summary of Results

The interpretation of these results is necessarily somewhat subjective because the data from the experiments are not directly comparable. Some principles for minimising the production of aerosol particles are however evident.

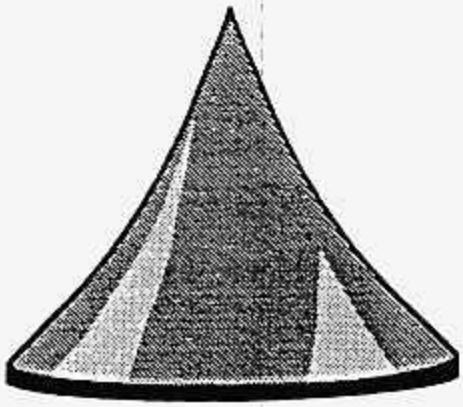


Figure 17 : The elliptical cone

- Taps should produce a smooth stream of water over their full flow range. There is no evidence to suggest an advantage for either an aerated stream or a homogeneous stream. Flow limiters may be useful in preventing excessive flows.
- Contact of the stream with a hard surface should be as near tangential as possible followed by smooth flow with continuously reducing velocity. This requires that the shape of the sink or basin must be matched with the trajectory of the stream from the tap over the whole range of flow rates. This is not difficult where the trajectory is vertical because it will not vary but an angled trajectory will probably vary with water velocity.
- Where rinsing in the water stream is not required, consider piping the water to the bottom of the sink to avoid impact when filling with water.
- Where impact of the stream with the water surface is unavoidable a vertical stream is preferable to an inclined stream
- As stated previously the main value of the experimental work reported lies in the various comparisons. The aerosol particle generation rate of tap 2 flowing at 10 litres/minute which has been taken as a datum 100% was in the order of $100 \times 10^3$ particles/sec. The figures used in the worked example in section 5 are believed to be realistic.

## 7. Discussion

The main value of the work reported is seen as the development of: 1) a model of the processes involved in the transfer of Legionella in tap water to a human host; and 2) an experimental method of measuring aerosol generation rates by taps.

It is clear from the model that exposure to airborne Legionella is as much dependent on the duration of exposure, the room involved and its ventilation rate as on the concentration of the Legionella in the water and the aerosol generation rate. Bathrooms and kitchens do not exist in isolation and there will generally be air transfer between these rooms and the rest of a building. The model developed in section 5.3 is for an isolated room but it would not be difficult to extend it to cover several rooms. The theory of multi-cell models is described by Heinsohn[7]. McKone[6] has described a three compartment model - shower enclosure/bathroom/remainder of house - to estimate daily contaminant concentration profiles. He found that the estimated average concentration ratios for shower/bathroom and bathroom/remainder of house were both in the order of 10/1.

It is significant that the impact of the stream of water appears to be the main source of aerosol particles and that the stream itself is relatively unimportant. All the experimental work done and the resulting guidance is relevant to impact with the surfaces of the sink or water in the sink. We have not attempted to examine what happens during activities such as hand washing or rinsing of objects under a running tap. This is likely to be a complex situation with an initial impact followed by a very disorganised flow of water into the sink. How significant this is for particle generation is open to conjecture.

The shower tested was clearly a prolific generator of aerosol particles but there was no assessment of the relative importance of the impact and the stream. It is however reasonable to expect that the impact is a significant source. There would appear to be little prospect of reducing particle generation when one of the attractive features of showers is the sensation resulting from the impact. It would be interesting to know what lies behind the manufacturer's claim mentioned in the introduction. This consideration of showers leads to questions about spray taps: are they mini showers with high generation rates or do the lower flow rates produce lower generation rates?

The mathematical model used for estimation of aerosol production rates and prediction of concentrations in rooms uses the long established theory of ventilation with perfect mixing. The major assumption in both applications is that of perfect mixing. This may well be justified in the glove box where the air velocities were reasonably high and a stirrer provided to improve mixing. One student took samples from different positions within the box to investigate the possibility of poor mixing. These tests were inconclusive though some suggested non-uniform ventilation. Mixing in rooms is however more problematic. Many studies have been carried out in this area. Results quoted by Heinsohn[7] report "mixing factors" of 1/10 for rooms with ventilation by infiltration and natural draught and 1/6 with ceiling exhaust fans. The factors mean that for some points in the rooms the effective ventilation rate is only 1/6th or 1/10th of the actual air flow rate. Conversely other points in the rooms will be better ventilated. It would be advantageous to position the potential human host in the clean incoming air flow and the source in the outgoing flow but such finesse is seldom evident in building design.

This idea would be further developed by designing a basin for hand washing integral with an air exhaust hood for use in critical areas such as hospital accommodation for high risk patients. This could be a more cost effective approach than the present practice of trying to ensure a completely sterile water supply.

The experimental method described was developed as our understanding of possible sources of error improved. The main problem area was the elimination of fortuitous sources of airborne particles. The use of an enclosure pressurised by particle free air is obvious. It is worth highlighting the precautions to be adopted on the water side.

1) Use distilled water to eliminate any dissolved impurities.
2) Use a fine filter fitted as near the taps as practical to trap any residual particles in the system
3) Use only corrosion resistant pipes and fittings.
4) Flush system thoroughly before and after use.

The major potential source of error lies in the use of salt to simulate the particulate Legionella. We have not demonstrated that there is no effect on the generation of water droplets but we have no reason to believe that there is any significant difference. In the work reported the concentration of the salt in water was about 1.8% by weight. This would increase

the density by 1.8% and the surface tension by some 0.6% at $20^0$C. The effect, if any, on viscosity is not known. On the other hand raising the water temperature to $60^0$C would reduce the surface tension by some 9% and halve the absolute viscosity. It therefore seems probable that variations in water temperature could effect aerosol generation rates and particle sizes more than the use of salt as a simulant. Hot water taps are not recognised as generating more splashing than cold water taps so these variations may well be insignificant. These potential sources of error and the relationship between salt concentration and dry particle size derived in section 5.2, should be checked experimentally in any future work.

## 8. Conclusions

The impact of the stream of water from a tap hitting water or the solid surface of a basin or sink, is the main source of aerosols of the water and any contaminant it may contain. There is scope for reducing the rate of generation by modifying the design of the basin + tap combination. The resultant steady state concentration of contaminant in a room is a function of the ventilation rate. Room volume and ventilation rate define the time constant for the build up and subsequent decay of the contaminant concentration. Exposure of an individual to the contaminant is a function of the integral of the concentration over the period of exposure and physiological variables. If some Permissible Exposure Limits were available it would be possible to design quantitatively.

Further work is required to test assumptions made to verify the validity of the experimental method described. Manufacturers would then be able to develop low emission assemblies of tap and basin with confidence.

Particle generation rates from existing hardware are very variable but values of up to hundreds of thousands of particles per second have been observed. Showers appear to produce many more particles than taps. Local exhaust ventilation is suggested as an economic method of limiting airborne contamination levels where the risks are significant. It is probably only in these areas or where concentrations of Legionella in water are high that aerosol generation from taps is likely to be a significant hazard.

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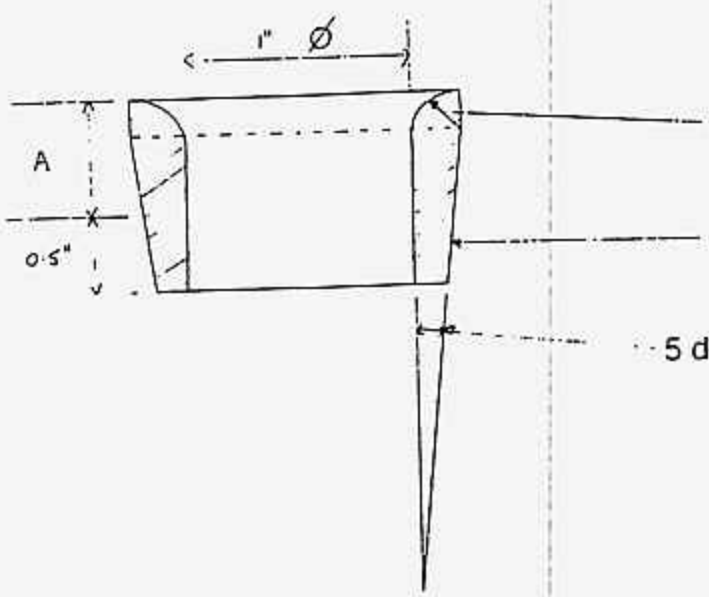
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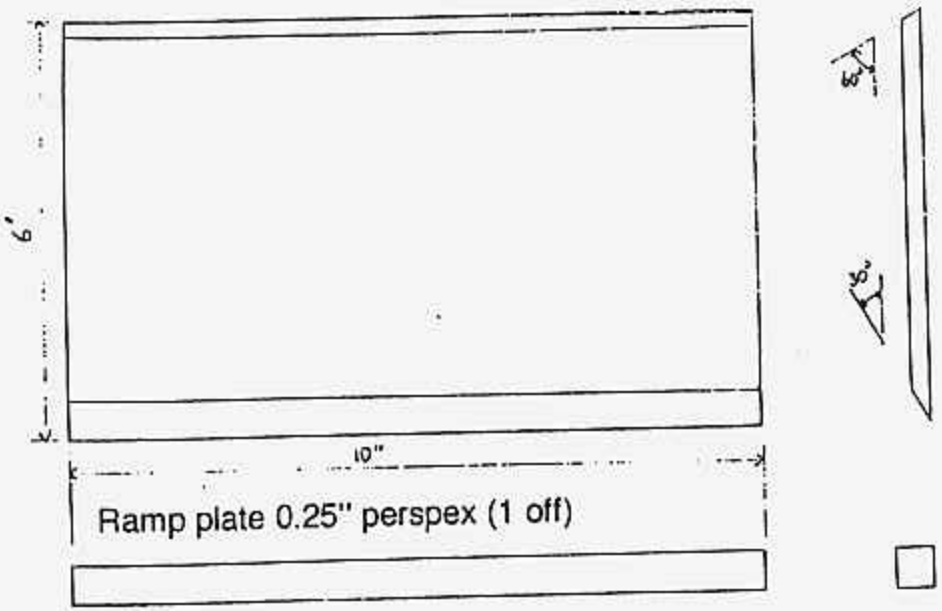
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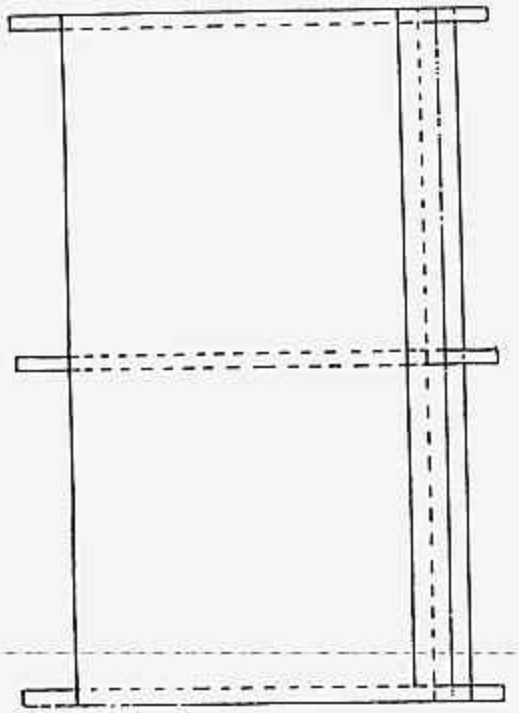


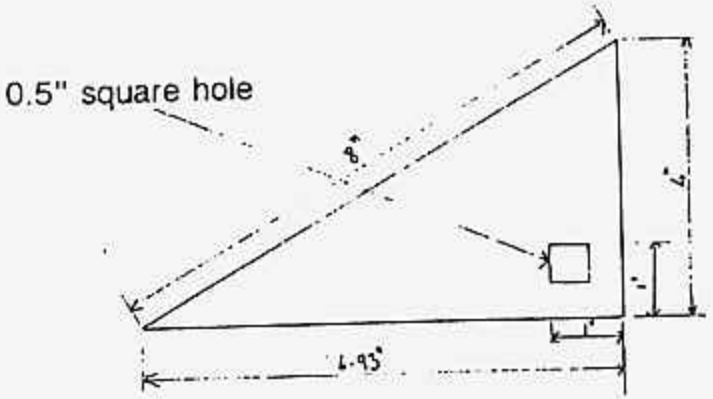

One off with A=0.5 inches

One off with A=3 inches

**Diagram 1 : Overflow plugs**





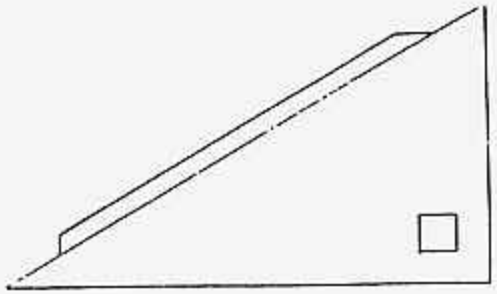



Diagram 2 : Splash ramp assembly

# Topic A5

## Recent Trends in Water Closet Testing

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SEMINAR CIB W62

LOSTORF, SWITZERLAND

September 16 - 18, 1996

# TESTING IN STANDARDS
# WATER CLOSET HYDRAULIC PERFORMANCE REQUIREMENTS

Lawrence S. Galowin

SUMMARY

Test methods in standards are required to provide performance measurements for evaluations for pass/fail acceptance criteria, or to assure that specified properties of products and materials are achieved. Sufficiency and reliability of testing requirements are essential for confidence in test measurement methods which are set to achieve minimal uncertainty in processes and procedures undertaken. Capability for reproducing test results in test laboratory measurements requires that standards contain well defined protocols/instructions, instrumentation requirements and calibration traceability (as appropriate) for measurements, and test arrangements with uniform test media that eliminate scatter and variability in data.

Low flush volume water closets and other water conservation fixtures are of major interest because the Energy Policy Act of 1992 establishes national regulations for water conservation. Revisions in standards have been undertaken since the time that national requirements were passed which revise or update evaluations from laboratory test methods for plumbing fixtures that provide data on conformance.

Changes of test materials and establishment of acceptable performance levels for water closets in the standard cited in legislation are discussed. Revisions include four classifications for water closet installations for intended usage based upon building types. New requirements for extraction of waste mixed bulk media materials for each class have been adopted for testing methods in laboratory evaluations with different loads and extraction values for each class. Mixed bulk test media loading tests are reviewed for impacts of different types of materials and loadings applicable to categorized different building purposes. Pass/fail criteria from evaluations of source data are reviewed with observations on possible statistical suitability for practices in water closet performance determinations.

## INTRODUCTION

Development of test methods and application of test data from standards require a basis for technical accuracy and clarity in descriptions for understanding or interpretation of test data. Standards must adopt terminology that avoid different interpretations, particularly where technical disciplinary orientations require special materials applied to product evaluations.

Standards are applied for regulatory purposes, support codes by reference, used for design and specification, provide construction safety and fire resistance qualifications, and serve other scientific/engineering purposes. The diverse applications of standards facilitate trade and commerce and now take on broadened significance with worldwide expansion for conformance evaluations in quality assurance systems and quality registration systems, such as the ISO-9000 series. United States legislative reference to standards are advanced further by the National Technology Transfer and Implementation Act of 1995 that requires use of voluntary consensus standards by Federal agencies and departments to carry out policy objectives or activities.

Development of standards relies upon authoritative technical input for confidence in the credibility and reliability that test measurements, analyses of data and that conclusions for acceptable performance be derived, and have a basis, from credible research. Technical input must be sufficient for confidence and reliance upon evaluation techniques from appropriate measurement methods in testing for determination of satisfactory performance. Furthermore, precision and bias statements for test data have become necessary requirements in procedures adopted by several standards sponsors. In many instances standards link measurements for traceability and calibration purposes to national reference standards that assure confidence for accuracy.

## DEFINITIONS

For distinct recognition in testing mechanisms common sets of definitions are found for use in standards; those definitions appear in publications from different standards organizations/sponsors. Although common applications exist it is oftentimes maintained that there is a need for a distinctive connotation that is required for specialized sectors of technology, so that differences from common use of terminology and definitions occurs. Here, illustrative sample terms used in test standards are given from among several listed as ASTM definitions [1] (from among the groups of definitions):

> *Accuracy - a concept of exactness. When applied to a test method, it denotes the extent to which bias is absent; when applied to a measured value, it denotes the extent to which both bias and random error are absent.*
> *Bias - a persistent positive or negative deviation of a test method average value from the assumed or accepted true value.*
> *Precision - the closeness of agreement between randomly selected individual measurements or test results. Note - the standard deviation of the error of measurement may be used as a measure of "imprecision".*
> *Reproducability - the precision of a method expressed in terms of agreement expected between measurements made in different laboratories using similar apparatus and the same procedure.*

In standards for water closets those terms have not received particular attention. That is due to concern that water closets, produced of china (fired clay and coatings), are produced by a manufacturing process that impedes precise dimensional control which limits tolerances in quality control. Then, performance

conditions determined from tests must permit (it is claimed) wide ranges in allowable test requirements for performance. Laboratory evaluation measures have accommodated allowances for manufacturing impacts that have accommodated the issue of performance expectations from test methods in standards as less stringent and with lesser statistical validations due to the product materials differences. Tests for capability to extract mixed solid wastes and waste transport in drains involve assertions that complex interactions between materials and fluid dynamic aspects at interfaces are both unpredictable as well as limited in reproducibility. Consequently, dependence on trials/experiments with various simulant waste materials have been necessary and that wide variability has customarily been acceptable from test methods. Considerations for water closet testing improvements are discussed in this report.

Compliance to regulations from test data must rely on accepted statistical methods to estimate reliability and confidence for levels of performance from results based on standards. It is essential that methods adopted to set prescribed pass/fail criteria have confidence interval(s) (determined or estimated) for the mean of samples that lead to achievement of the established performance requirements. A variety of statistical methods are available from quality control procedures, or probability density function, *t-distribution*, (from statistics literature) that is insensitive to departure from normally distributed data. Those considerations have not been adopted for water closet testing.

## NATIONAL PLUMBING REQUIREMENTS

The applicability of ASME/ANSI A112.19.2 [2] and 19.6 [3] voluntary consensus standards for plumbing fixtures in the United States to regulatory purposes for water conservation is contained in the Energy Policy Act of 1992, Public Law 102-146 (EPAct). Flow rates and volumetric consumption are specified as :

| | | |
|---|---|---|
| Lavatory faucet | ..... | 2.5 gallons per minute |
| Lavatory replacement aerators | ..... | 2.5 gallons per minute |
| kitchen faucets | ..... | 2.5 gallons per minute |
| Kitchen replacement aerators | ..... | 2.5 gallons per minute |
| Metering faucets | ..... | 0.25 gallons per cycle |

manufactured after January 1, 1994. The following water consumption requirements are specified for water closets after the same date:

| | | |
|---|---|---|
| Gravity tank type water closets | ..... | 1.6 gpf |
| Flushometer tank type water closets | ..... | 1.6 gpf |
| Electromechanical hydraulic toilets | ..... | 1.6 gpf |
| Blowout toilets | ..... | 3.5 gpf |

and other fixture requirements are specified for later dates.

## TESTING REQUIREMENTS IN STANDARDS REVISION

The new A112.19.2 draft is intended to be combined for material(s) and hydraulic requirements. Then, ASME/ANSI A112.19.6 "Hydraulic Performance Requirements for Water Closets and Urinals" will be discontinued.

The draft standard includes major changes for:

- New mixed bulk test materials for evaluation of water closet discharge of waste solid simulants;
- Acceptable discharge which requires 75 percent average of mixed bulk media solids loading (no solids differentiation) to be extracted from the bowl;
- Performance criteria based upon different quantities of solids removal that differs for four building classifications;
- Elimination of a waste solid drainline transport distance test.

Similar requirements have been included in the draft standard from tri-lateral harmonization efforts with Canada and Mexico for North American acceptance; it is currently being balloted. The mixed bulk media consists of sponges and toilet tissue "balls" which were adopted as test materials for extraction tests (different loads for each class) and plastic balls have been replaced by the new mixed test materials.

In assigning test loadings tests it was assumed that representative conditions should include clogging effects from disposal of different materials and the degree of severity for user disregard that water closets were strictly a device for sanitary purposes. Considerations of diverse and extreme ranges of usage of water closets in buildings by owners, residential building occupants (renters), visitors and workers in commercial facilities, spectators and attendees at public events or airports, led to introduction of the varying requirements for increasing severity of discharge loadings in tests. Furthermore, lack of commitment to care and maintenance of sanitary facilities and public attitudes that tolerate disposal patterns not practiced in homes, apartments and office buildings, which differ widely in buildings and industrial parks or shopping malls, contributed to the basis for the test loadings adopted.

In U.S. building practices it is not uncommon to have building codes, and/or local regulatory agencies set different requirements (for equipment, installed thermal barriers, zone differences, multistory housing systems/greater protective requirements than single family or low rise buildings). Categories for building usage or occupancy types appears appropriate for setting plumbing fixture standards which set different load conditions to applications that are consistent with other accepted building practices.

## TEST MATERIALS and REQUIREMENTS

Standard simulant waste materials loadings and extraction testing were advanced by research at Stevens Institute of Technology, directed by Tom Konen, in support of the HUD/NIST national potable water conservation program in the late 1970's. Significant recognition of those efforts led to adoption of a basis for rational loadings with test materials/methods, and water supply standardization for water closet testing that are retained in standard requirements. Subsequently, changes of test materials for low flush volume water closet testing materials resulted from committee efforts, in particular manufacturers, that led to adaption of Konen's work, included plastic balls for loading extraction tests and waste transport distance requirements in drains.

Recognition of need for mixed bulk media as more representative conditions brought new efforts by Kannan [4] for a group of materials that indicated limits on transport from repeated patterns of load sequences; those results have been widely misunderstood and interpreted since transport limits with repeated patterns of flush/loads were demonstrated. Swaffield and Galowin [5] generalized those for 3.5 gallon flush water closets and details for other pipe sizes and slopes beyond tests. Yingling and Galowin [6] reported mixed bulk media tests from Washington Suburban Sanitary Commission (WSSC) experimental study on drainline sizing, and evaluated water closet performance, as input to standards.

More recent efforts were carried out through extended test evaluations with mixed bulk media materials, that were conducted by a task group of ASME A112.19.6. That intensive program included several varieties of mixed media solids which were specific to the proposed classifications adopted by the committee and now are the basis for materials and performance requirements included in the draft A112.19.6. replacement.

## TEST MATERIALS IN REQUIREMENTS FOR WATER CLOSETS

The program plan of the WSSC testing program in a new test facility included many details for reliable data by selecting mixed bulk test media and have assured reliability with replication of results as essential to recommending and adopting pipe sizing code changes; the requisite specification was:

> *Complete waste simulants extraction from the bowl for as many fixtures as possible in the priority effort for entry into the drains so that pipe sizing data for code purposes could be developed. Additionally, the residential user expectation is that complete load removal occurs in one flush. For heavy loads - at the time a newly adopted perception and consideration - was to obtain a reasonable added load for study of both water closet and drainline conditions - (no data with load changes was available to assist in undertaking the design of the experiments). The plan included a first and second flush (even with a first flush clearance) since the transport study for drain sizing with solids included recognition that successive transport events are necessary for clearing drains and therefore essential to drain sizing requirements for the code.*

Confidence in testing with mixed bulk media was obtained from a series of trials of materials in preliminary tests. It was imperative that many water closets extracted all solids so that pipe sizing would be based upon commonality and reliability of test results. Existing standard test procedure that allows partial extraction with a first flush of wastes was considered unacceptable. Drain carry tests with plastic balls (from the A112.19.6 Standard) indicated frequent rolling in the new facility with four drains installed in the new laboratory (at two diameters and two pitches). Twenty water closets were utilized in the testing program; two were 3.5 gallon flush types, the other eighteen were low flush volume 1.6 gallon (6 liter) types and included gravity and flushometer tank models.

Preliminary mixed media test evaluations indicated two sponge types and baby wipes were useful materials. Those fulfilled all requirements for development of consistently reproducible results (for light loads), durability of physical characteristics, minimum variability of material properties and shape changes, and repeatedly sustainable for first flush and second flush. The early evaluations eliminated toilet paper, tampons, and other sanitary products from further consideration. Selection of light (residential) loads and heavy (commercial) loads was made from the series of preliminary tests with several trial loads with a second flush as an integral part of the original test plan.

For assurance that laboratory staff could repeat the tests and obtain comparable results a test media load introduction was established through a guide (jig) that was included so solid(s) loading would be uniformly duplicated. Detailed instructions for carrying out the test protocol were established to minimize potential for error in conducting the tests.

The test rig included provisions for branch flow entry at a downstream junction fitting located in each of the four drainlines. Inflow simulations with values set in EPAct for faucets and showers lessens assist from waste stream supplements. Those simulations were important since information was not available for such conditions. Favorable additive transport conditions were, and continue to be hypothesized,

such assertions are wrong since other phenomena occur, e.g., transient hydraulic jumps carry wastes upstream (due to flow reversal) and is actually deleterious to transport. Second flush testing also is not a topic found in research reports about solids not extracted in a first flush.

Test media sections cut from dry sponge materials simplified preparations and reduced variation in sizes; estimated dimensional control was less than ten percent variation. Laboratory beaker measurements for displacement volume (in soaked condition) and specific gravity determination were made in laboratory quality beakers. Average data for sample materials of the components of the mixed media loads are given in the following table. Packaged towelettes (baby wipes) supply was assumed as sufficiently

| SOLID WASTE SIMULANT TEST LOADS | | | | | | |
|---|---|---|---|---|---|---|
| Simulant | | Light (Residential) Load | | | Heavy (Commercial) Load | | |
| Material | Size Sp. Gr. | Qty. | Displ, | Wt. | Qty. | Displ, | Wt. |
| Syn.Sponge | 1"x1"x1" .83 | 8 | 131 ml | 109 g | 12 | 197 ml | 164 g |
| Natl.Sponge | 1"x1"x1" 1.04 | 12 | 197 ml | 238 g | 14 | 229 ml | 238 g |
| Towelettes | 6.5"x 6.2" .75 | 0 | - | - | 4 | 30 ml | 23 g |
| Total | | 20 | 328 ml | 346 g | 30 | 456 ml | 425 g |
| Avg. Specific Gravity | | | 0.96 | | | 0.93 | |

uniform from the sealed packages as purchased; no readily apparent discrepancies were found during testing. Preliminary tests showed that complete discharge of light loads was feasible and heavy loads would challenge the complete extraction need. Those findings were substantiated from the completed full test series.

The extent of "filling the well" was observed for heavy mixed media loads which exceeded the water seal height in the bowl of some water closets with narrow trap entry volumes (at rest and complete trap refill condition). In all cases soaked synthetic sponges floated, and soaked natural sponges (introduced first) sank; towelettes tended to be essentially neutral and were introduced last in the test loading. The test proceeded after all solids came to rest. Usually natural sponges were discharged first into the drains and generally had the greatest transport distance. In tests where solids did not clear the bowl the synthetic sponges (which floated) had greater extraction difficulty; for commercial loads it was observed that towelettes were difficult to extract in a first flush and usually exited with a second flush.

Test Results for Light Loads

Water closets were assumed to meet A112.19.6 requirements in effect at the time. Each water closet was subjected to 24 repeated tests; for the 20 water closets 480 tests were conducted. All test materials were discharged from 18 water closets (including the two 3.5 gal models). For those tests the standard deviation was zero. Results demonstrated confidence in the testing, established procedures and that these mixed materials had high reproducibility and reliability validated from the testing.

The following table presents transport distance data from the light loads testing in two drains. The standard deviations are from the five repeated tests for each water closet which had complete extraction of the test load in each case. Those data are plotted in figure 1 for distributions of transport distances

| LIGHT LOADS FIRST FLUSH TRANSPORT TESTS (WSSC) [Only for 20 solids out] | | | | |
|---|---|---|---|---|
| Water Closet # | 3" Diam. 2% Pitch | | 4" Diam. 1% Pitch | |
| | Avg. Dist. (ft) | Std. Dev., $\sigma$ (ft) | Avg. Dist. (ft) | Std. Dev., $\sigma$ (ft) |
| 4 | 24.8 | 5.7 | 22.7 | 8 |
| 5 | 39.2 | 3.2 | 20.4 | 1.9 |
| 6 | 43.5 | 4.8 | 19.3 | 1.6 |
| 7 | 32 | 1.5 | 17.4 | 1.8 |
| 8 | 24.2 | 2.3 | 12.2 | 3 |
| 9 | | | 15.1 | 1.6 |
| 10 | 55.2 | 4.8 | 22.8 | 2.2 |
| 11 | 29.1 | 5.9 | 20.1 | 1.5 |
| 12 | 36.8 | 2.2 | 19 | 1.2 |
| 13 | | | 18.1 | 1.7 |
| 14 | 38.6 | 4.4 | 22.5 | 0.9 |
| 15 | 40.7 | 4.8 | 24.4 | 2.8 |
| 16 | 45.8 | 5.8 | 28.4 | 3.5 |
| 17 | 75.4 | 4.8 | 28.7 | 2.6 |
| 18 | 40.1 | 6.9 | 18.5 | 1.8 |
| 19 | 50.6 | 11 | 18.5 | 2.1 |
| | SET AVG 40 | SET $\sigma$ (ft) = 15.6 | SET AVG 20.5 | SET $\sigma$ (ft) = 4.2 |

obtained for two drainlines. The data are grouped in segments of measured length. Both results show nearly normal distributions of the average distances with light loads. About 60 percent of transport distances were within two standard deviations. Elimination of rolling (of plastic balls) during transport eliminates the uncertainty from ball tests and provides a more credible representation of the transport events. Note in first flush discharges with different mixed bulk media in the Stevens Institute tests of drainline carry [4] showed variability range (for the same water closet) for each first flush from 20 to 40 feet (average) in initial distance with the same fixture.

Variable complex hydraulic interactions with deformable solids mixing during passage in the trapway, deceleration and acceleration zones in the vicinity of the drain entry turning elbow were initially described at the Brunel University test facility [7]. Beyond the entry region the cause of differences in test data results from surge attenuation in the drain with solids deceleration that is determinable from computer program numerical solution of the governing equations that yields the deposit location in the pipe [7]. Effects of different water closet discharge profile and subsequent surge profile changes can also be taken into account. Therefore, the drainline investigation can be made by valid analysis and

tolerances established on waste carry allowable variations through a statistical basis for probable distribution allowances to account for variable parameters and friction factors. Design and code information from the figures also should be noted - greater transport results from smaller pipe diameter and increased slope ([8] and as reported previously by Swaffield and Galowin to CIB W-62).

Distribution of solid deposits along the drain invert is due to the instantaneous locations of solids in the discharge profile (rise, plateau, or tail). The peak discharge flow rate, effects the transport distance. However, wave attenuation is dependent on the pipe slope and diameter, so the coupling effects influence transport distance. There remains a "hidden" factor in waste distributions in the bowl that is somewhat unspecified which effects position and extent of solids distributed prior to moving out through the trapway; rapid discharge of solids at the leading edge of the surge may be impeded and introduces uncertainty with variations for delivery into the drain.

Another variable of solids discharged from the bowl which relates to transport is the extent of "swirl" (a vortex-like motion) within the water closet; then, the order and early positioning of solids is delayed from immediate extraction. Downwash models tend to remove solids expeditiously from the bowl and mostly in the leading portion of the discharge profile. Delayed exit from the bowl occurs with vortex swirl although it is integral to the design concept for other purposes in design considerations for flushing action, but has a deleterious relationship to the carry/distributions of solids in the drain.

Consideration for Data Analysis - A "YOUDEN" Plot

A new consideration for examining test data is proposed to expand tools available for selecting an d verifying methods for introduction of test materials and to increase reliability from tests from plumbing standards. The test data format suggestion, is known as a "Youden plot" [9]. It is an indicator applied to analysis of test data which indicates trends for bias and randomness. The method is frequently applied in round robin and proficiency testing for laboratories in comparative tests; there, it permits determination of "outliers" from data groups for limits of acceptability or setting criteria, with specified confidence limits, for pass/fail from comparative evaluations. It may have application to discriminating reliability in test measurements from methods applicable to plumbing tests in standards.

In figure 2 light loads data from 4 inch diameter pipe, 1 and 2 percent slopes, are introduced in the form of a "Youden" plot. Usually, the method uses two conditions or properties as "reference values or as well established measurements". The plot uses the reference point as an "artificial origin" about which test data are grouped for comparisons with the expectation that data will be organized and have a statistical scatter. Comparisons within a specified level of confidence can then be determined and data outside the prescribed bounds set aside. Here, the consideration proposed would apply to average transport distances in different drains from sets of tests. The apparent "representative value" for reference would be the average from each set of tests. Test data scatter from the "reference value" takes on particular meaning. Along the major line the spread of data indicates an order with preferential shift (bias). Data in a transverse direction, i.e., spread of data from the reference point is indicative of random error data (large differences becomes questionable data).

Representation of confidence level curves (usually in shape of ellipses with major axis and minor axis along the major/minor directions) can be overlaid to represent the applicable population from the parameters in the study. Design and specification information displayed shows effects for different drain pitch and diameter that could consolidate design guides and code sizing requirements in a convenient form for installation practices. Reactions to introduction of new considerations for standards and codes are sought, as well as for other means than this introductory concept.

Test Results - Heavy Loads

For heavy loads 12 repeated tests for each water closet were performed, for a total of 240. The heavy loads consisted of 30 solids, 12 synthetic and 14 natural sponges and 4 towellettes. For many water closets those challenge clearance in first flush extraction; for some water closets a second flush did not achieve clearance. Testing in the proposed standard with current revisions do not consider any requirement for a second flush, although the pass/fail criteria allows partial extractions of sample materials in the first flush to be an acceptance criteria. With the new loading categories a conspicuous shortcoming exists in the proposal for new standard testing methods without factual records, or sources of research for confidence, or experiences from field data trials and analyses for the dependency on test materials and only single flush evaluation. In the WSSC tests reliance on adequacy of the testing method and materials came from light loads testing with first flush extraction of all solids and the outcome in the heavy load performance tests showed several capable of full extraction.

A test summary with heavy loads is presented in the following table (where, $\sigma$ is the population standard deviation). The data is limited to only the low flush volume water closets that demonstrated full extraction capability (out of 18 low flush volume water closets). Those data also are presented

| AVERAGE TRANSPORT DISTANCES (ft) - HEAVY LOAD | | | | | | |
|---|---|---|---|---|---|---|
| Water Closet Number | Drainline: 4" D., 2% Slope | | | Drainline: 4" D., 1% Slope | | |
| | Run # 1 | Run # 2 | Run # 3 | Run # 1 | Run # 2 | Run # 3 |
| 6 | 33.5 | 31.5 | 34 | 11.4 | 15.4 | 16.4 |
| 10 | 34.5 | 45.7 | 52.5 | 22 | 17.5 | 16.7 |
| 12 | 11.8 | 21 | 24.1 | 16.7 | 16 | 15.8 |
| 16 | 50.8 | 45.7 | 42.5 | 19 | 15.7 | 20.7 |
| 17 | | | | 16 | 18.9 | 17.2 |
| | Gp. Avg. = 33.3 ft; $\sigma$=14.8 ft | | | Gp. Avg. = 16.9 ft; $\sigma$=2.03 ft | | |

in the "Youden" plot format in figure 2. For the 4" diameter and 1 percent slope the range of average transport distances are over a small range, about 16 to 18 feet, with two outermost values. These measurement distributions differ from distances for the same water closets with other drainline conditions. The two coupled influences that effect distributions are: i) heavy loadings alter discharge profiles extensively, and ii) drain pitch and diameter effects predominate in attenuation of the reduced surge at lesser pipe slope. Recognition of such changes are of importance to designers and installers that is not currently in information in standards and codes.

## CLASSIFICATIONS IN STANDARDS

Classification of water closets according to building categories for usage was adopted in revision of the A112.19.6 standard that includes increased extraction capacity with mixed bulk media test solids. The

basis for the varied loads results from consideration of user disdain for sanitary environment appearances and little concern about water closet usage for only the intended purposes. Disposal of other material(s) and products other than removal of excreted wastes, toilet tissue and sanitary products, results in a need for greater severity of test loadings (observations at airports, paper towel disposal, toilet seat covers, paper towels, diapers). Those effects do not apply to residential situations and commercial facilities regularly used by a stable population where commitment to preserve the quality in sanitary facilities frequently remains high. However, where little concern for maintenance, or congested diverse traffic is experienced, unusual loads and usage conditions can be experienced. The classifications and test loadings adopted are:

Class I Installation - residential, owner use installations such as one, two, and multiple family homes and condominiums (7 sponges and 5 paper balls);

Class II Installation - transient use installations such as all lodging (hotels/motels) and offices with controlled or limited access (8 sponges and 7 paper balls);

Class III Installations - casual assembly use such as hotel lobbies, mercantile, industrial, school, dormitory, military barracks, churches and offices with public access (10 sponges and 10 paper balls);

Class IV Installations - high occupancy assembly with potential for abuse such as airports, bus terminals, stadiums and prisons (15 sponges and 15 paper balls).

## WASTE SIMULANTS - MIXED BULK MEDIA TESTS

Waste simulant load testing was conducted through efforts by manufacturers in support of the standard revisions. An extensive series of tests were performed in laboratories for evaluations with prescribed toilet tissue and sponge loads and some limited variations in materials evaluated. Specific conditions and common procedures were established to achieve uniformity at different facilities for staff conducting trial testing of the materials. Then, recommendations and data were made available to the standards committee for review and consideration for adoption of test procedures, test materials loads and acceptable performance levels for the four classes.

A toilet tissue wet test for absorption and tensile strength is specified in the instructions. Formation of the paper "ball(s)" is described by preparation on a cylinder (mandrel) then removed to form the desired tied ball shape. Sponges are designated as open cell polyurethane and dimensionally specified; when completely wetted (by immersion) they are heavier than water and sink. The specified loads for each class and specified values for acceptable discharge performance from testing are shown in the table.

The polyurethane sponges are 20 mm x 20 mm x 57 mm, density 17 kg/m$^3$, and are water saturated by soaking. A toilet tissue test requirement for resistance to tearing was established; then four sheet formation into soft balls are described with sketches to aid in preparation. The allowable tolerance for the ball diameter is 25 to 32 mm (1 in to 1 1/4 in). Flush cycle extraction tests with mixed solids are performed to obtain five sets of data. The test requires a minimum of 75 percent test media extracted as the acceptable performance without distinction for the number of solids of each type discharged. (Note - no solids that float are included as a component of the mixed materials.)

| SOLID WASTE SIMULANTS | | | | |
|---|---|---|---|---|
| Current Standard - 100 Plastic Balls; x in Diam. Vol. = Wt. = gms | | | | |
| | Class I | Class II | Class III | Class IV |
| Paper Balls | 5 | 7 | 10 | 15 |
| Sponges | 6 | 8 | 10 | 15 |
| Total number | 11 | 15 | 20 | 30 |
| Req'd. Average Minimum Discharged (75%) | 8.25 | 11.25 | 15 | 22.5 |

The paper ball dimensional tolerance is 25 to 32 mm (1 to 1 1/4 in). The volumetric variation (from the formula for volume - a cubic dependency on diameter) is $(32/25)^3 = 2.08$, i.e. up to twice the volume, or 100 percent. A "ball" is not uniformly dense or homogeneous; each may differ from one sample to another with unknown impacts and uncertainty upon test results. Sponge dimensional requirements allow 5 percent or less variations.

Test Data

Data for extraction of bulk mixed media materials are shown in the tables below, the last pages and in figures 3 to 8. The table lists the average number of solids discharged for each class from each test round. A test series consisted of five repeated tests by an individual tester; then that cycle of five repeated tests was conducted by four more testers, so that in general twenty five tests were obtained (not achieved for all of the water closets and test series planned). The entire testing series was then repeated for each class designation.

In figure 3 the average number of solids extracted in tests are plotted with two lines to indicate i) the adopted 75 percent pass/fail criteria; and ii) the line with equal number of solids out equal to number of solids in (an ideal 100 percent extraction). The draft standard for all classes requires 75 percent of inserted loads to be extracted, without differentiation by type of solid(s) for acceptable performance. In figure 4 a bar chart display shows average numbers of solids extracted for each class designation and for comparison with elimination of the lowest (unacceptable value(s)) of extraction. The increased remaining average performance is greater than 85 percent for classes I to III and class IV at 75 percent. Neither result supports 75 percent as an acceptable level of performance for all classes.

The standard requires five tests with average of 75 percent removal of the mixed solids for acceptance without any limits from any one test. Without limits for each test run there may be any variation in each test. Differing values that can lead to a satisfactory average can be illustrated from (assumed) test results with the following patterns (in percent): 100, 100, 75, 50, 50; and another set with 100, 100, 100, 40, 40. Both examples yield 75 percent average extraction and satisfies the test criteria. Whether such performance is acceptable when disparate performance occurs in each test set requires reexamination and reevaluation for adequacy and sufficient demonstration of extraction capacity. Reliable performance of water closets should not require a second flush as an expected performance condition.

Number of solids in each class:

Class I - 6 sponges, 5 paper balls
Class II - 8 sponges, 7 paper balls
Class III - 10 sponges, 10 paper balls
Class IV - 15 sponges, 15 paper balls

| TEST MATERIALS AVERAGE SOLIDS REMOVAL A112.19.6<br>Average of 5 successive tests;<br>Each set - 5 tests by individual staff | | | | |
|---|---|---|---|---|
| Water Closet | Class | | | |
| | I | II | III | IV |
| | Avg. Solids Out | Avg. Solids Out | Avg. Solids Out | Avg. Solids Out |
| A | 9.5 | 10.1 | 8.2 | |
| B | 11 | 15 | 20 | 29.6 |
| C | | | 18.2 | 7.8 |
| D | | | 18.4 | 21 |
| E | 11 | 15 | 19.4 | 28 |
| F | 9.5 | 14.1 | 16.1 | 15.1 |
| G | 8.1 | 8 | 11.3 | 5.8 |
| H | 9.8 | 12.4 | 13.7 | 8.5 |
| I | 10.9 | 13.8 | 15.2 | 13 |
| J | 11 | 15 | 18.4 | 18.9 |
| K | | | 19.8 | 23.6 |
| L (3.5 gal) | | | (20) | (30) |
| Average | 10.1 | 12.9 | 16.6 | 17.1 |
| Sigma $\sigma$ = | 1.1 | 2.4 | 3.7 | 8 |

A simpler and immediate change, for example, would require that each test result be no less than 75 percent extraction in any one test. However, a more meaningful condition that would assure users, specifiers and installers or others concerned with sanitary concerns and appearances, that a single flush extracts all wastes; two of the tests set for 100 percent removal and a minimum of 80 percent in any other test run so that an average of 85 percent or more would be achieved, which is in accord with the findings from the trial tests (and presumably was the purpose) but not integrated into the proposed standard. Improved level of minimum requirements is also necessary since increasing installations of automated sensors and actuation controls, with no readily perceived means for flush actuation, makes it essential that consistently higher extraction test demonstrations are required in the standard. The potential for residual waste materials not extracted from prior usage in a restroom installation is highly objectionable.

Additional details from the tests are shown in figures 5 to 8. Individual water closet test data shows

several repetitive scores and others that widely differed. Those with large difference that were not repeatable have not been explained. The causes for those results need to be found for demonstration of reliance to substantiate performance expectations are within a logical tolerance. Variable test result ranges found in the trials are not appropriate for the intended sanitary function purposes for testing acceptance from the standard. Further investigation of test materials, specific directions and instructions for load placement, and other contributing causes of large differences need to be resolved. Paper balls are permitted to be unusually different with the specified tolerance that impacts on repeatability. Test materials other than toilet tissue balls may need to be introduced to reduce variability.

In figures 6 to 8 for both types of water closets, the number of solids discharged from the water closet in each test by each tester is presented with the average from the set. Individual tests in some cases show wide differences that need explanation and then a means for reducing those differences; the same water closet with the same materials and test procedure applied should be expected to have greater repeatability (within a range) than shown. The displayed instances with reasonably duplicated test results under the same test conditions demonstrates a basis for the desired replication possibilities and also that the expectation is realistic for the same conditions.

Two data sets in the proposed "Youden" format for comparisons are shown in figures 9 and 10. The information contained in this form also provides a useful appraisal chart that could assist designers in studies for selection of pipe parameters and fixture specifications.

Comment - Test Material Variability

Permissible variations of test paper balls to 100 percent needs to be modified since it may be a primary cause of differences in load extraction test comparisons. That wide allowance is not an acceptable test parameter since the nonuniform conditions cannot be correlated to predictable effects on differences in testing. Volumetric size differences become more important with the increased severity of loading conditions for higher class designations.

Wide differences in test media sizes do not apply to the fact that actual usage experiences may be over a broad spectrum of loadings (mass, materials, volumes). However, if such condition are to be tested then other practices with suitably controlled dimensional sets of materials for reproducible specific ranges of volumes (or quantities) need to be specified, with details for loading conditions. Uncertainty from the current paper balls must be eliminated by adopting more stable and uniform test media.

## CONCLUSIONS

Contributions for development of precision and bias statements for limiting uncertainties from test procedures carried out under quality systems operations and direction need to be achieved for greater assurance and confidence in the tests for application in regulations and by manufacturers, researchers, public, local officials and inspectors.

Important contributions for achieving improved performance testing was demonstrated in endeavors of the participants in the standards evaluations program. The body of data is extremely useful for further evaluations of variables for test stand water closet data analysis. That, in turn, would permit improved accuracy for confidence in tests in laboratory conditions with tests and methods applied for qualifications.

The major changes in the draft standard(s) for water closet testing with new bulk media loads and

category classifications have only a conjectured basis for selection of satisfactory load conditions, proposed tests, acceptance criteria. Field data are required for confirmation from building installation field trial verifications. Prudent and cautious adoption practices would set acceptance criteria at rigorous levels that could later be reduced if experience shows it possible.

Elimination of tests for drainline transport permits the fixture that introduces "bulk mass solids" into drains will be acceptable without any testing for demonstrating reasonable carry distances in drains. In particular, (heavy load conditions - Classes III and IV) in commercial and public buildings require lengthy branch and collector drains, or drain extensions for sites at many locations, e.g., shopping malls, industrial parks, sports and entertainment arenas, low rise motels, that have only single fixture loadings. Performance assurance needs to be from test measurements.

Changes discussed here indicated concern about elimination of waste transport tests since the deposit of solids occur in distributions along the pipe lengths, and not concentrated at an average location; such conditions can only be obtained from tests of water closets and there is a need to show if the extent of a second flush can continue transport. Potentials for deposits/blockage with reduced water flows cannot be dismissed; it is the purpose of standards to consider conditions that can arise, even if such problems have not been prevalent. Recognition for testing other fixture operations have been retained although there have been no problem occurrences, then why eliminate drainline tests?

Transport with significant differences between the 20 water closets were evident. The performance comparisons from testing with light and heavy load simulations identifies and supports methods for newly introduced classification categories. Explicit confirmation from field data monitoring of installations is required for confirmation of sizes and mixed constituents for test loads and acceptance criteria.

The major change of classifications for categories by building purposes needs a follow-up study program to assess the characterization for classes assigned for water closets in designated installations. Those classifications for diverse building types have been made without experiences and/or data. Also, support needs to be provided for design or code changes specific to reduced flows and applications of class designations to varieties of building drainage systems for pipe sizing.

## CLASS I - WATER CLOSET TEST WASTE SIMULANT SOLID DISCHARGE (11 Solids)

| WATER CLOSET | TEST SET | STAFF TEST OPERATOR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | | 4 | | 5 | |
| | | Sponges | Paper Balls | Sponges | Paper Balls | Sponges | Paper Balls | Sponges | Paper Balls | Sponges | Paper Balls |
| | | Total Load: 6 Sponges, 5 Paper Balls | | | | | | | | | |
| B | 1 | 6 | 5 | 6 | 5 | 6 | 5 | 6 | 5 | 6 | 5 |
| | 2 | 6 | 5 | 6 | 5 | 6 | 5 | 6 | 5 | 6 | 5 |
| | 3 | 6 | 5 | 6 | 5 | 6 | 5 | 6 | 5 | 6 | 5 |
| | 4 | 6 | 5 | 6 | 5 | 6 | 5 | 6 | 5 | 6 | 5 |
| | 5 | 6 | 5 | 6 | 5 | 6 | 5 | 6 | 5 | 6 | 5 |
| | | Average: 6 Sponges, 5 Paper Balls; Standard Dev. = 0 | | | | | | | | | |
| F | 1 | 6 | 5 | 6 | 5 | 6 | 5 | No Tests | No Tests | 5 | 4 |
| | 2 | 6 | 5 | 6 | 5 | 6 | 5 | | | 3 | 3 |
| | 3 | 6 | 4 | 6 | 5 | 6 | 5 | | | 4 | 3 |
| | 4 | 6 | 5 | 6 | 4 | 6 | 5 | | | 5 | 4 |
| | 5 | 6 | 5 | 6 | 5 | 6 | 5 | | | 1 | 0 |
| | | Average: 3.6 Sponges, 2.8 Paper Balls; Standard Dev. = 1.97 | | | | | | | | | |

## CLASS II - WATER CLOSET TEST WASTE SIMULANT SOLID DISCHARGE (15 Solids)

| WATER CLOSET | | STAFF TEST OPERATOR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | 2 | | 3 | | 4 | | 5 | |
| | TEST SET | Sponges | Paper Balls | Sponges | Paper Balls | Sponges | Paper Balls | Sponges | Paper Balls | Sponges | Paper Balls |
| | | Total Load: 8 Sponges, 7 Paper Balls | | | | | | | | | |
| F | 1 | 8 | 7 | 6 | 6 | 8 | 7 | 7 | 7 | No Tests | No Tests |
| | 2 | 8 | 7 | 7 | 3 | 8 | 6 | 8 | 6 | | |
| | 3 | 8 | 7 | 7 | 4 | 8 | 7 | 8 | 7 | | |
| | 4 | 8 | 7 | 8 | 7 | 8 | 7 | 8 | 7 | | |
| | 5 | 8 | 7 | 6 | 7 | 8 | 5 | 8 | 7 | | |
| | | Average: 7.7 Sponges, 6.4 Paper Balls; Standard Dev. = 1.8 | | | | | | | | | |
| H | 1 | 8 | 7 | 8 | 7 | 8 | 7 | No Tests | No Tests | 4 | 3 |
| | 2 | 8 | 7 | 8 | 7 | 8 | 7 | | | 5 | 5 |
| | 3 | 8 | 7 | 8 | 7 | 8 | 7 | | | 3 | 4 |
| | 4 | 8 | 5 | 2 | 0 | 8 | 7 | | | 3 | 4 |
| | 5 | 8 | 5 | 8 | 7 | 8 | 7 | | | 5 | 4 |
| | | Average: 6.7 Sponges, 5.7 Paper Balls; Standard Dev. = 1.98 | | | | | | | | | |

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6. Regulatory Compliance Division, Code Enforcement Section. "Drainline Transport Performance With 1.6 GPF Water Closets", (Yingling, Galowin), Washington Suburban Sanitary Commission,

7. Swaffield, J.A. and Galowin, L.S. (1992), 'The Engineered Design of Building Drainage Systems', Ashgate Publishing Co., Brookfield, VT or Aldershot, U.K.

8. Swaffield, J. A., Galowin, L. S., "Drain Sizing for Plumbing Codes", American Society of Plumbing Engineers Convention and Exposition, Kansas City, October 23-26, 1994

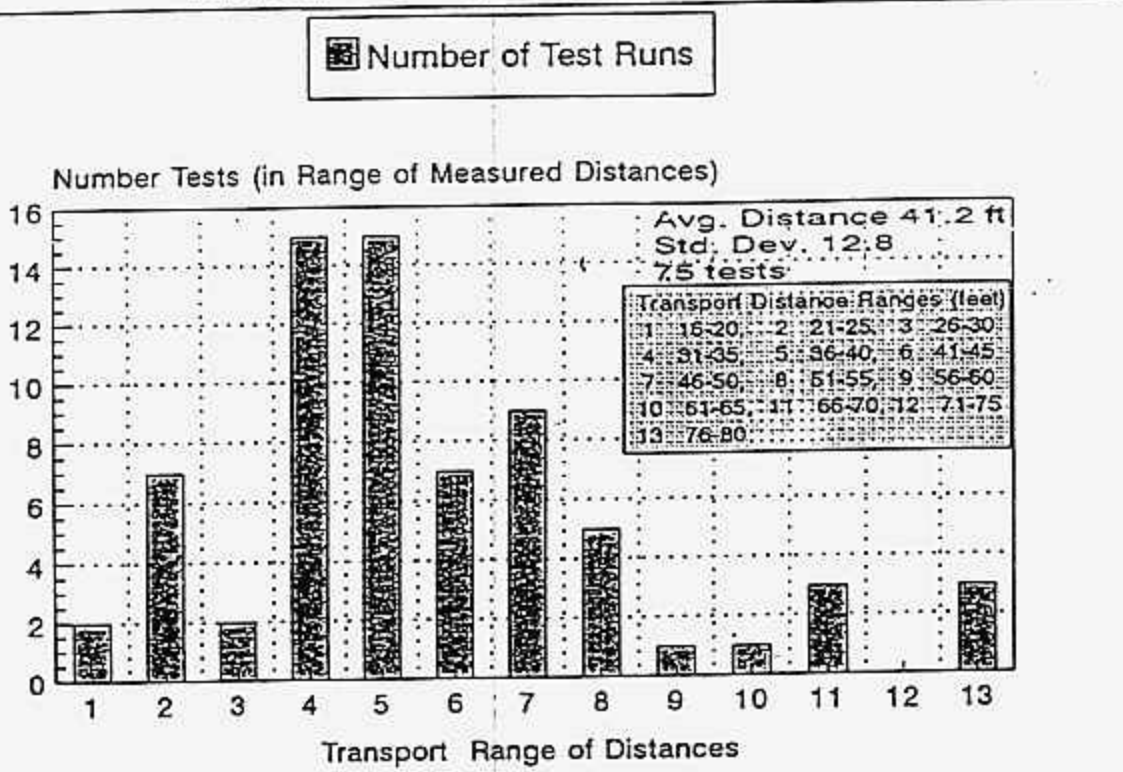
9. Youden, W. J., Experimentation and Measurement, NIST Special Publication 672, Reprint May 1994

10. Swaffield, J. A. and Galowin, L. S. "Drain Sizing for Plumbing Codes" American Society of Plumbing Engineers, Kansas City, October 1994

11. Swaffield, J. A. and Galowin, L. S., "Big Drains, Small Drains How do Your Wastes Flow, American Society of Plumbing Engineers, Washington, DC, November, 1992

## DATA SUMMARY LIGHT LOADS (WSSC) FOR 3 in DIAM. 2% SLOPE

LOW FLUSH VOL. WC'S; ALL 20 SOLIDS EXTRACTED



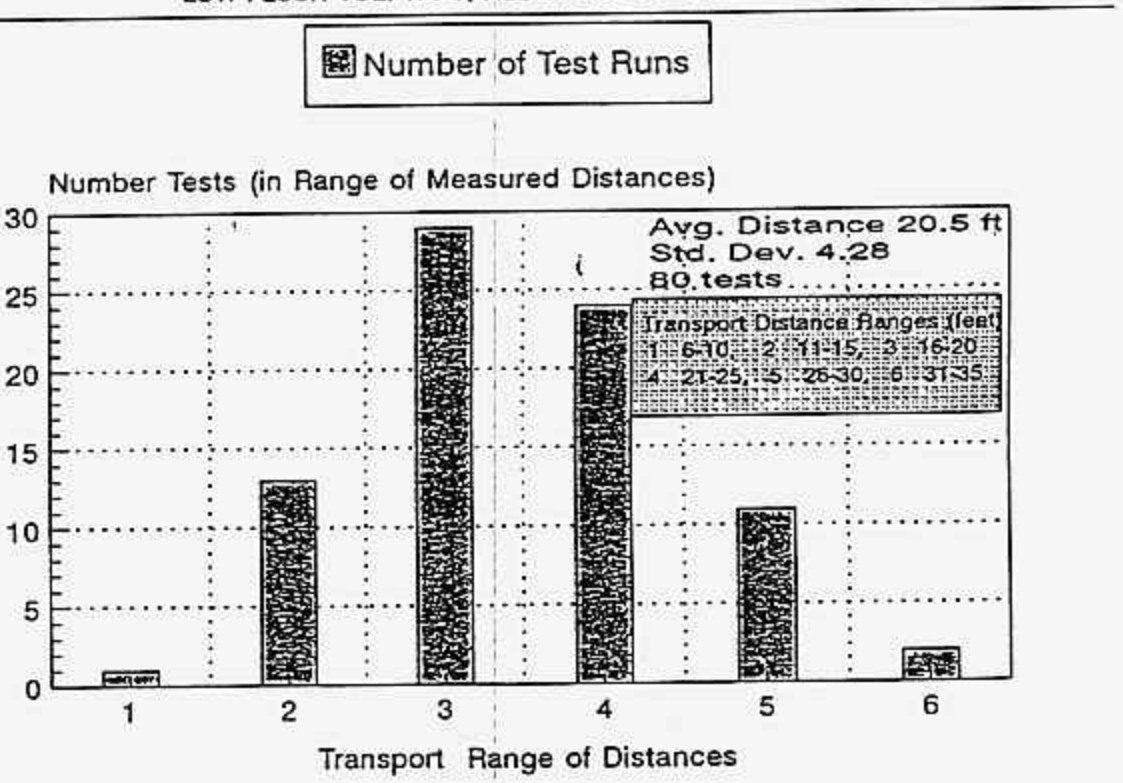

Loads: 6Syn. (float), 12 Natl. (sink) Spoanges

1-w62-96

*FIGURE 1*

## DATA SUMMARY LIGHT LOADS (WSSC) FOR 4 in DIAM. 1% SLOPE

LOW FLUSH VOL. WC'S; ALL 20 SOLIDS EXTRACTED

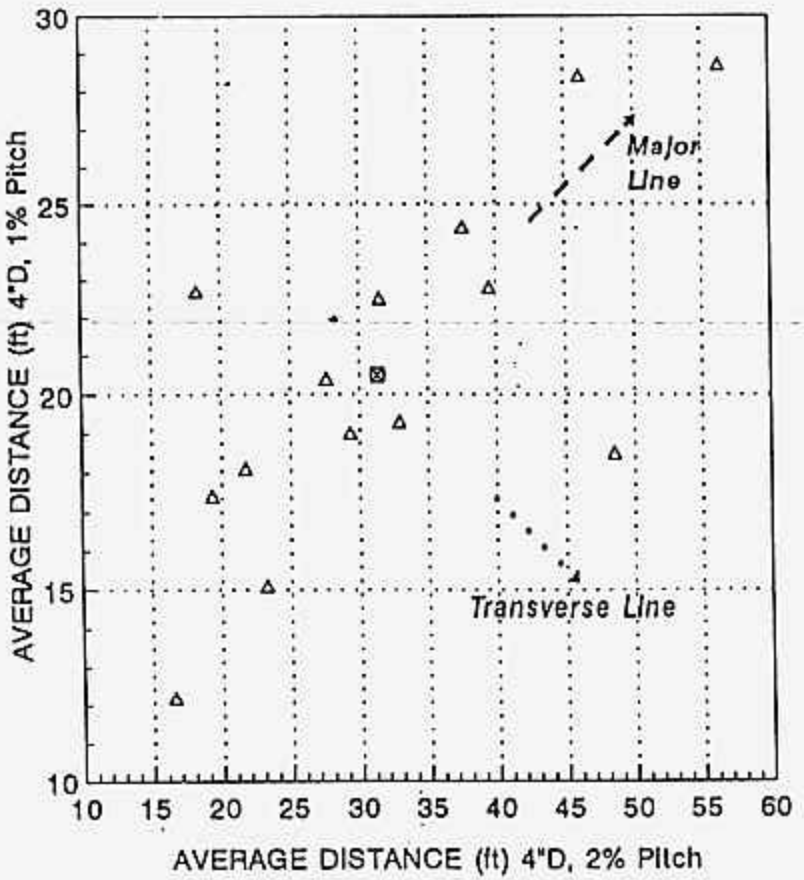



Loads: 6Syn. (float), 12 Natl. (sink) Sponges

2-w62-96

LIGHT LOADS - TRANSPORT DISTANCES IN 4" DIAMETER DRAIN
1% & 2% PITCH; AVERAGE 5 TESTS EACH WC - LOW FLUSH VOL
20 SPONGE SOLIDS; 8 Synthetic, 12 Natural Sponges

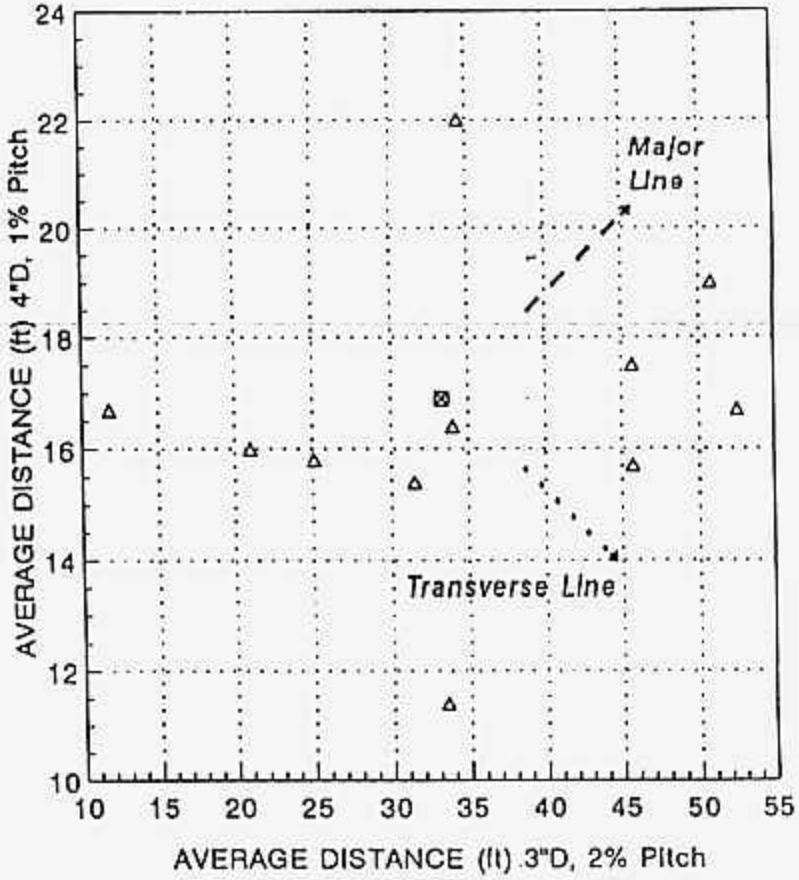
△ Avg. Transport Length ⊠ AVG IN EACH DRAINS




W62-96-AA

HEAVY LOADS - TRANSPORT DISTANCES 3 TEST RUNS EACH WC
3" DIAM, 2% PITCH; 4"DIAM 1% PITCH; - LOW FLUSH VOL. WC's
30 SOLIDS; 12 Synthetic, 14 Natural Sponges, 4 Towelettes

△ Avg. Transport Length ⊠ AVG IN EACH DRAIN



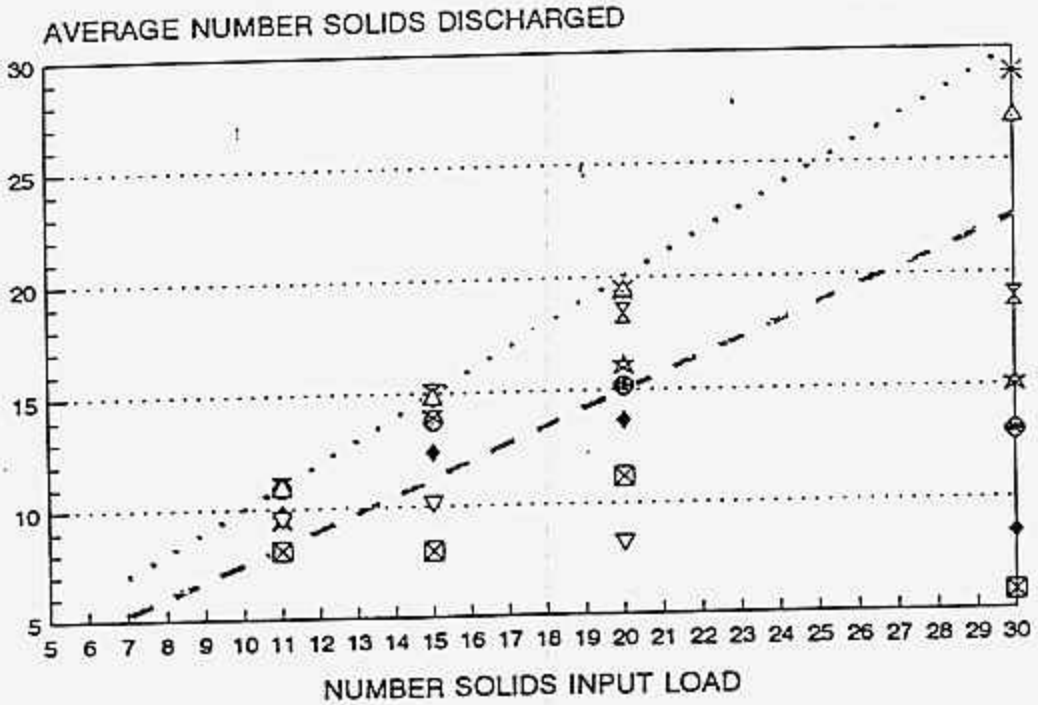

W62-96-AB

*FIGURE 2*

# A112.19.6 TEST DATA FOR WC'S (AM.STD/MNSFLD)

▽#1 △#2 ✳#3 ☆#4 ⊠# ♦#6 ●#7 ⧖#8 ···Ideal, linear —75% CRITERIA-PASS

*FIGURE 3*



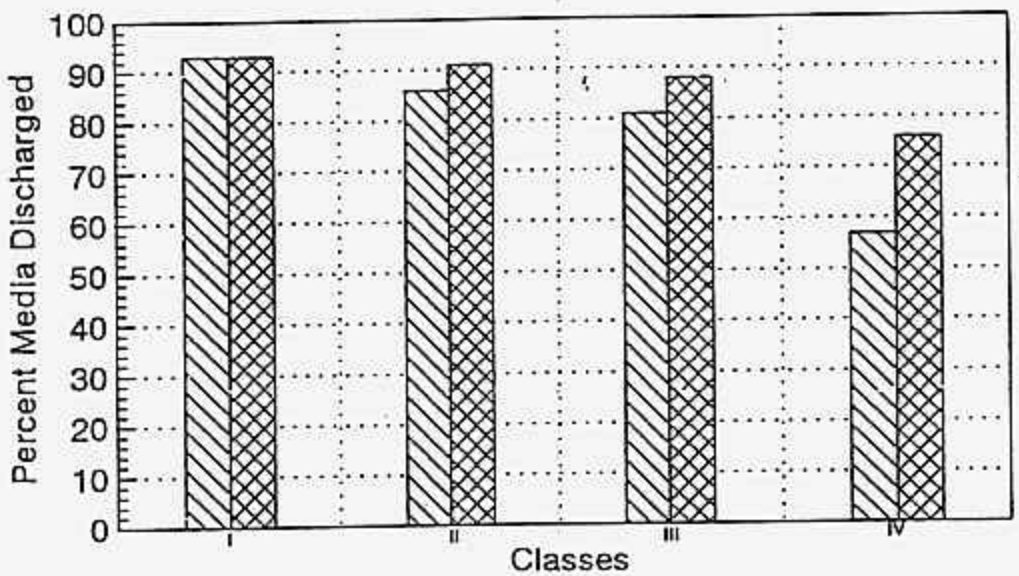

TSTDTAWC

# AVERAGES BULK MEDIA TESTS TYPES A - K

## Amer. Std./Mansfield Proposed Classes I, II, III, IV

⊠Average A-K 1.6 gpf ⊠Selected Deleted WC's

*FIGURE 4*




ONLY 1.6 GPF WATER CLOSETS

Select Removals: Cl I No Drop; Cl II Drop G; Cl III Drop A(41%), G(56%); ClIV Drop CHI(26%,28%,43%)

## CLASS III LOADS - 10 Sponges, 10 Paper Balls Discharged From WC's
### AVERAGES OF FIVE TESTS - EACH SET BY TESTER 1, 2, 3, 4, 5 (A112)

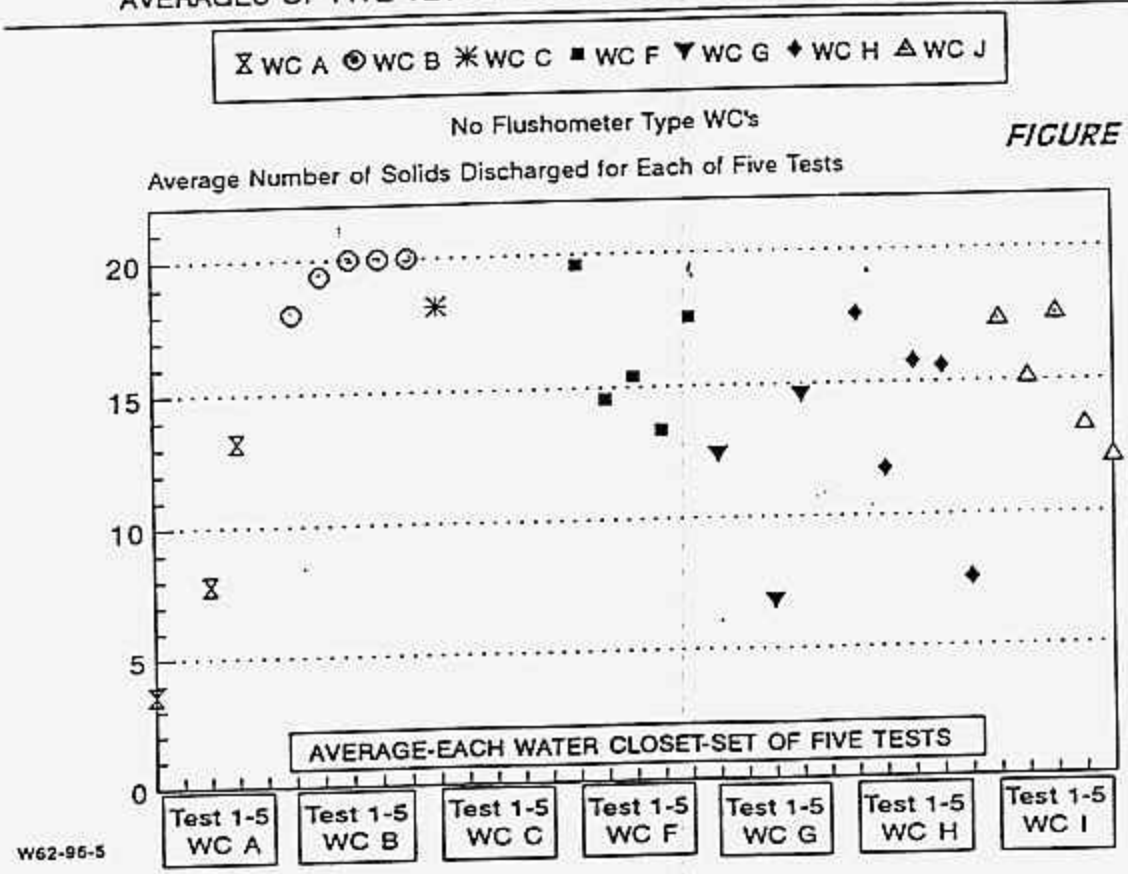



*FIGURE 5*

## WC F; CLASS III LOADS - 10 Sponges, 10 Paper Balls
### EACH TEST RUN (FIVE TESTS) - EACH SET BY TESTER 1, 2, 3, 4, 5 (A112)

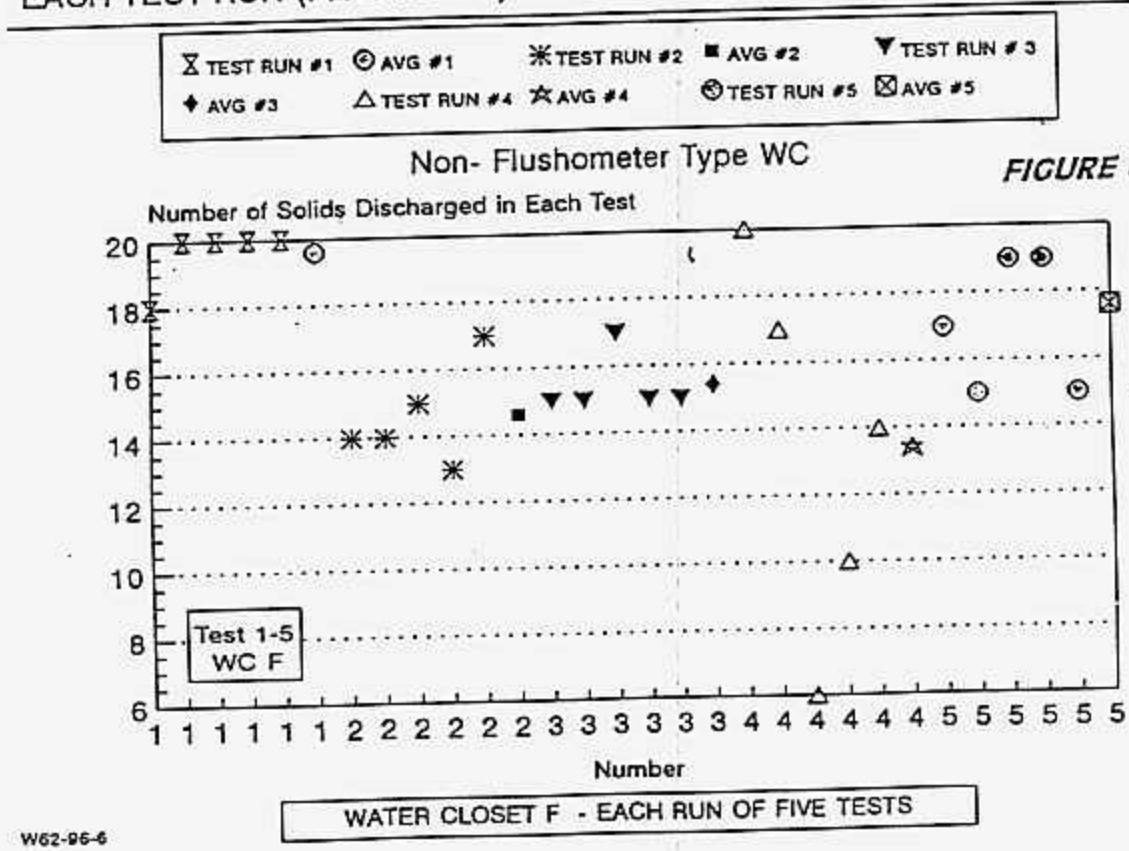
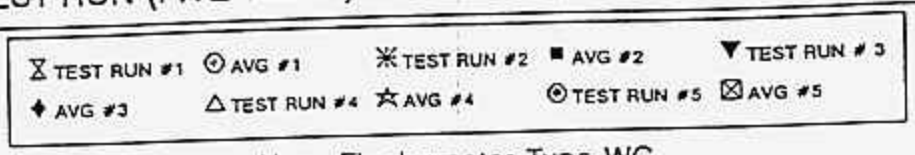


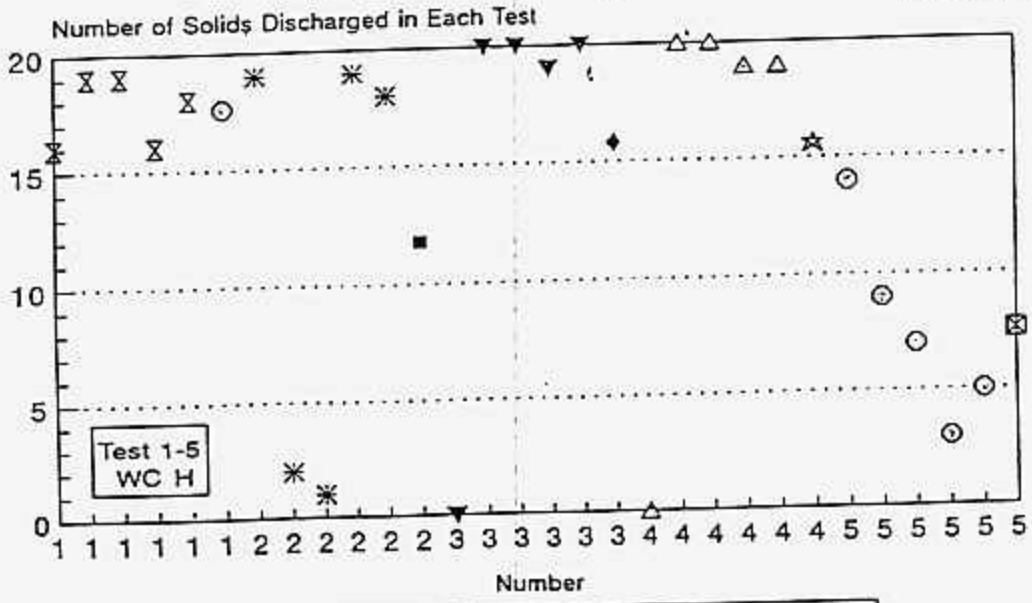

*FIGURE 6*

## WC H; CLASS III LOADS - 10 Sponges, 10 Paper Balls
## EACH TEST RUN (FIVE TESTS) - EACH SET BY TESTER 1, 2, 3, 4, 5 (A112)




Non- Flushometer Type WC

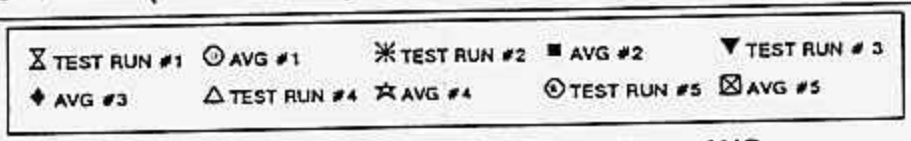
*FIGURE 7*




WATER CLOSET H - EACH RUN OF FIVE TESTS

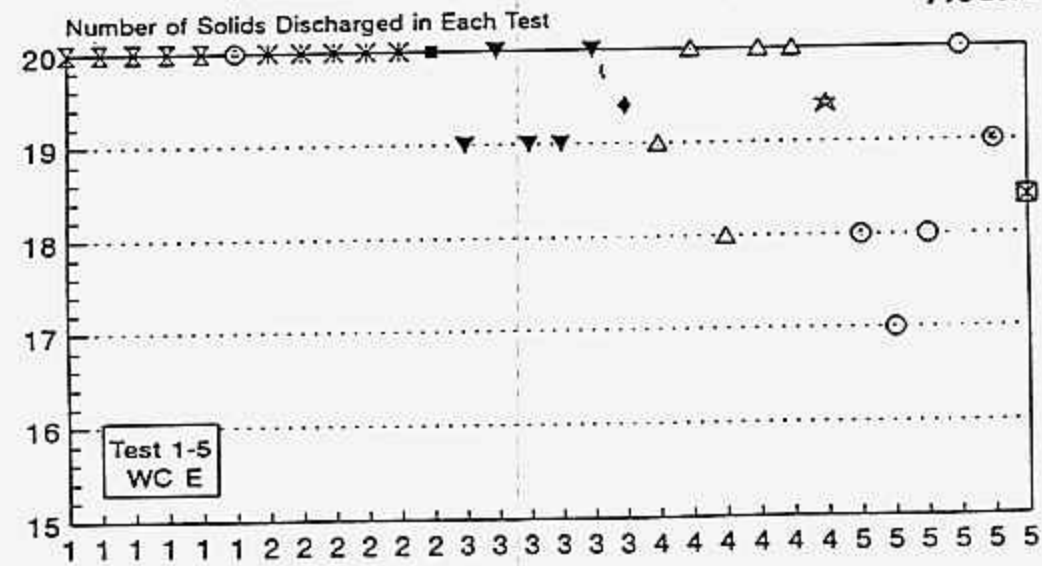
W62-96-7

## WC E;CLASS III LOADS - 10 Sponges, 10 Paper Balls
## EACH TEST RUN (FIVE TESTS) - EACH SET BY TESTER 1, 2, 3, 4, 5 (A112)




Flushometer Tank One Piece Type WC

*FIGURE 8*




WATER CLOSET E - EACH RUN OF FIVE TESTS

W62-96-8

## SIMULANT WASTE TESTING NEW MATERIALS FOR STANDARD A112.19.2

CLASS I AND II COMPARISON

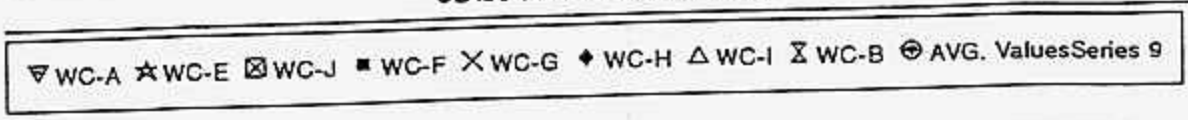
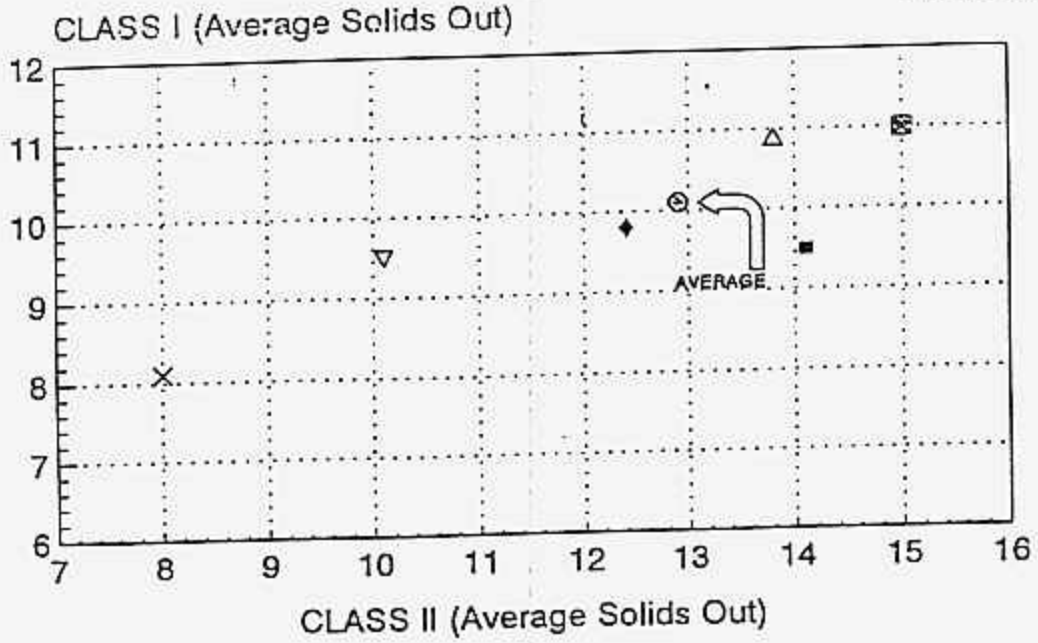



*FIGURE 9*




W62-3/96

## SIMULANT WASTE TESTING NEW MATERIALS FOR STANDARD A112.19.2

CLASS II AND III COMPARISON

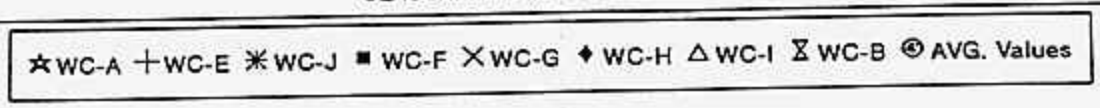
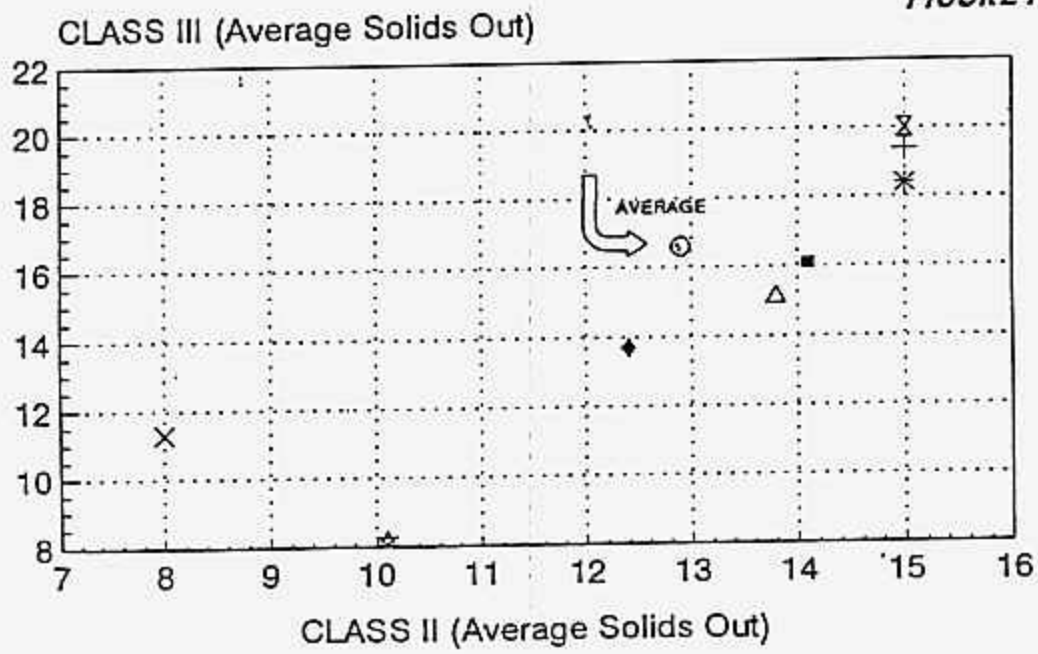



*FIGURE10*




W62-4/96

# Topic A6

## Prewall-Installation, Sanitary Technology of the Future?

R. Westphal, A. Schweizer, Switzerland

# Prewall-Installation, Sanitary Technology of the future?

**Dipl.-Ing. Rolf Westphal**
**Geberit International AG, Rapperswil (Switzerland)**

This lecture deals with plumbing technology in sanitary rooms. Sanitary installations are still literally 'built in' to the building and therefore grow with the building process of an object. The demands for faster, simpler, more flexible and cheaper building were never more important than they are now. Meeting these demands, however, will eventually mean equipping instead of building in and mounting instead of installing. This can only be done by rigorous separation (technically and chronologically) of installation and object (= pre-wall installation). Modern installation systems based on 'dry construction' allow installation which is largely independent of the building object; supplementary software supports the planning, procurement and assembly. This lecture presents the structure and function of such installation systems and documents them with examples.

## 1. Subdivision of the Subject

Sanitary installations are a must in all buildings inhabited and used by man. They serve in connection with sanitary devices and fittings to meet the requirements:

- disposal of excrement
- washing and care of the body
- refreshment and relaxation

as well as

- nutrition
- washing and cleaning

} kitchens, work rooms

For this purpose, water is brought into a building, partly heated, used and then taken out again as effluent. On the whole this can be divided into two areas:

| **Technical area** | **Equipment area** |
|---|---|
| • Location and design of sanitary rooms | |
| • Dimensioning and design of drinking water and waste water pipes | • Choice and arrangement of sanitary devices (sinks, baths) and fittings |
| • Connection and fixture of sanitary devices and fittings | • Additional equipment (e.g. in hospitals and homes for the elderly and disabled) and accessories |
| • Heat insulation, damp, sound and fire proofing | |
| • Panelling measures for the plumbing technology | • Design of room surfaces (tiling) |

The extended field of sanitary installations also includes heating, ventilation and electrical lines as well as guttering. These are usually installed together at least in installation shafts of multi-storey buildings.

**This lecture concentrates on the plumbing technology in sanitary rooms.**

## 2. General Information about Plumbing Technology in Sanitary Rooms

### 2.1 Legal and Economical Aspects

The customer and contractor structures are changing dramatically at the moment in the building industry. Whereas in the construction of smaller objects (e.g. single family houses), those involved usually know each other, the investor sector is becoming more and more anonymous. General entrepreneurs are coming more and more to the fore. Investor in Vienna, architect in Frankfurt, planner in Basle, general entrepreneur in Prague, plumber on site - that is today's practice! Consults for directly protecting the builder's interests do not simplify things either.

Invitations to tender with detailed designation of the individual services are being replaced by verbal formulations of the builder's requirements (= functional invitation to tender). The plumber has to take care of the planning process himself in order to be able to make an offer at all. Detailed legal and technical knowledge are a pre-requisite for success here. Weaknesses are mercilessly exploited - a building project is often only 'terminated' in court.

The different interests of the various participants in the planning and execution automatically lead to conflicts. The sanitary installation especially, which usually involves intervention in the building structure, is bound to cause conflicts in communication and co-ordination. Conflict-free building is therefore what is required - and this means separating the individual trades and clearly allocating the services.

A conflict reducing strategy for modern installation must therefore be:

**Decoupling of building construction and sanitary installation as far as possible.**

In practice this can only be achieved by installation 'in front of the wall', a form of installation which has come to be known throughout Europe as

**pre-wall installation**

## 2.2 Technical Aspects

The architect has the overall responsibility for the construction and function of a building, and this includes the sanitary installation, even if he enlists the appropriate specialists (engineers for housing technology) to do the job.

The conditions for pipe installation, sound and fire proofing are set in the planning phase with the positioning of the sanitary rooms in the building.

The number and dimensions of the sanitary devices and the appropriate areas of movement determine the size of the room. The minimum sanitary equipment depends on the type and use of a building governed by laws and regulations. The execution itself is only restricted by the builder's financial possibilities.

Usually, pipes and connections are installed in walls and ceilings in the building shell phase in such a way as to determine the positions of the sanitary devices. Changing these devices is no longer possible or only at a very high cost. This may not be important for rented apartments but it certainly is for owner-occupied apartments. For sales-related reasons it is extremely important to consider the buyer's individual wishes even at a later stage of the building.

To make room for the sanitary installations at all, walls need to be broken open and re-closed. Reconstruction measures during the building so to speak! In addition to the often unqualified interventions (static) in the building substance, problems are literally built in. An adequate sound insulation for example is practically impossible.

The extra costs for this type of built-in installation are rarely transparent according to the motto 'that's the way we've always done it'. It's the builder who has to pay because also in the building industry nobody works for nothing.

Modern installation technologies therefore largely separate the building and the plumbing technology.

This produces a basic planning rule for the linking of installations to the building construction:

> 'The installation of pipes and apparatus in the building may not affect or interfere with the requirements of the building with respect to stability, sound protection, fire protection, heat insulation and damp-proofing specified by legal regulations, contract and accepted rules of technology'.

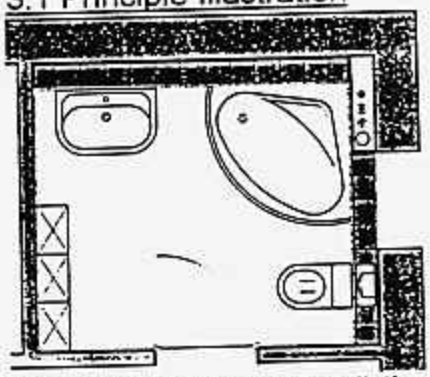
For technical reasons this also has the following consequence:

> **The whole plumbing technology is placed in front of the walls and then panelled = principle of the pre-wall installation**

This enables an installation which is largely independent of the building progress and 'flexible' in its arrangement. This is on precondition that the space for the pre-wall installation has already been provided for during planning.

## 3. Principle of Pre-wall Installation

### 3.1 Principle Illustration



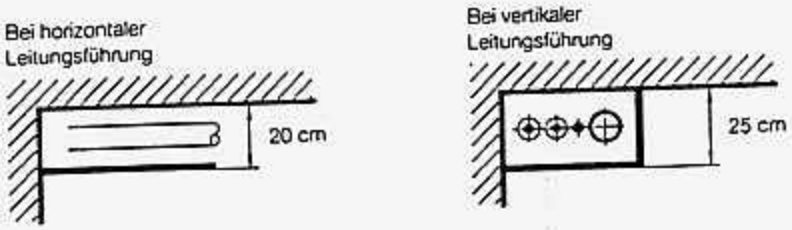
The example shows an installation placed completely in front of the walls. In the case of storey-connecting pipes at full room height otherwise at half room height.



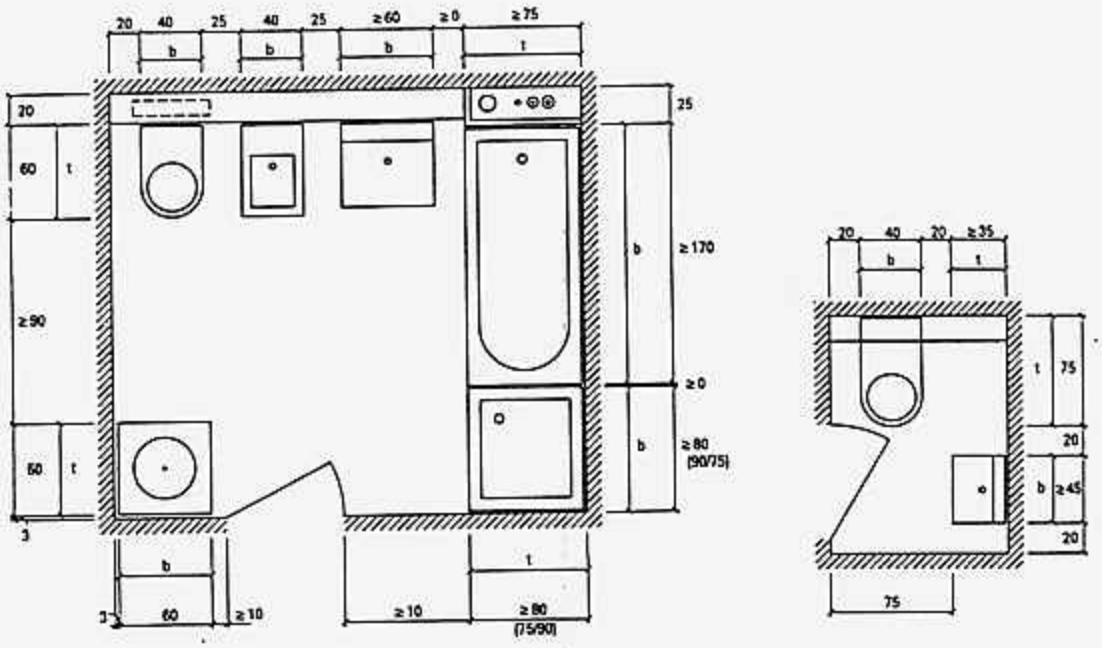
Bathroom with consistent pre-wall installation

## 3.2 Planning Principles

In Germany, the pre-wall installation is covered by a planning standard (DIN 18022):

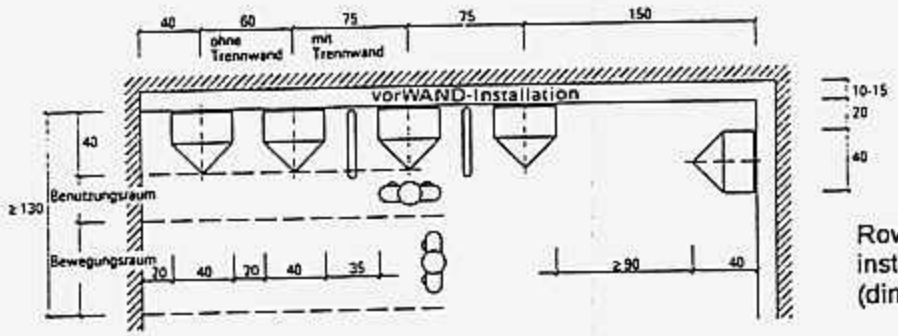



Space required by pre-wall installations

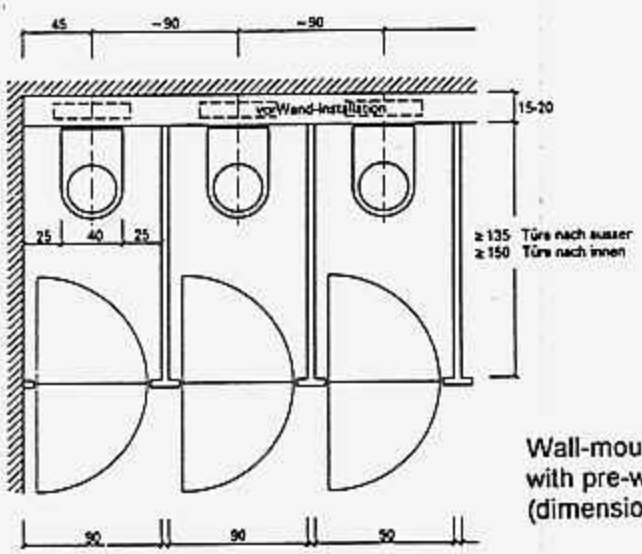



Planning example bathroom / WC with pre-wall installation according to DIN 18022 (dimensions in cm)

These rules can also be applied as follows for the public trade sector:



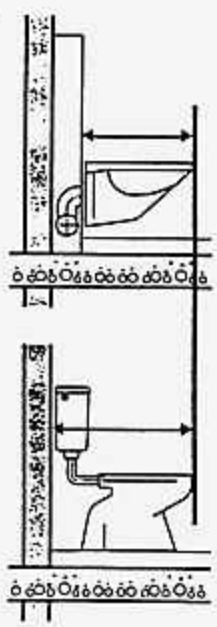

Row of urinals with pre-wall installation
(dimensions in cm)




For WC row systems a full room height pre-wall installation is recommended so that commercially available partition walls can be used.

Wall-mounted WC row system with pre-wall installation
(dimensions in cm)

It is incorrect to equate the space required by pre-wall installations generally with additional space requirements. As the next figure shows, the space required by a wall-mounted WC with concealed cistern integrated in the pre-wall is no more than that required by a floor-mounted WC with an attached or low cistern.



# 4. Examples of Installation

## 4.1 Manually-erected Pre-wall Installations

All details are measured in and assembled on site. Uneconomical, expensive → rarely used.

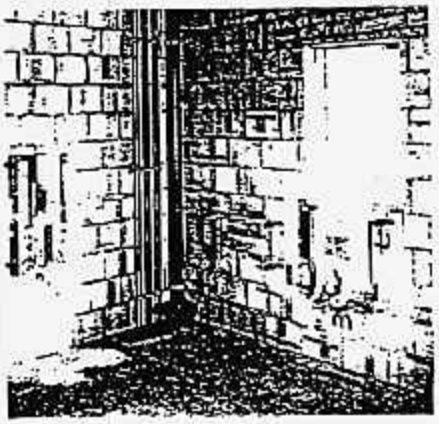
## 4.2 Pre-wall Installation with Single Assembly Elements

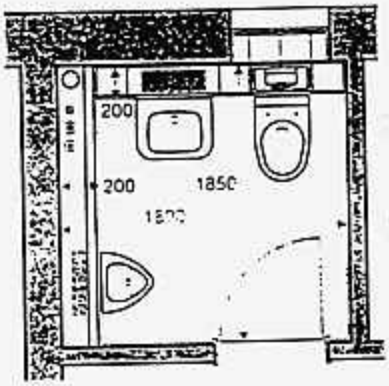
One installation element (metal frame) pre-assembled at the factory is used per sanitary device. All installation details are already provided by the manufacturer of the elements. All that needs to be done at the building site is to assemble them according to the desired center spacings and install and connect the drinking water and waste water pipes.

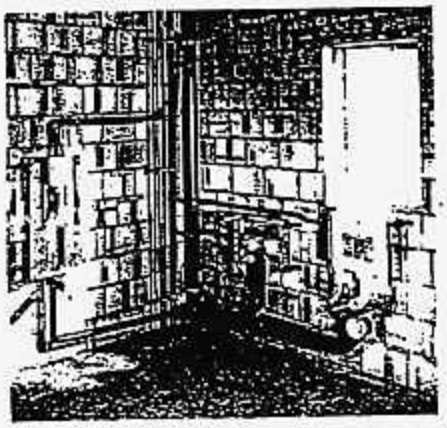
### 4.2.1 Type of Installation for Solid Construction

All cavities are cladded or the installation is covered by a pre-wall.







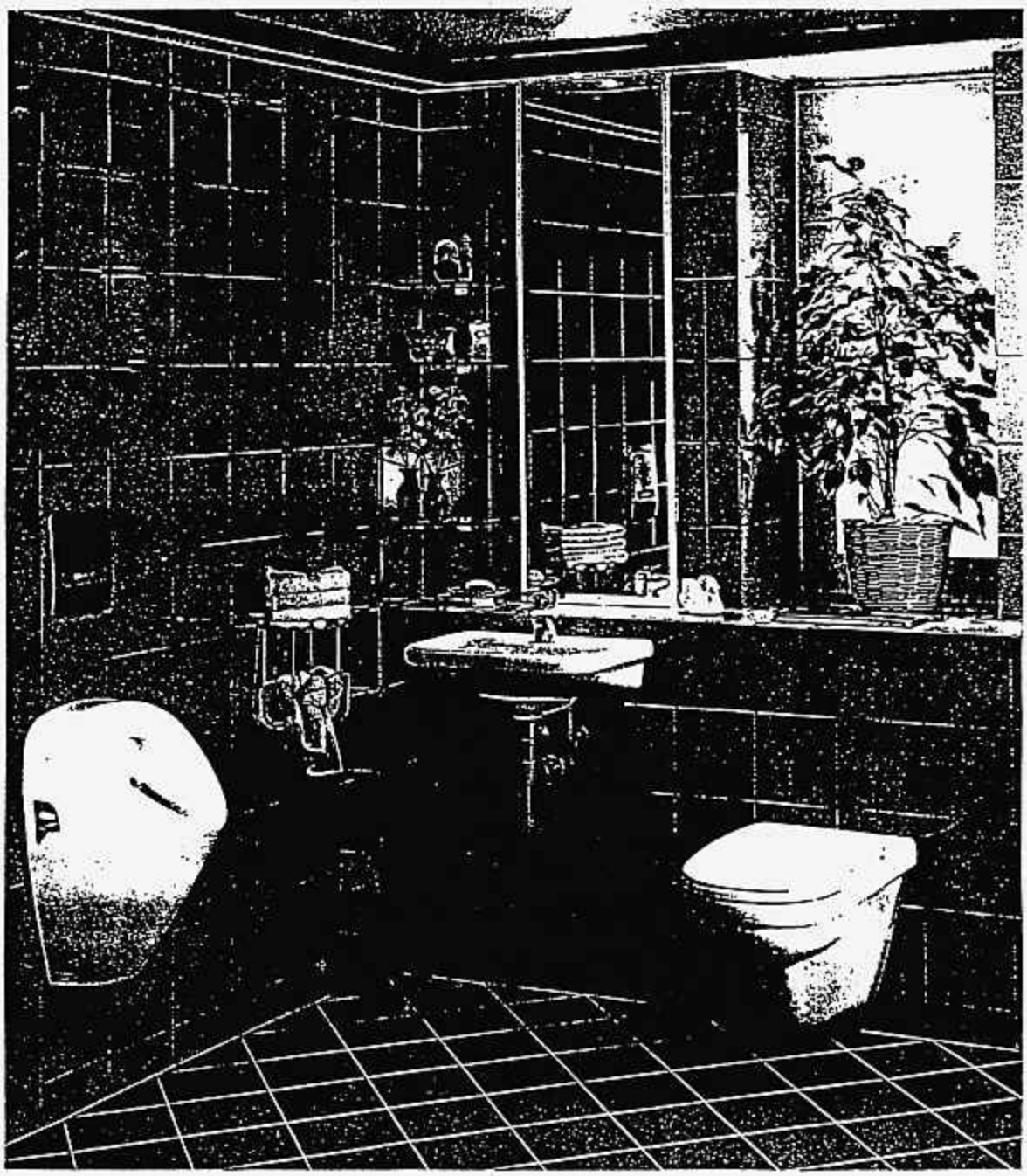


The assembly example shows the development of a WC room in pre-wall installation. Geberit Kombifix are used as installation elements.

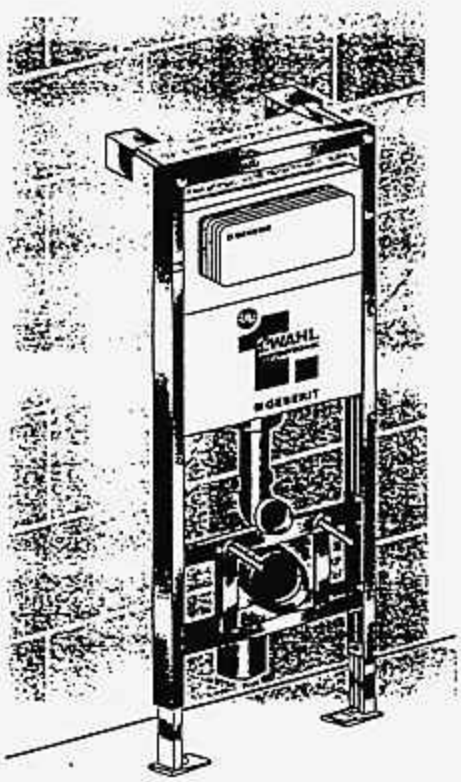
The problem of mounting a wall-mounted WC underneath the window has been solved by using an installation element with a top-operated concealed cistern. Installation height 90 cm.

Half room height walling in the area of the window and full room height blocking up at the side wall.

Urinal with automatic contact-free electronic flush (infra-red)



## 4.2.2 Type of Installation for Dry Construction (Lightweight Construction)

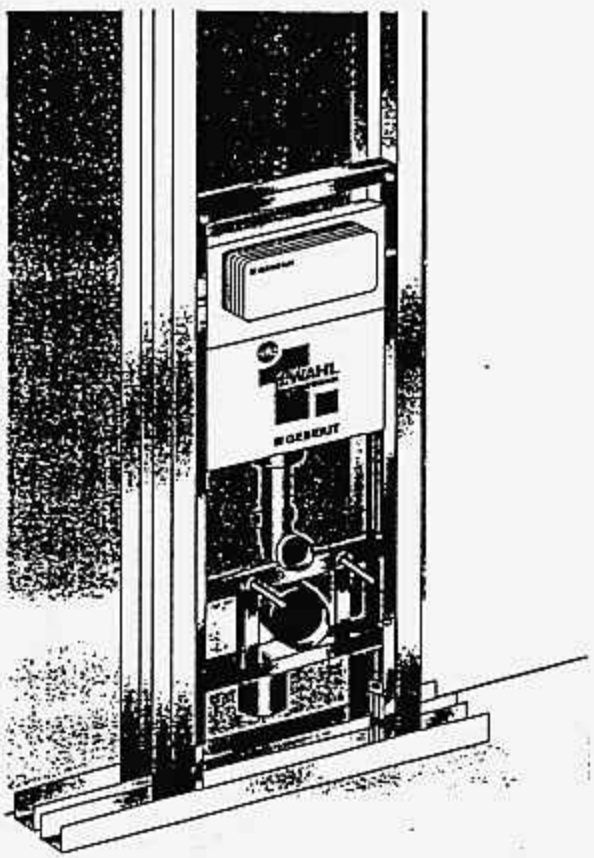


Here the installation is also mounted in front of the wall but then not cladded but panelled (plasterboard or wooden panels). Since the supporting wall is missing, the installation elements must be much more stable than in the solid construction. A fast, clean method of installation.

Pre-wall installation with wall-mounted WC assembly element prepared for subsequent panelling.

Installations in plasterboard-framework walls are a special case. The planned cavities in the walls are tailor-made for accommodating the plumbing technology.

The illustrated Geberit DUOFIX installation elements can be used universally.



Installation in a plasterboard-framework wall with a wall-mounted WC installation element

## 4.3 The Geberit Installation System GIS

Extensive market research has revealed the following basic requirements of the builder for a modern installation:

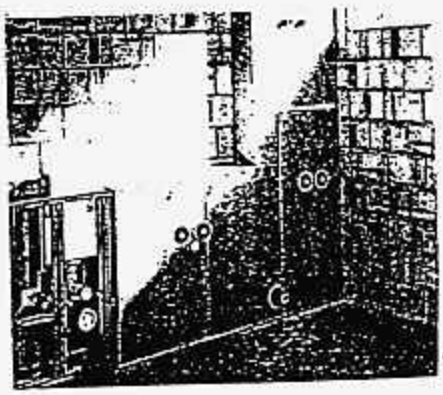
1. **Freedom of planning and design**
2. **Provision of services by as few people as possible, ideally by one provider**
3. **Price transparency prior to purchase**
4. **Fast, on-time realisation**

The pre-wall installation using single installation elements is a first step in this direction. However, an optimum solution can only be found with an installation system which:

- **takes into account the builder's wishes and includes them in the planning**
- **is in itself autonomous and therefore largely independent of the building technology and building construction**
- **enables an exact calculation of material and assembly**
- **supports the procurement of material and work preparations**

It consequently consists of

a product system and a service system



"Hardware"



"Software"

The Geberit Installation System GIS provides these services

- The GIS product system consists of
  - profile material
  - connection and installation elements

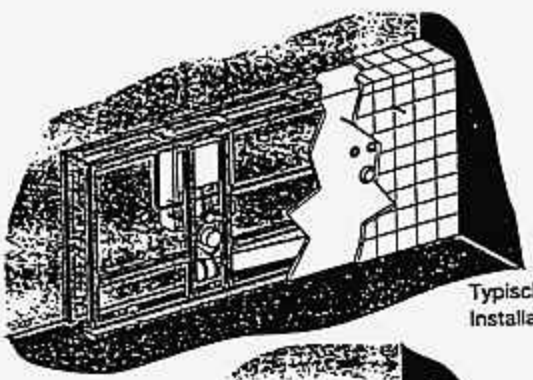
  } → walling
  - installation elements, e.g. for wall-mounted WC, washbasin etc.
  - drinking water and waste water pipes and connections
  - panelling with adaptable panels

Pre-wall installations, partition walls and whole walls can be built with these system components. Such installations can be built on site or pre-assembled at the workshop.

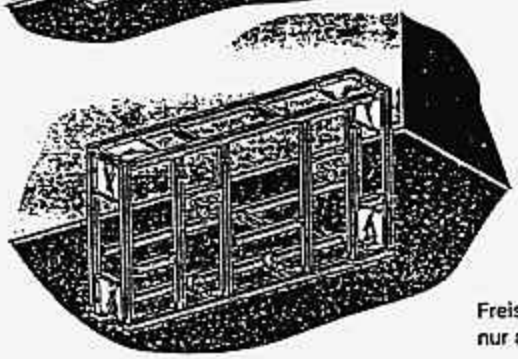
Typical pre-wall installation, half room height

Free-standing GIS installation, only fixed to bare ceiling

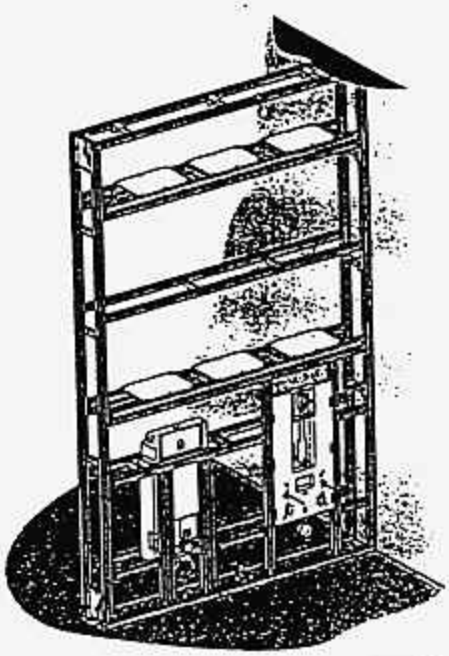
Full room high GIS wall, fixed to floor, ceiling and side wall.



Typische vorWAND-Installation, halbhoch.



Freistehende GIS-Installation, nur auf Rohdecke befestigt.



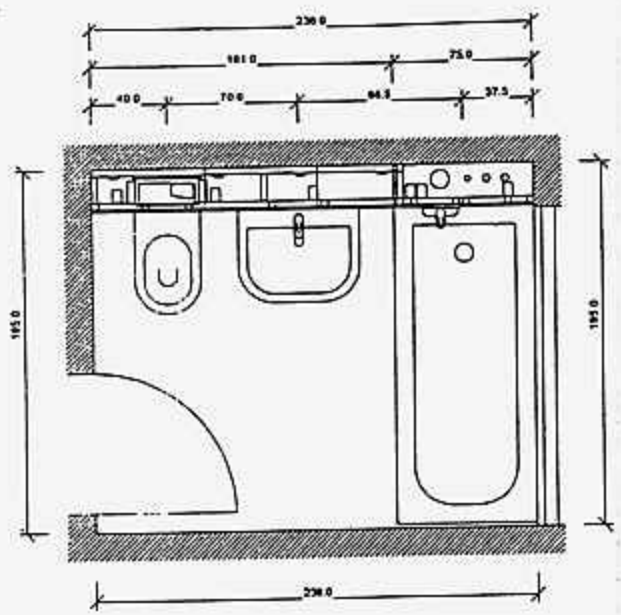
Raumhohe GIS-Wand, an Boden Decke und Seitenwand befestigt

- The GIS planning system (= service system "DLS") is a software which runs under Windows on a normal PC.

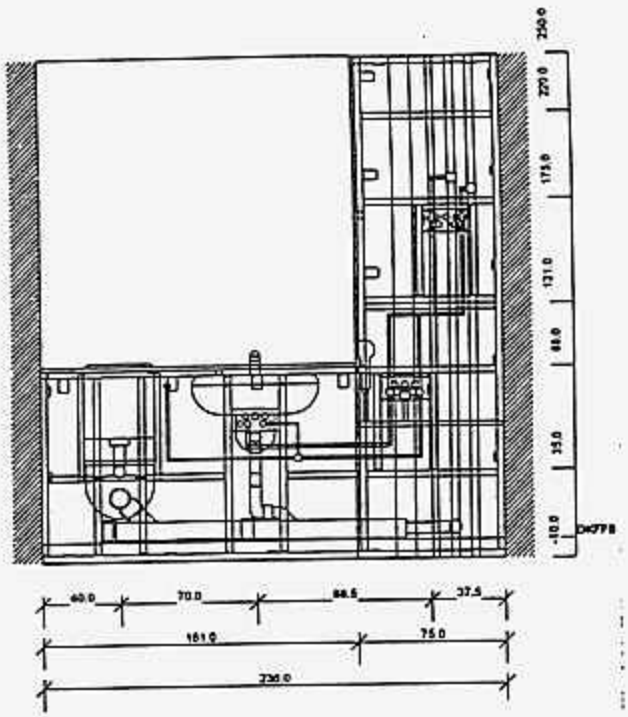
  It enables:

  - planning of sanitary rooms on the screen
  - a 3-dimensional visualisation of the room
  - an automatic material determination (parts list, order list) and calculation
  - compiling an offer
  - creating assembly drawings

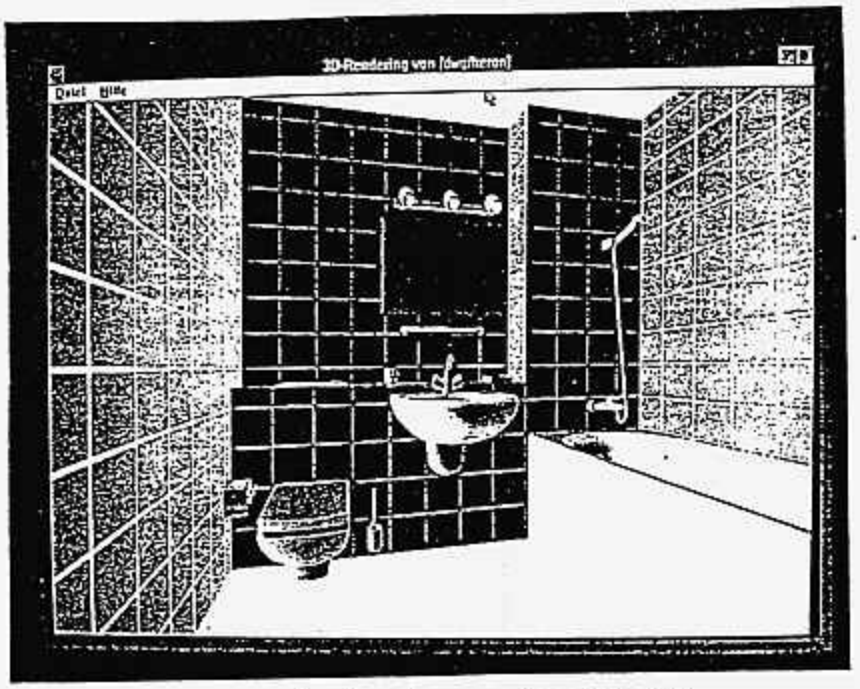
  Of course all the screen displays can also be printed. The quality, especially of the 3-dimensional diagram, depends on the type of printer.



Dimensioned groundplan with GIS created by DLS.



Corresponding elevation created by DLS.



The sanitary room can be shown in perspective with the 3D module and can be printed in photographic quality providing the right hardware is available.

**The GIS product system does of course work without using the service system!**

An installation example with GIS is enclosed as an appendix.

## 5. The Future of Sanitary Technology

The planning and design of sanitary rooms will be done entirely on a PC monitor. Equipment, fittings, accessories, lighting as well as wall and floor coverings will be taken from electronic catalogues. The availability and price situation will be kept up to date by the product suppliers via the Internet. The customer will get a picture of his own sanitary room in photo-realistic quality. The appropriate sanitary technology is determined automatically by the planning system and converted into a materials list and assembly instructions. This is realised in the shortest time possible with a product system like the GIS.

Legende für Abbildung Seite 6

| | |
|---|---|
| Bei horizontaler Leitungsführung | With horizontal pipes |
| Bei vertikaler Leitungsführung | With vertical pipes |

Legende für Abbildungen Seite 7

Obere Abbildung

| | |
|---|---|
| ohne Trennwand | Without partition |
| mit Trennwand | With partition |
| Benutzungsraum | Usage space |
| Bewegungsraum | Movement space |

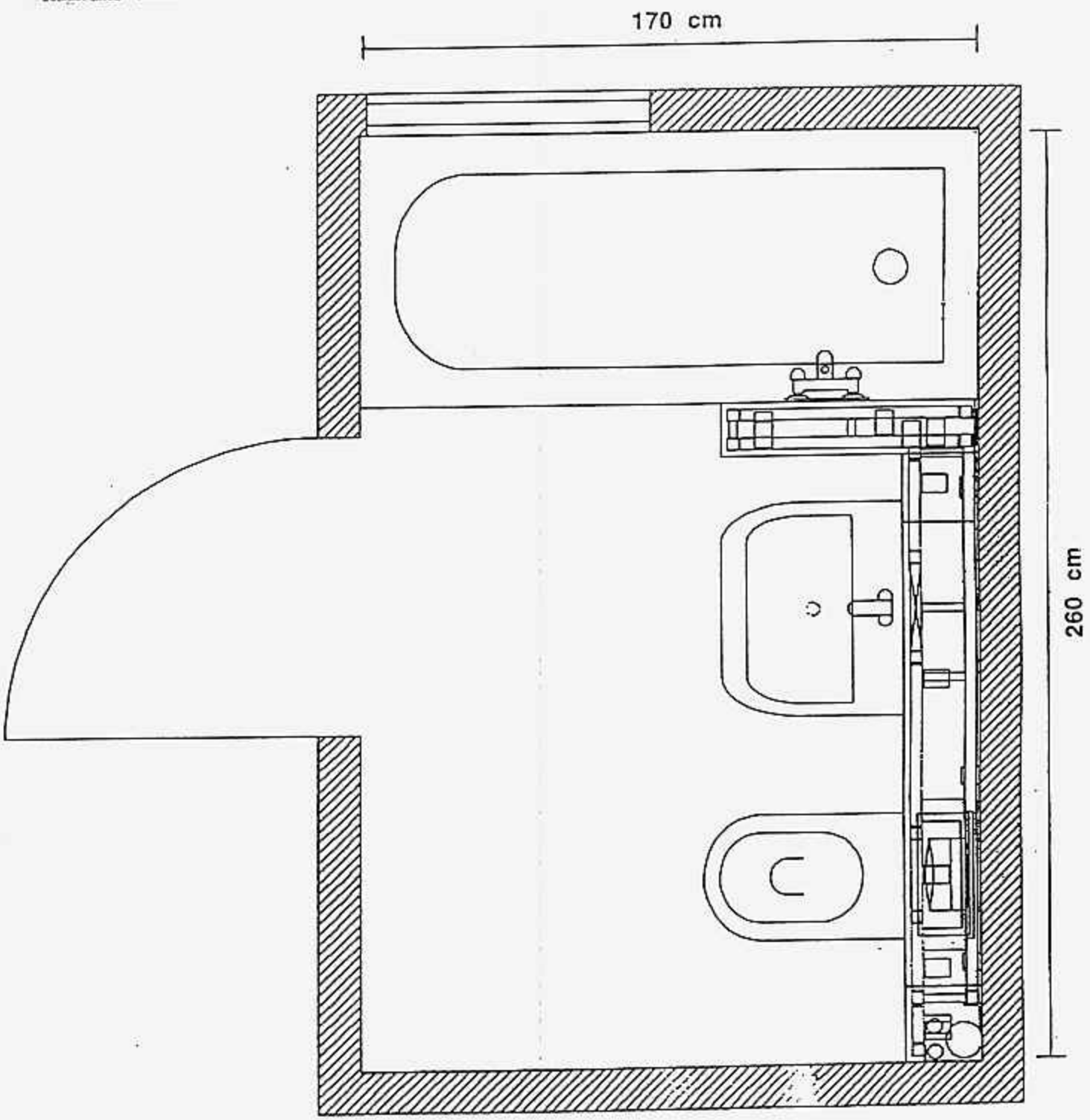
Mittlere Abbildung

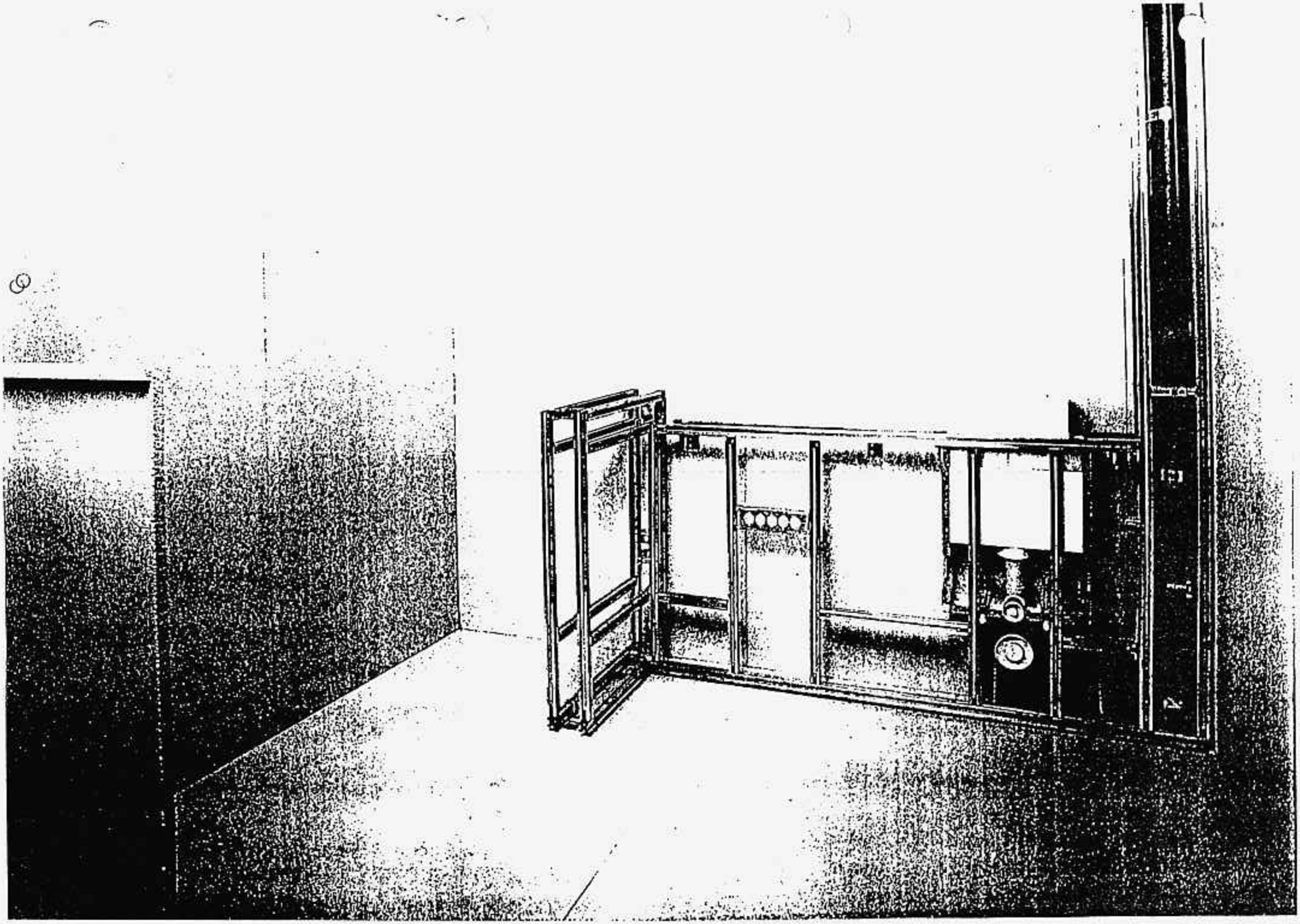
| | |
|---|---|
| VorWand-Installation | Pre-wall installation |
| Türe nach aussen | Door opens outwards |
| Türe nach innen | Door opens inwards |

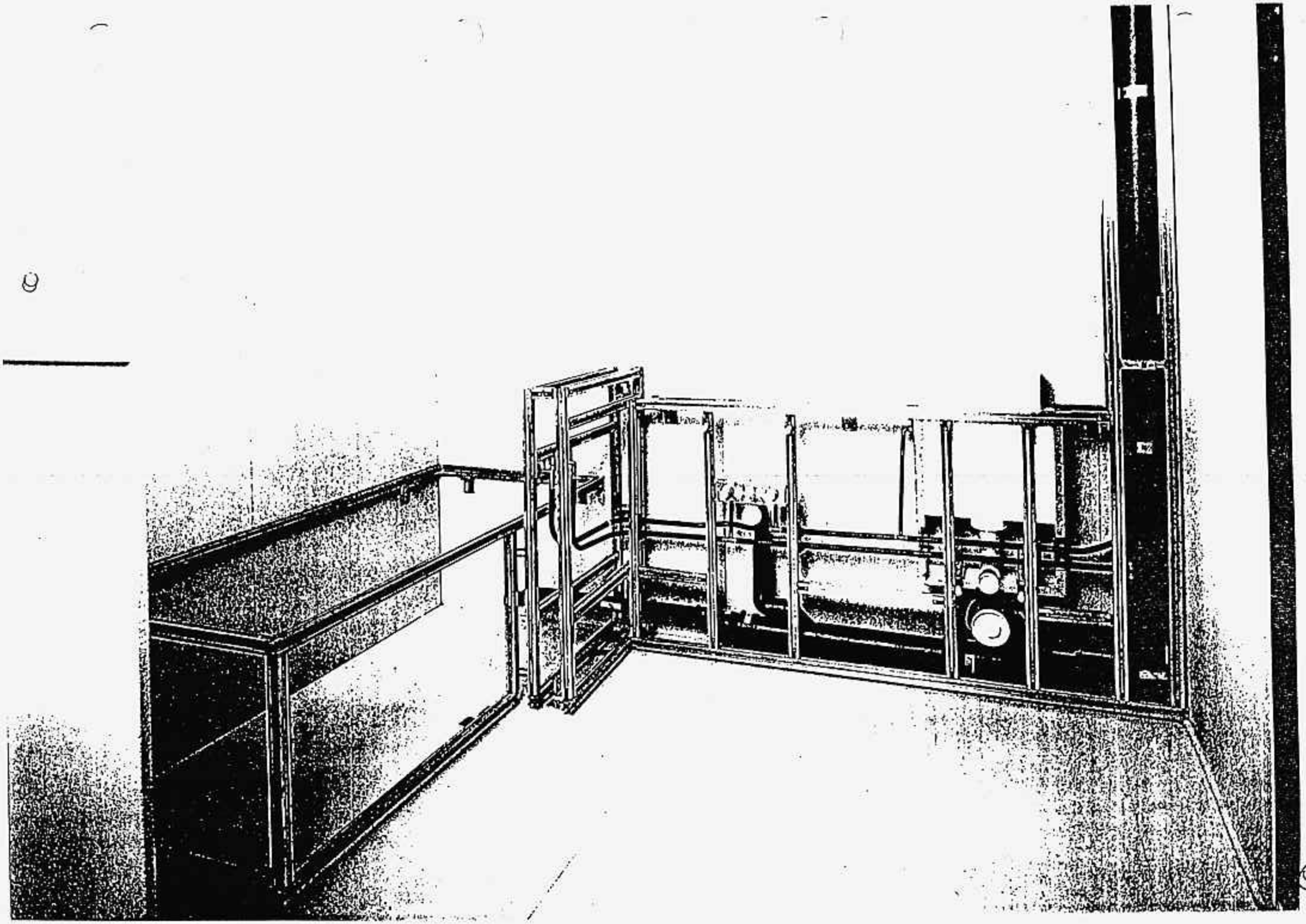
Anlage (1)

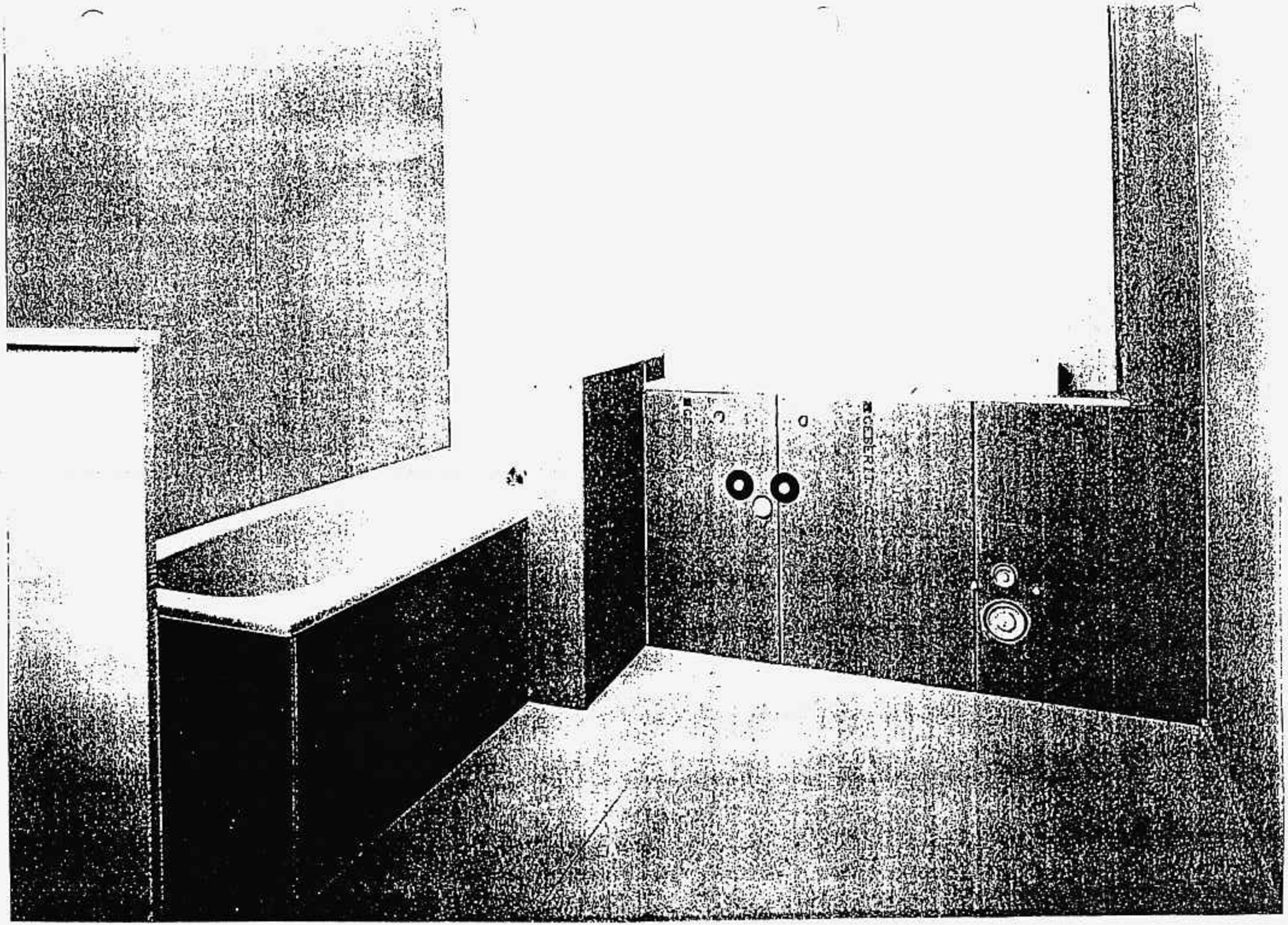
Instapbadkamer A1

de Vrije
Badkamer Formule








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# Topic A7

## Belgian Recommendations for Lowering the Risk on Legionella Pneumobhilla Contamination in Installations for the Distribution of Sanitary Water

K. De Cuyper, Belgium

# MINIMISING THE RISK OF LEGIONNAIRES' DISEASE RECOMMENDATIONS FOR DESIGN AND USE OF DOMESTIC HOT AND COLD WATER SERVICES

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## Abstract

The domestic water system is one of the reservoirs for the Legionella bacterium, this bacterium being responsible for a pneumonia-like illness called Legionnaires'disease. Research conducted between others by CSTC/WTCB in the early 90's revailed the extend of the occurrence Legionella bacteria in domestic water services. This paper reviews briefly these results and presents the Belgian recommendations for minimising the risk of Legionnaires' disease.

**Keywords**: Legionnaires'disease, domestic water services, recommendations,

## 1 Introduction

Since in 1976 a mysterious epidemic pneumonia-like illness killed 29 participants of the 58th American Legion Convention in Pennsylvania, USA, the world has knowledge of one disease more: the Legionnaires' disease. It was however only a year later that biologists were able to identify the origin of this illness: an unknown bacterium, called "Legionella pneumophila". This bacterium seems to have been present in little water droplets, with a diameter of a few micrometer (aerosols), which were suspended in the air of the conference room. The origin of this aerosol being the humidification treatment of the air. The inhalation of this contaminated air induced the disease in certain persons [1].

Since that date a multitude of epidemic outbreaks of the Legionnaires'disease have been noticed in all parts of the world. In Europe, although some important outbreaks -like the one in the Stafford Hospital (UK) in 1985 and the one in the BBC building (UK) in 1988- were related to the air installation, a lot of problems were linked to the installation for the distribution of sanitary hot water.

As the presence of the legionella bacterium, in the plumbing installations of hospitals, was recognised to be a major health problem in Belgium, and given the fact that the design and use of those installations seemed to be of importance for the development of the bacterium, rising the risk of Legionnaires' disease, a research was set up by the Belgian Building Research Institute from 1991 till 1993. The aim of this research was :

- to evaluate the extend of the Legionella problem in the drinking water installations inside the different type of buildings: single family houses, apartment buildings, office buildings, sport complexes, hospitals and homes for elderly;
- to identify and to analyse the parameters inherent at installation- and use which influence the development of the bacterium;
- to set forward recommendations for minimising the risk of Legionnaires'disease.

On the occasion of the CIBW62 Seminars in Washington (1992) and in Porto (1993), we had the opportunity to report already on the first two objectives [2], [3]. In this paper we will present the recommendations which were established as a result of our research, taking into account the information provided in literature [1],[6],[7], [8]. Before considering these recommendations we will however first remember in §2, some facts about the legionella bacterium and the Legionnaires'disease. In §3 we will regroup our research results, while the recommendations will be presented in §4.

## 2 Legionella bacteria and the Legionnaires'disease

Legionella bacteria are micro-organisms, 2-6µm long, which are responsible for a pneumonia-like illness, called Legionnaires' disease. About 2 to 15 % of the pneumonias seem to be caused by these bacteria [1]. The overall death rate for the Legionnaires' disease is about 25%. The susceptibility to this disease is however not equal for all persons :

- most people who become ill are older than 50 years;
- men are 3 times more susceptible than women;
- especially smokers are susceptible;
- person with health problems are also more susceptible, especially alcoholics, those receiving immunosuppressive therapy, diabetics,.. .

The infection chain is always the same: multiplication of the bacteria, aerosolisation and inhalation.

These bacteria were found in all aquatic environments: lakes, cooling towers, drinking water installations,... etc. Multiplication of legionella starts around 26°C, and has an optimum between 35°C and 40°C. Pasteurisation occurs above 46°C and rapid killing above 60°C.

Besides a pneumonia-like disease, bacteria of the legionella family can also cause a fever, called Pontiac fever, which is however never fatal.

## 3 Results of the CSTC/WTCB research

The results of our research were presented in [2] and [3], we only briefly review here the most important.

According to our findings (table 1) the legionella bacterium is not detected in domestic hot and cold water service of single family buildings or in apartment buildings with an individual hot water production. The bacterium is however

commonly found in apartment or collectivity buildings with a centralised hot water production.

Table 1 Occurrence of legionella bacteria in different types of buildings in Belgium

| type of building | total number examined | number with legionella bacteria |
|---|---|---|
| single family houses | 30 | 0 |
| apartment buildings | 16 | 4 |
| hospitals | 8 | 5 |
| sport complexes | 6 | 1 |
| office buildings | 2 | 2 |
| homes for elderly | 1 | 0 |
| total | 63 | 12 |

The occurrence of the bacterium is influenced by several factors, between which :

- The type of water distributed: in the great majority only hot water services are contaminated; the presence of legionella in cold water services is less frequent and only when the hot water installation is also affected (table 2).

Table 2 Occurrence of legionella in hot and cold water services of collectivities

| | type of water sample | | total numbers of samples |
|---|---|---|---|
| | cold water | hot water | |
| total number of samples examined | 36 | 86 | 112 |
| number of samples contaminated | 4 (11%) | 16 (19%) | 20 (16%) |

- The dimension and type of the installation: 'little'installations are not affected, while 43% of the collective buildings with central hot water production present a legionella contamination (table 3).

Table 3 Occurrence of legionella in collective buildings, according to the type of hot water installation

| | type of hot water production | |
|---|---|---|
| | centralised | decentralised |
| total number of samples | 14 | 9 |
| number contaminated | 6 (43%) | 0 |

- The presence of corrosion phenomena: the chance to have a contamination raised with the concentration of iron ions in the water.
- The temperature at which the hot water is produced and distributed: the lower this temperature, the greater the chance to find legionella.
- The presence of some materials: some rubbers seem to have a positive effect on the legionella development.

Summarising, one can say that the elements to be considered when wanting to minimise the legionella development, are:

- the temperature;
- the total water volume of the hot water installation;
- the choice of the materials;
- the possibly to have deposits.

# 4 Recommendations

## 4.1 Recommendation with respect to the initial quality of the distributed water

The quality of water that should be distributed as sanitary water inside a building must be drinking water which comply with local Belgian prescriptions. These last are however the transposition of the concerned Directive of the European Union.
Water distributed by public distribution companies fulfil normally these prescriptions.

When using water from another origin, information should be taken about its potability and the presence of Legionella bacteria. A control, four times a year minimum, is recommended.

Softening of the water at the income is possible if the characteristics of the materials used for the piping are taken in consideration and as far as the softening apparatus correctly maintained.
Physical water treatment, to prevent scaling can also be considered, but a regular intense flushing of the pipe downstream the apparatus is necessary.

## 4.2 Recommendations for the design of the water services

### 4.2.1 General recommendations

The current codes of good practise must be taken into account for the design of hot and cold services.Regular maintenance is needed in all cases.

### 4.2.2 Recommendations for sanitary hot water generators

#### 4.2.2.1 Decentralised instantaneous boilers

For instantaneous generators localised in the neighbourhood of the point of use of the hot water, no special measures should be taken. In all other cases the recommendations under § 4.2.2.2. are to be considered.

#### 4.2.2.2 Appliances not covered by § 4.2.2.1

For appliances which cannot be considered as instantaneous decentralised water heaters, the following recommendations apply :

1° **Hot water boilers with a storage capacity** must be equipped with easily accessible openings which allow an easy maintenance of the apparatus. Herefore, it is also needed to have at their lower point, a high capacity drain-off-valve.

2.° **All hot water boilers** must be such that they are able to maintain at normal peak load, a watertemperature of 60°C on their outlet. An accurate thermostatic regulation must be provided herefore.
The cold water inlet with boilers with accumulation, must be so that a great mixing area is avoided .

3° **In small installations** (see terminology list at the end), no other requirements have to be considered for the hot water boilers, than those mentioned under 1° and 2° above.

4° **In large installations** (see terminology list at the end) the recommendations under 1° and 2° above must be taken into account, and all boilers with a storage capacity greater than 400l, must be conceived so that :
- the heating of the water is uniform;
- there are no areas with temperatures below 60°C.

### 4.2.3 Recommendations for the design of the distribution pipes

#### 4.2.3.1 Materials to be used

Materials used in the installation for the distribution of sanitary hot water must be suitable for service temperatures of at least 60°C. Materials which can be used normally are listed in the table 4 below. This table formulates also some recommendations and comments with respect to the use of these materials.

Table 4 Materials for hot and cold domestic water services

| Usable material | Recommendation/comment |
|---|---|
| Galvanised steel | To be used in strict compliance with the recommendations of TIN 145[4], excepting the temperature limitations (see hereafter §4.2.3.4). However this material is easily subject to corrosion, phenomena which is favourable for a contamination with Legionella.<br>In this context, it must be made clear that this material cannot be used for the distribution of rain water. |

Table 4 - Continued

| | |
|---|---|
| Copper | To be used in compliance with the recommendations of TIN 154[5].<br>In several studies is indicated that copper is a material which reduces the risk on a Legionella contamination. It must be noticed however, that the use of copper pipes is not sufficient to prevent the development of Legionella : in the WTCB-CSTC - research Legionella-bacteria were also identified in copper installations. The other recommendations are surely to be considered also. |
| Stainless steel | It is recommended to use pipes with a technical approval (ATG-approval) of the BUtgb/UBatc. |
| Plastics | It is recommended to use plastic pipes with a technical approval (ATG-approval) of the BUtgb/UBatc. Pipes destinated for heating systems must be avoided.<br>Some laboratoriumstudies indicate that there is an easier development of Legionella bacteria in the presence of certain plastic materials. However, for the time being it is not proven that with these pipes the risk for Legionnaires' disease is greater than with other kinds of pipes.<br><br>Some rubbers used for certain parts of accessories (sealings,...), seems to constitute a nutritive support for Legionella. Their use must be avoided or surely reduced to a strict minimum. All valves used must satify the approval of the water companies. |
| Other materials | Only to be used if it is proven that they do not constitute a nutritive support for Legionella. |

#### 4.2.3.2 General lay-out recommendations

1° The lay-out of the piping has to be as simple as possible.

2° A slope of about 0.1% has to be foreseen so that it is possible to empty the pipes completely.

3° The diameter of the pipes has to be calculated so that at peakflow the velocity of the water reaches at minimum 1m/s. The allowed maximum velocity of the water depends on the type of material used and on acoustic considerations.
The diameter of the recirculation pipes -in case of a looped system- must be such that a minimum velocity of 0.5 m/s is obtained.

4° The presence of a filter at the income of the installation ( after the water meter) is highly recommended, so that sediment and particles in suspension are retained and don't enter the piping indoor. Filters with a pore-size between 50 and 120 µm are generally used in this context. Such an equipment has to be maintained in

good working conditions, the maintenance frequency being function of the water consumption. Filters with automatic cleaning by "backwashing" are to be prefered on manual types.

5° The installation for the distribution of sanitary hot and cold water has to be designed in a way that maintenance can be done very easily.
Draining valves at the lowest points have to be installed and they should be easy accessible.

#### 4.2.3.3 Supplementary recommendations for cold water pipes

Provisions must be taken to avoid to warm up the cold domestic water pipes to above the 25°C at the tappoints. This implies :

1° that cold water pipes have to be protected from all possible heating sources like
- direct sunlight;
- the neighbourhood of hot water pipes ( sanitary or central heating pipes)
- the heat-release in a fire-place

This can be realised by an appropriate lay-out, or by the use of appropriate thermal insulation.

2° The storage of cold water has to be avoided . If storage is inevitable :
- the storage volume has to be limited ,
- an appropriate insulation has to be foreseen
- storage tanks should be designed to have a complete turnover every 24 hours

#### 4.2.3.4 Supplementary recommendations for hot water services

##### 4.2.3.4.1 Small installations

For small installations, no special requirements have to be taken in to account, unless the general guidelines of good practice and the recommendations given above.

##### 4.2.3.4.2 Large installations

For large installations it is recommended that :

1° The temperature of the water remains at minimum 55°C in all points of the main pipes. This can be achieved by having looped installations with recirculation, or by providing heating strips on the pipes.
In case of looped circuits the circulationmust be pump driven, thermo-siphon circulation is not allowed. These circuits must be so designed the temperature difference between the departure and the return at the heating appliance, is not more than 5°C. In no case the temperature of the recirculated water will be less

than 50°C; this requires an appropriate design of the circulator, and the pipe insulation as function of the pipe diameters and length.

In case heating strips are used, these must have an ATG-approval, and be of the selfregulating type.

2° Branches of the main pipework, where the water can not be kept at of 55°C are only allowed if :

- their length doesn't exceed 3m, in case of buildings which are **not** specifically destinated to persons who are susceptible to be easely infected by the legionella bacterium;
- the length of these branches doesn't exceed 1m in buildings where sentive people can normally be awaited, such as hospitals, elderly homes.

3° As water temperatures above 55°C represent a certain risk of scalding, the use of thermostatically controlled valves is has to be generalised.
The temperature of the water at the inlet of the thermostats may not be below 55°C, even when there is no water consumption.

4° Deadlegs and tap-points which are rarely used , or tap-points still to be installed must be avoided.
In case this is impossible ,provisions should be taken to isolate the pipes from the rest of the circuit, e.g. by using a stop valve.

### 4.3 Recommendations for the use and maintenance

1° The installations for the distribution of hot and cold water inside the buildings must be regularly controlled and maintained by specialised staff.
Special attention is required for the water treatment equipment and the production of sanitary hot water.
Recommendations hereabout are described in the CSTC/WTCB maintenance manual.

2° The temperatures recommended for the production and the distribution of hot water may not be changed in service.

3° The circulation in the hot water looped circuits shouldn't be stopped more than a 8 hours per period of 24 hours.
In case of duplicate pumpsystems, care must be taken that no pump is stopped more than 24 hours, daily alternation is therefore recommended.

4° All tappoints should be regularly used. Taps unused during a certain time, must be closed off from the rest of the installation.

## Terminology list

*Small installations:*
Small installations involve:
installations in single or two family buildings;
installations in other buildings, but where the capacity of the storage is less or equal to 400l, while every pipe connected to the storage vessel has a water content less or equal to 3l (contnet of the recirculating pipe not included).

*Large installations:*
Large installations are those installations which can not be considered as small ones.

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Germany.

# Topic B1

## Simulation and Design of Building Drainage Vent Systems

Prof. J. A. Swaffield, Dr. D. P. Campbell, Mrs. L. B. Jack

# SIMULATION AND DESIGN OF BUILDING DRAINAGE VENT SYSTEMS

by

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As a result of notable developments in building drainage and vent systems in the 1900s, mainly due to an increase in the understanding of air pressure transient propagation and the availability of high speed computers, researchers and designers are now able to accurately predict the dynamic response of even the most complex of systems. Subsequent to the introduction around 1970, and the now common use in the UK, of the single stack system, this new knowledge has meant that networks can now be fine tuned and further predictions made.

The maintenance of trap seals is a prerequisite of any system and ongoing research into air pressure transient propagation within a network, and the ways in which this may affect traps, can increase this knowledge further. This paper will describe how, by examining the parameters upon which the suction within a stack is dependent, it can be shown that by using empirical data collected through extensive testing, a relationship between pressure coefficient and the ratio of imposed water flow to entrained air flows can be developed which is applicable to any system configuration. Such relationships can then be utilised as a factor in modern computer models used to predict the dynamic response of both design stage and built systems.

## INTRODUCTION

In order to prevent foul air ingress into any habitable space it is necessary in building drainage systems to maintain appliance trap seals. Some air pressure transients set up within a drainage system have the capability of depleting or completely removing the water from a trap. Depending on the amplitude and profile of the transient, traps can either be lost directly into the stack or, in the case of a positive pressure transient, water can be lost by upwards displacement or can spill over into the stack as the oscillating column returns through the trap. There are several ways in which these transients can be generated and the study of their propagation, as well as the effect they can have, is vital to drainage design.

## DRAINAGE SYSTEM DESIGN

Historically, the development of drainage systems follows a definite path from the two-pipe system (1900-1930), where wc discharge was separated from all other waste flows, to the one-pipe design (1930 onwards), where all waste flowed through one pipe but all appliances were connected to a vent stack. This was followed by the modified one-pipe system (1950 onwards) where the waste stack was connected at regular intervals to a vent stack. Although some one-pipe and modified one-pipe networks can all still be seen in

use today, the single stack system (introduced around 1970) where all appliance types (including wc's) discharge into one pipe is now the most common in the UK, with ongoing research providing information on such issues as pipe and branch size, slope, length and design as well as the use of devices such as air admittance valves.

Throughout this development, maintaining trap seals has always been of paramount importance, with research and investigation into the theory of building drainage and vent systems providing a much clearer understanding of the effect of stack water flowrate on air pressure transient propagation. Early work into the flow capacity of vertical stacks was carried out by Hunter (1924), Babbitt (1935) and Dawson & Kalinske (1937). Investigations concluded that a stack should not run more than 25% full in order that a central air core be maintained and plug flow prevented. This in turn would then prevent the generation of air pressure transients large enough to deplete or destroy trap seals. The outcome of further work by Hunter et al (1938) and Dawson & Kalinske (1939), examining the sizing of vent systems and branch to stack flow conditions, together with investigations by Wyly & Eaton (1961), generally led to the replacement of the two-pipe network by the one-pipe system.

Further work into the theory behind the one-pipe system was carried out by Wise (1952) and was extended to cover investigations into the operation of a single stack system. The response of buildings up to a height of five storeys was investigated by Wise & Croft (1954), leading to site experimentation on a building 30 storeys high by Pink (1973). Much of this latter work, combined with previous knowledge, led to the development of the accepted UK design guidelines in the form of BS 5572.

Recent developments in computing technology and the accepted application of numerical simulations to the theory of fluid mechanics now means that it is possible for researchers, designers and installers to optimise methods of analysis of building drainage and vent systems, allowing the inherently unsteady nature of drainage flows to be considered. The flexibility of computer generated networks and the speed with which designs can be simulated means not only that modifications to existing systems can be tried and tested but that new and more innovative designs can also be investigated.

## APPLICATION OF NUMERICAL BASED SOLUTIONS TO THEORY REPRESENTING LOW AMPLITUDE AIR PRESSURE TRANSIENT PROPAGATION

Air pressure transients, such as those experienced in building drainage and vent systems, may be expressed mathematically using the unsteady fluid flow equations of continuity and momentum. Combining these equations and then rewriting them in terms of velocity and wave propagation speed yields a pair of total derivative characteristic equations which may be solved using a finite difference technique.

$$\frac{du}{dT} \pm \frac{2}{\gamma - 1}\frac{dc}{dt} + \frac{4 f u \mid u \mid}{2D}\Delta t = 0 \qquad (1)$$

$$\frac{dx}{dt} = u \pm c \qquad (2)$$

where u is the air flow velocity, c is the appropriate acoustic velocity, that depends on both air density $\rho$, pressure p, and the adiabatic index $\gamma$, expressed as $c = (\gamma p/\rho)^{0.5}$; f is the appropriate friction factor and hence allows drain material and frictional losses to be included in the simulation.

Equation (2) is known as the Courant Criterion and the finite difference solution of the two simultaneous equations represented by equation (1) is only valid if this relationship is true. Effectively the Courant Criterion determines the relationship between the solution time step, dt, and the internodal distance, dx, used in the simulation.

A method commonly used to progress this solution is that of the method of characteristics as developed by Lister (1960). Here, characteristic curves are drawn in the x-t plane, the slope of these curves depending on local wave propagation and flow velocities. This slope also determines the model time step which is generally very small. As a result, in order to obtain an accurate and fast solution, a good efficiency computer is required. It is for this reason that since the introduction of such computers in the 1970s, analysis and prediction of air pressure transients has notably progressed. The method of characteristics technique has been widely developed and in its flexibility allows application to a varied range of transient problems.

In order to predict the travel and amplitude of air pressure transients in a drainage system, the variables upon which the suction pressure in the stack depends must be defined. With reference to Figure 1, these are:

$$\Delta P = \Phi_1 (\rho_a, \rho_w, Q_a, Q_w, D, k, t, \mu_a, \mu_w)$$

where

| | | |
|---|---|---|
| $\rho_a$ | = | air density |
| $\rho_w$ | = | water density |
| $Q_a$ | = | air flowrate |
| $Q_w$ | = | water flowrate |
| D | = | stack diameter |
| k | = | stack wall roughness |
| t | = | annular water flow terminal thickness |
| $\mu_a$ | = | air viscosity |
| $\mu_w$ | = | water viscosity |

Using Buckingham's $\pi$ theory, this can be reduced to show the $\Delta p$ group dependent on six dimensionless groups ie

$$\frac{\Delta P\ (D - 2t)^4}{\frac{1}{2}\rho_a\ Q_a^2} = \Phi_2\left(\frac{\rho_a}{\rho_w}, \frac{Q_a}{Q_w}, \frac{k}{D}, \frac{t}{D}, Re_w, Re_a\right)$$

where Re, is the entrained airflow Reynolds Number defined as $\frac{\rho_a Q_a}{D \mu_a}$ if the assumption that t ≪ D is complied with.

In this case the suction pressure in the stack has been non-dimensionalised with air flowrate rather than water flowrate to maintain consistency of fluids. However, it can be shown that for annular flow:

$$Q_a = \frac{\pi}{4}(D - 2t)^2\ V_a$$

giving

$$\frac{\Delta P}{\frac{1}{2}\rho_a\ V_a^2} = \Phi_2\left(\frac{\rho_a}{\rho_w}, \frac{Q_a}{Q_w}, \frac{k}{D}, \frac{t}{D}, Re_w, Re_a\right)$$

the $\left(\frac{\pi}{4}\right)^2$ term being constant.

The term $\frac{\Delta P}{\frac{1}{2}\rho_a\ V_a^2}$ may be recognised as a form of pressure coefficient which is non-dimensional in terms of $V_a$. Once determined, this coefficient then becomes applicable to any vertical stack whose other parameters including imposed water flowrate are known. It can therefore be used in the development of a numerical model representing the suction pressure and entrained air flowrate generated by particular water flowrate.

## DETERMINATION OF THE PRESSURE COEFFICIENT

In order to determine the pressure coefficient flow ratio relationship, it is first of all necessary to acquire sufficient experimental data to which the above dimensional analysis techniques may be applied. In order to achieve this, three working single stack drainage pipes were tested. The pipe materials and diameter were selected mainly by accessibility to full scale working systems. Two plastic pipe stacks of diameter 75mm & 100mm each with a height of approximately 15m (5 storeys) and one cast iron stack of diameter 150mm and height 52m (17 storeys) were selected for testing. Data from previous investigations was also accessed.

Since the density and viscosity of the fluids can be assumed to be fixed and the stack parameters of diameter and roughness are also fixed for each individual case, the remaining variable parameters were all monitored (with the exception of annular water flow terminal thickness which is determined by the pipe roughness, diameter and water flowrate).

Figure 3 shows the method by which entrained airflow, water flowrate and suction pressure, were measured. All of the stacks tested terminated at roof level where straight lengths of smaller diameter plastic pipe fitted with pitot-static tubes were connected. In each case a long enough length was used to allow the airflow distribution to stabilise prior to measurement. Where this was not possible due to practical restrictions, airflow traverses were monitored for each different case and applied to any later measurement. In order to prevent the ingress of air into the stack via other routes, every branch not used as a water inlet point was cut and sealed.

The suction pressure and entrained air flow were induced by predetermined water flowrates which were pumped into each stack via connecting branches. Where possible, existing branches were used, however, in some cases, additional branch connections had to be fitted to the 75mm and 100mm stacks. These additional connections were always run through working traps in order to simulate normal working conditions.

In each case the pitot static tube and several pressure tappings were then connected to diaphragm transducers which in turn relayed a 4-20mA signal to a central computer. These transducers had a range of $\pm$ 1000 Pascals, enabling them to measure both positive and suction pressures. Figure 2, showing the air pressure variation down the length of a vertical water carrying stack, demonstrates how the water curtain at the drain entry can generate a positive back pressure. Tappings measuring suction pressure in the stack were connected at evenly spaced height intervals and where water was being pumped in via a connecting pipe, the tapping was placed just above the branch, even although the minimum pressure exists just below. The reason for this was that below the junction, the pressure transducer becomes susceptible to water ingress and noise due to the high degree of swirl generated as the water flow impinges on the opposite side of the stack.

Several configurations were tested in order to yield the greatest amount of comparable data, mainly achieved by varying water flowrates and water inlet heights. A range of blockages, both partial and full were also used at roof level to induce a varied suction pressure ie allowing movement along the $\Delta P$ vs $Q_a$ curve. A few tests were run with two or more pumps running simultaneously in order to assess the dynamic response of the system to multiple flows. Although not necessary for determination of the pressure coefficient, additional tests were also carried out which demonstrated the effects of various transient conditions applied to the water flowrate.

## RESULTS

Due to a slightly different approach and the sheer volume of data collected on testing the 150mm cast iron stack, only the 75mm and 100mm stack results will be presented here, with the 150mm stack results to be contained in a separate paper.

Figures 4 and 5 show the results obtained for the 75mm stack while Figures 6 and 7 showing those for the 100mm stack. Figures 4 and 6 represent the data resulting from the application of different flowrates to each stack whereas Figures 5 and 7 show the results obtained when suction pressures and corresponding entrained air flowrates for each water flowrate were used to calculate values for the non-dimensional groups as described previously.

It can be seen from these sets of experimental results that:

- *for either diameter stack, entrained airflow increases with an increase in water flowrate.*

  An increase in water flowrate and hence water velocity results in an increase in the shear force at the boundary between the falling annular water film and the central air core, which due to the no-slip concept results in an increase in entrained air.

- *for either diameter stack, the suction pressure generated within the system increases with an increase in water flowrate.*

  Since the movement of air into the stack must be accompanied by a pressure gradient to overcome frictional losses in the dry stack, any increase in entrained air flowrate with water flowrate will result in an increase in suction pressure. This increase in suction pressure with water flowrate is much more noticeable when the stack termination at roof level is partially or fully blocked. This is due to the additional forced increase in local air velocity through reduced openings with high loss factors, which generate local pressure losses.

- *Any water flowrate above approximately 0.8 litres/second was found to result in almost complete blockage of entrained airflow in the 75mm stack.*

  This occurred due to almost total coverage of the inside of the stack by the water curtain from the connecting branch and resulted in a minimal airflow measurement at the stack termination on the roof, although the pressure transducer did monitor substantial noise levels. The resulting restriction that only lower water flowrates could be set in order to maintain a measurable entrained airflow meant lower suction pressure and airflow values were obtained during testing. These lower levels became increasingly difficult to measure with accuracy as water flowrates were dropped and as the water inlet point fell. It is for these reasons that the empirical data for the 75mm stack appears poorer than that for the 100mm stack.

- *Regardless of diameter, the suction pressures generated by any one water flowrate were found to be in a similar range, whereas the corresponding entrained airflow rates were notably higher for the larger diameter stack.*

  Although the water flowrates used to produce the graphs shown in Figures 4 and 6 are not exactly comparable, similar flowrates show the difference in entrained airflow rates between the 75mm and 100mm stack. Frictional losses in the dry stack may be calculated from Darcy's Equation, ie $\Delta p_{friction} = \frac{4\rho f L_d Q_a^2}{2D A^2}$ where $L_d$ = length of the dry stack.
  Hence for similar lengths of stack the suction pressure due to friction at any $Q_a$ will depend on stack diameter $D^5$. Large diameter stacks will therefore have a higher entrained airflow for the same suction pressure.

- *Using experimental data representing water flowrate, entrained air flowrate and stack suction pressure, non-dimensionless groups can be established which demonstrate the generation of a pressure coefficient vs flow ratio relationship.*

  Figures 5 and 7 show how by non-dimensionalising the experimental data collected, a curve representing the pressure coefficient vs flow ratio relationship representative of the stack can be generated. This relationship is then applicable to any stack with the correct relevant parameters.

## CONCLUSIONS

The emergence of a pressure coefficient/flow ratio relationship from the non-dimensionalised groups (calculated with respect to entrained airflow) shows that with sufficient experimental data, the determination of similar relationships applicable to any network, regardless of its particular parameters is possible. It is predicted that data collected for both the 75mm and 100mm stacks (of which only a fraction has been displayed here) can be combined with results from the 150mm cast iron stack and results from Campbell (1992) and Pink (1973).
The use of relationships of this type, analogous to fan characteristics, although relevant to any network calculation, yields optimum benefits when used within a mathematical model capable of analysing drainage and vent system designs.

## ACKNOWLEDGEMENTS

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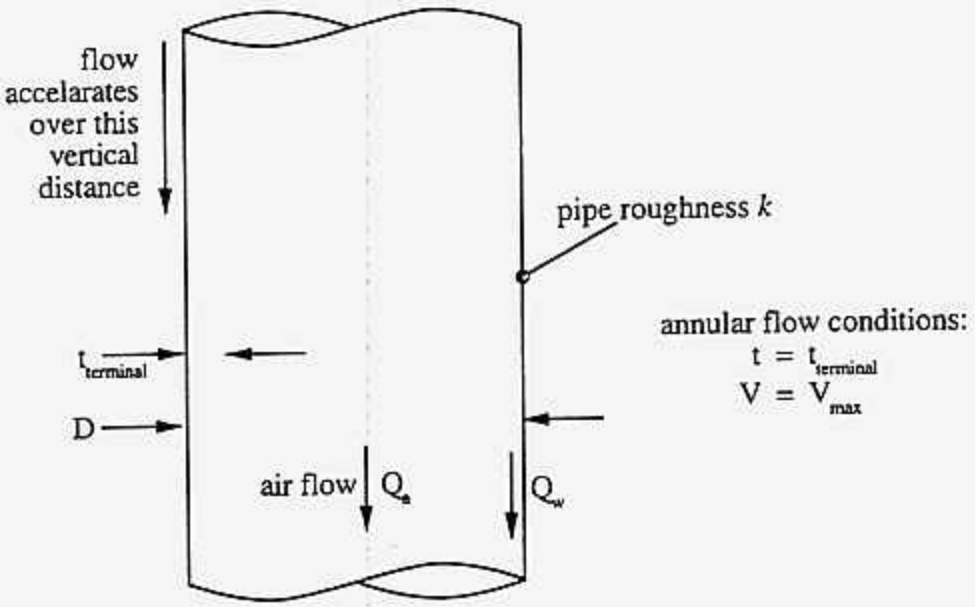



**Figure 1 Annular stack flow conditions**

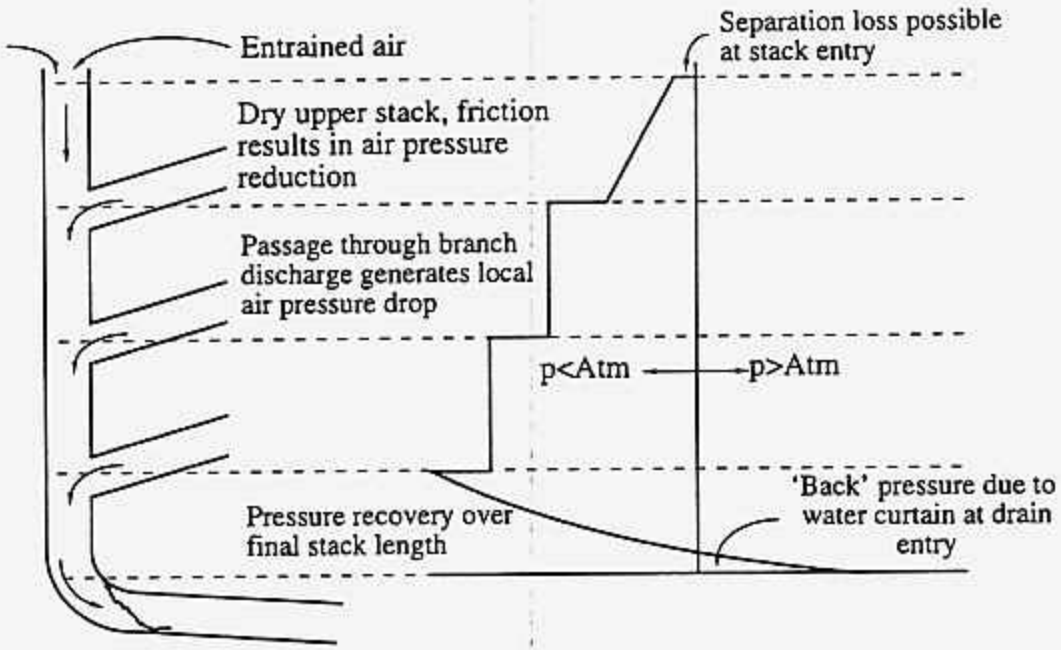



**Figure 2 Air pressure variation down the length of a vertical stack carrying both discharged water and entrained air**

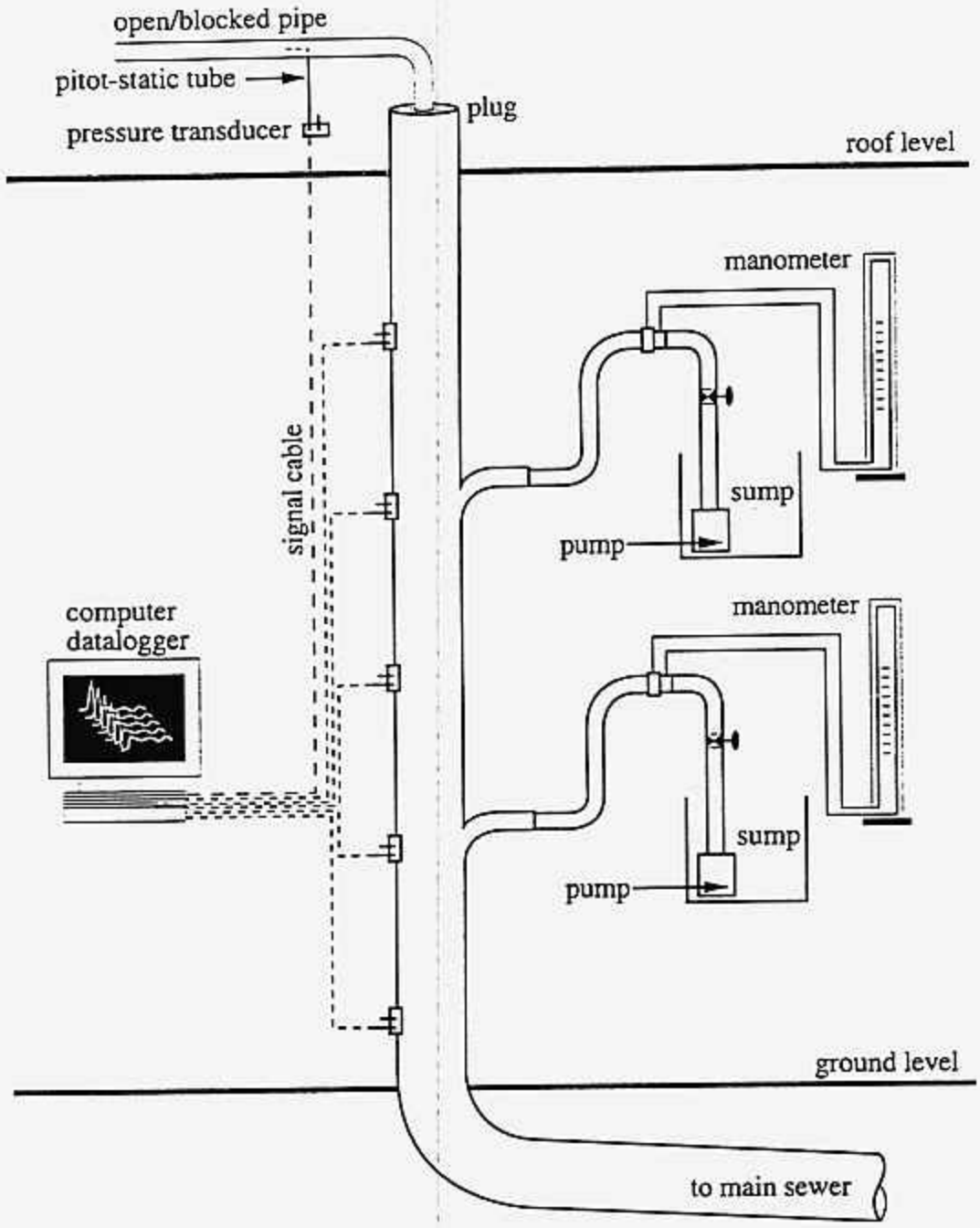



**Figure 3** **Apparatus used to collect data from 100mm and 75mm stacks**

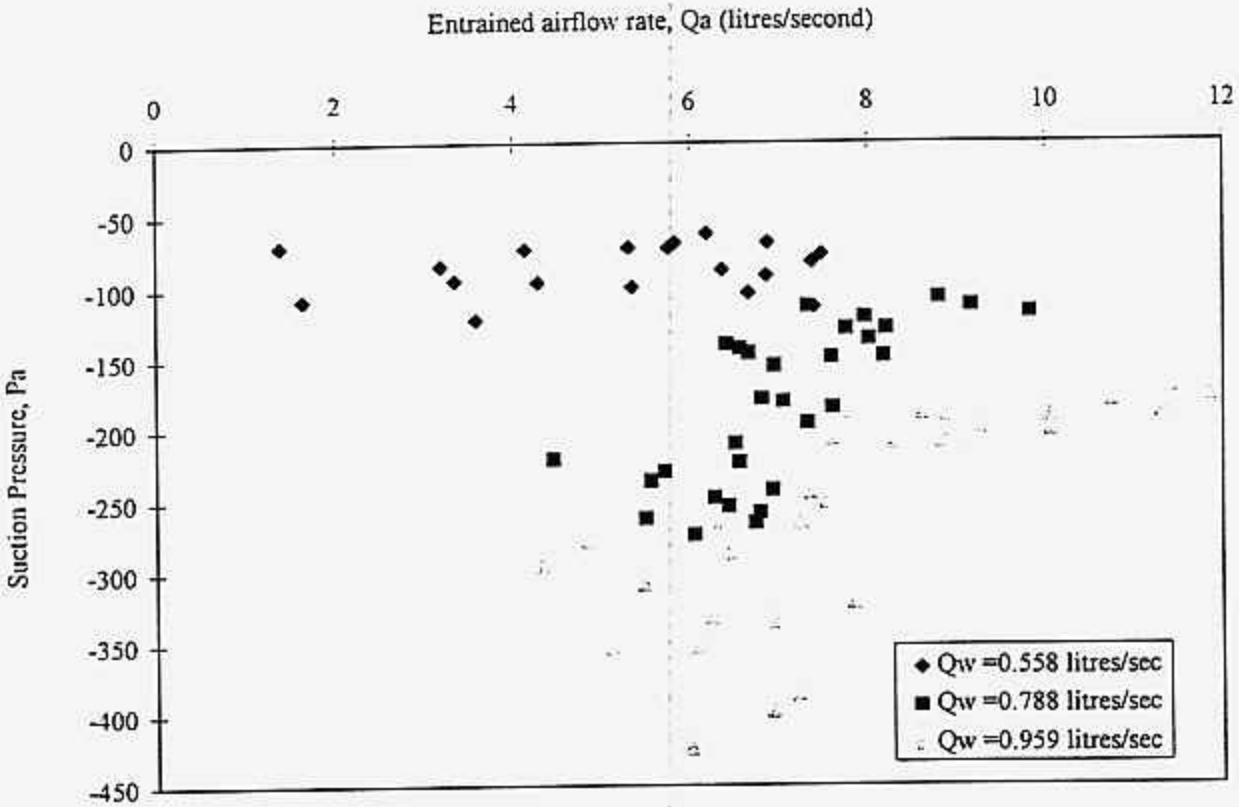



**Figure 4 : Suction Pressure vs Airflow Rate for 75mm Stack**

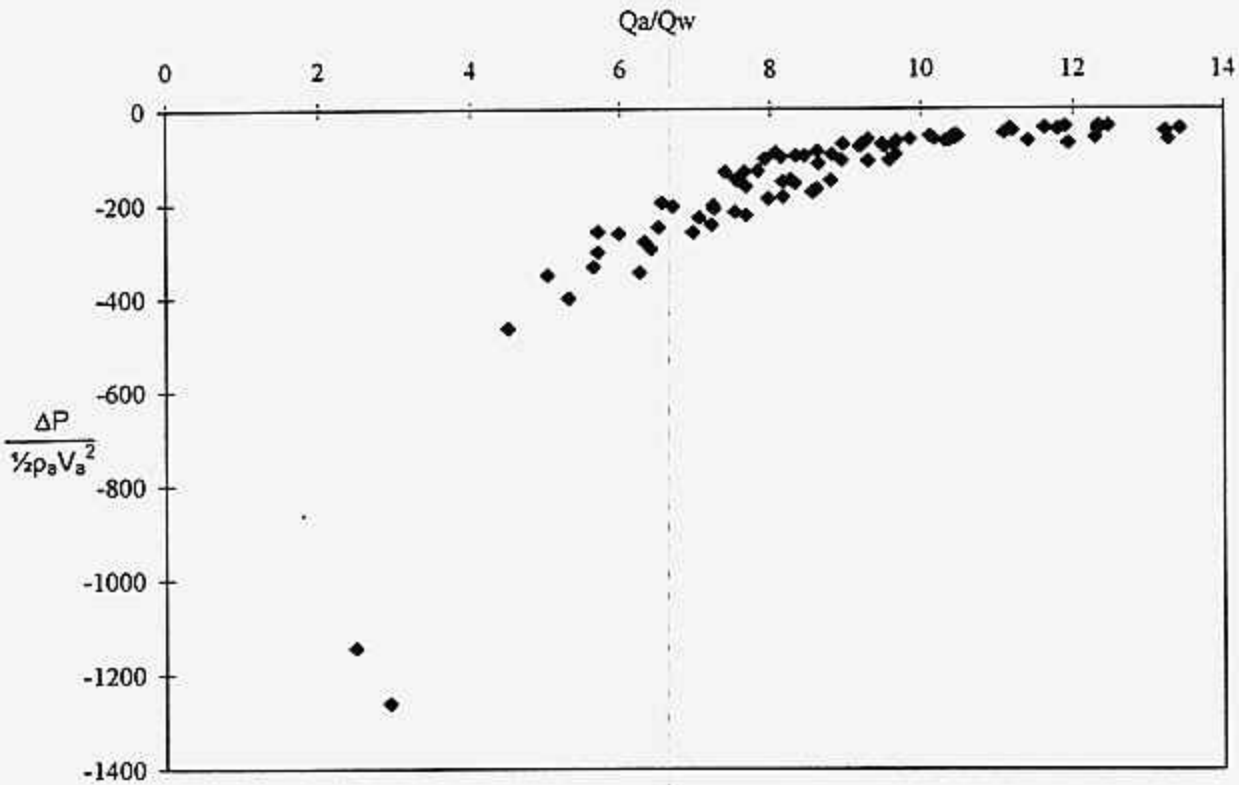



**Figure 5 : Non-dimensionalised 75mm Stack Results**

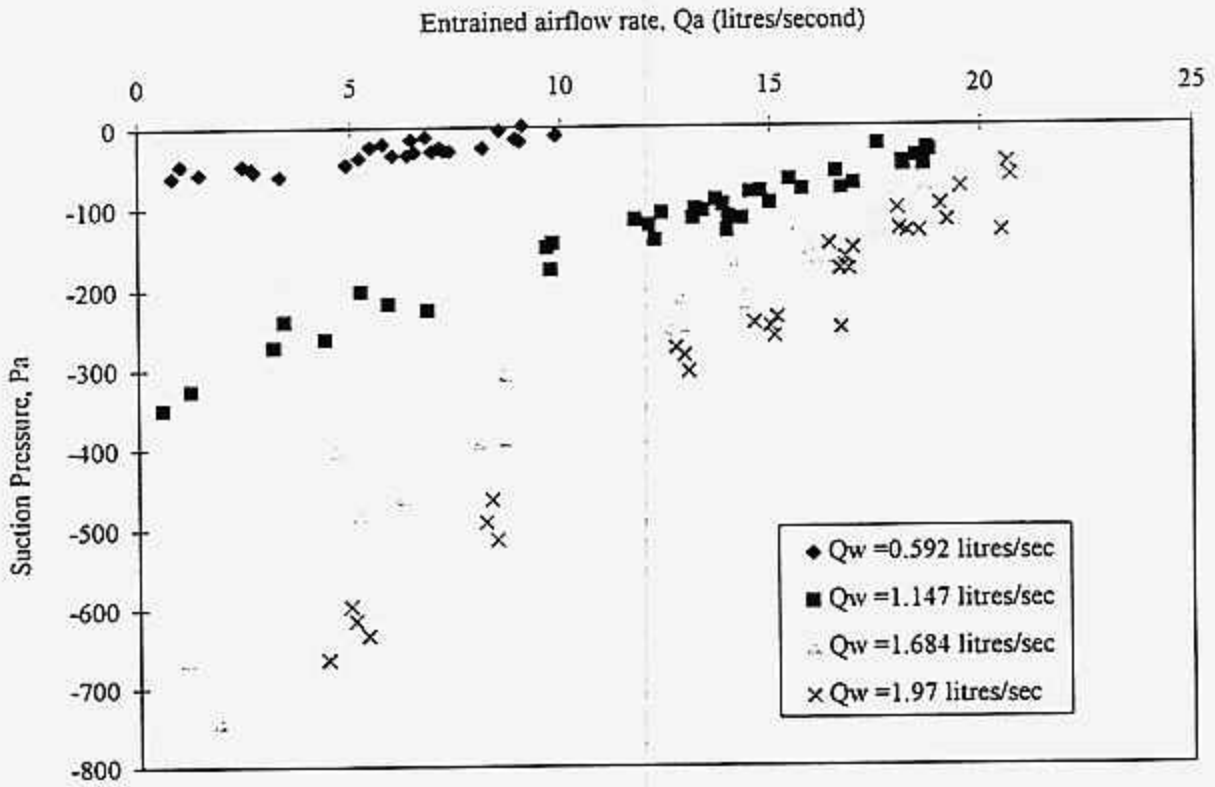



**Figure 6 : Suction Pressure vs Airflow Rate for 100mm Stack**

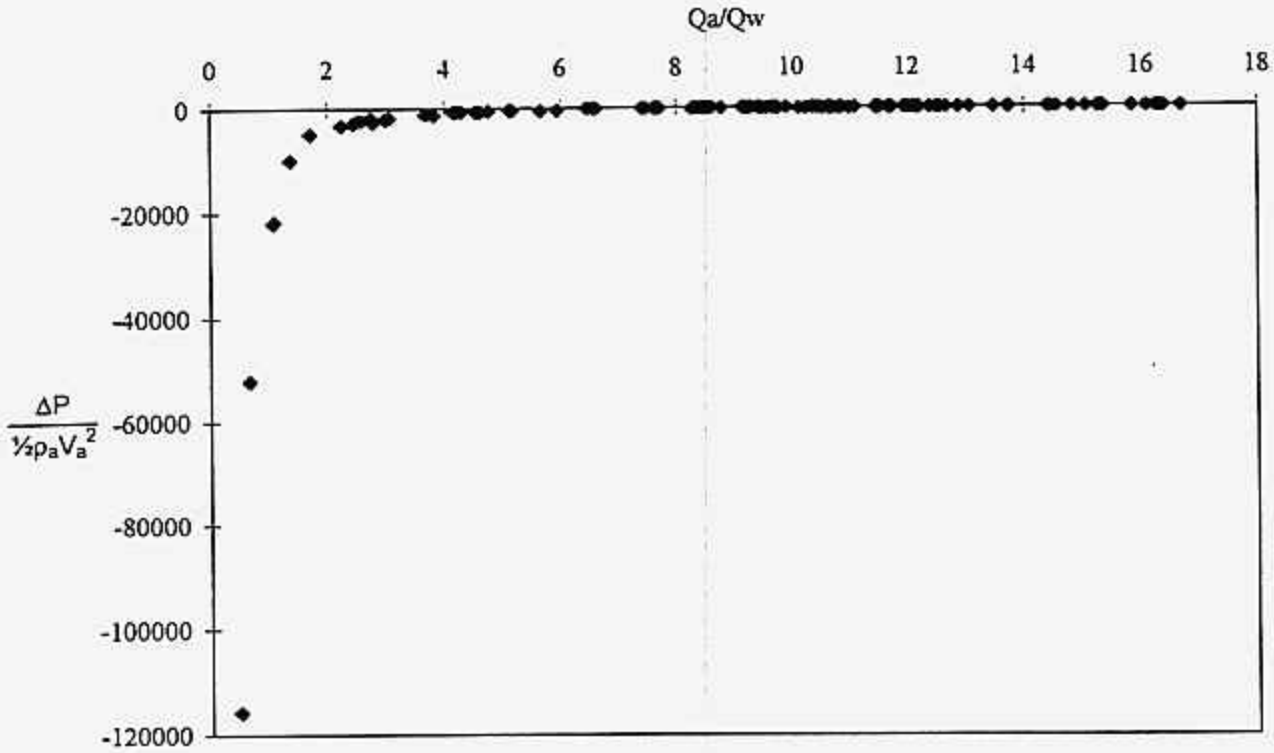



**Figure 7 : Non-dimensionalised 100mm Stack Results**

# Topic B2

## Design and Simulation of Drainage and Ventilation Systems within London Underground Stations

Prof. J. A. Swaffield, Dr. D. P. Campbell, G. B. Wright

# DESIGN AND SIMULATION OF DRAINAGE AND VENTILATION SYSTEMS WITHIN LONDON UNDERGROUND STATIONS

CIB-W 62 SEMINAR ON WATER SUPPLY AND DRAINAGE FOR BUILDINGS
Lostorf, Switzerland (September 16th - 18th, 1996)

by

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## ABSTRACT

In common with all types of building drainage networks and vent systems, the flow conditions within those installed in London Underground stations may be defined as unsteady. This coupled to the unorthodox layout and operating conditions of London Underground station drainage and vent systems, means that traditional, empirically based design methods are not suitable. The use of numerical computer models, based on the time dependent solution of the governing equations of unsteady flow and capable of accurately predicting flow conditions, is the only way to ensure the efficient and economical design of London Underground station drainage networks and vent systems.

This paper details the additional boundary conditions and model subroutine required to enable the general drainage and vent computer models, developed previously at Heriot-Watt University, to be used to simulate the flow conditions within the drainage networks and vent systems installed in London Underground stations.

## INTRODUCTION

The water flows within building drainage networks and the air flows within their associated vent systems are both examples of unsteady flow, the time dependency being due to random appliance usage patterns and the modification of appliance discharges due to wave attenuation. Traditionally, the complexity of the equations defining these types of unsteady flow, and the laborious nature of the available solution techniques, has meant that empirical design methods were used to design building drainage networks and vent systems. However, as these methods are based on steady state experimental data, they take no account of the unsteady flow conditions that actually occur within such systems. In addition, the probability dependency explicit in these empirical methods make them particularly unsuitable for the design of systems with a small number of appliances or for systems with unorthodox operating conditions. The only accurate method of predicting the flow conditions within any type of building drainage network or vent system, and hence ensure efficient and economical design, is to utilise a time dependent solution of the governing equations of unsteady flow. The recent availability of modern digital computing has now made this a practical option.

## CHARACTERISTICS OF LONDON UNDERGROUND STATION DRAINAGE AND VENT SYSTEMS

The drainage networks installed within London Underground Limited (LUL) stations are characterised by a relatively small number of appliances which, as a result of variations in staff levels/requirements, are used sporadically. In addition, LUL station drainage networks receive large pump discharges from low level collection sumps, the frequencies and magnitudes of which are primarily dependent on the prevailing weather conditions. These characteristics clearly indicate that the empirical design methods discussed previously are unsuitable for the design of LUL station drainage networks. Therefore, the efficient and economical design of such networks may only be carried out using a time dependent numerical model based on the relevant governing equations of unsteady flow.

As a result of the layout of LUL station drainage networks, where normally aspirated vents are often ineffective, mechanical fans are employed to provide venting for low level appliances and collection sumps. The complex interactions between the fan generated air flows, the water entrained air flows and the large air volumes contained within collection sumps, means that the empirical design methods discussed previously are unsuitable for the design of such systems. As with LUL station drainage networks, the use of a time dependent numerical model based on the relevant governing equations of unsteady flow, is the only method of ensuring the efficient and economical design of the vent systems installed within LUL stations.

## MATHEMATICAL BASIS FOR THE MODELS

The unsteady water flow conditions within building drainage networks and the propagation of air pressure transients within building drainage vent systems belong to a family of unsteady flow regimes which may be described by the St. Venant equations of continuity and momentum. These equations, representing quasi linear partial differential equations, may be solved by application of the numerical method of characteristics and computer based finite difference techniques (Lister, 1960).

### AIR PRESSURE TRANSIENT PROPAGATION

It may be shown (Swaffield and Galowin, 1992) that in the case of full bore air pressure transient propagation in building drainage vent systems, application of the method of characteristics to the relevant St. Venant equations yields the following total differential equations in terms of flow velocity ($u$) and acoustic velocity ($c$) :

$$\frac{du}{dt} \pm \frac{2}{(\gamma - 1)} \frac{dc}{dt} + \frac{4 f u |u|}{2D} \Delta t = 0 \qquad (1)$$

$$\frac{dx}{dt} = u \pm c \qquad (2)$$

where $\gamma$ is the adiabatic index of air, $f$ is the Darcy-Weisbach friction factor, $D$ is the pipe diameter and $c$ is defined, in terms of adiabatic index ($\gamma$), air pressure ($p$) and air density ($\rho$), as :

$$c = \sqrt{\frac{\gamma p}{\rho}} \tag{3}$$

The finite difference expressions given in equation (1) are only valid when the $\frac{dx}{dt}$ condition, given by equation (2) and termed the Courant condition, is satisfied. As such, characteristic lines, defined by equation (2) and drawn in a 2-dimensional space-time grid, may be thought of as routes along which information about the flow conditions at a particular location and time may be communicated to another location one time step in the future.

It should be noted that, as air pressure and density are linked, it was necessary to express equations (1) and (2) in terms of flow velocity and acoustic velocity. The local pressure ($p_p$) may then be calculated as :

$$p_p = \left(\left(\frac{p_0}{\rho_0^{\gamma}}\right)\left(\frac{\gamma}{c^2}\right)^{\gamma}\right)^{\left(\frac{1}{1-\gamma}\right)} \tag{4}$$

where the suffix $_0$ refers to undisturbed air properties.

Equations (1) to (4) form the basis of the computer model that has been developed at Heriot-Watt University to predict the air pressures and air flow rates within building drainage vent systems.

## UNSTEADY DRAINAGE FLOW

In the case of unsteady flow in building drainage networks, application of the method of characteristics to the relevant St. Venant equations may be shown (Swaffield and Galowin, 1992) to yield the following pair of total differential equations in terms of flow depth ($h$) and flow velocity ($v$) :

$$\frac{dv}{dt} \pm \frac{g}{c}\frac{dh}{dt} + g(S - S_0) = 0 \tag{5}$$

$$\frac{dx}{dt} = v \pm c \tag{6}$$

where $S$ is the pipe slope, $S_0$ is the friction slope and $c$ is the free surface wave speed defined, in terms of flow area ($A$) and free surface width ($T$), as :

$$c = \sqrt{\frac{gA}{T}} \tag{7}$$

These finite difference expressions will be recognised as in every way the equivalent of the equations derived for the propagation of air pressure transients in building drainage vent systems, i.e. equation (5) is only valid when the $\frac{dx}{dt}$ condition given by equation (6) is satisfied.

Equations (5) to (7) form the basis of the computer model that has been developed at Heriot-Watt University to predict the flow depths and flow rates within a multi-storey building drainage network.

## BOUNDARY CONDITIONS

In addition to the governing equations defined above, numerical models to predict the conditions within building drainage networks and vent systems must incorporate relationships, known as boundary conditions, to describe the effect of internal and external boundaries on flow conditions. The two models previously developed at Heriot-Watt University include boundary conditions to represent all commonly found elements in building drainage networks and their associated vent systems, e.g. appliance discharges, appliance trap seals. Additional boundary conditions, such as those detailed in this paper, must be added to the model to enable the effect of specific system appliances and configurations to be predicted.

# MECHANICAL VENT MODEL

## IDENTIFICATION AND DEVELOPMENT OF THE ADDITIONAL BOUNDARY CONDITIONS AND MODEL SUBROUTINE

Following consultations with LUL drainage engineers and consultants employed by LUL, it was determined that the following additional boundary conditions and model subroutine were required to accurately simulate the operation of the mechanical vent systems installed within LUL stations :

- A boundary condition to represent mechanical fans, including fan speed changes.
- A flow balancing subroutine.
- A boundary condition to represent pump sumps.
- A boundary condition to represent holding tanks.
- A boundary condition to represent an appliance discharge to a pump sump, a holding tank or a manhole.
- A boundary condition to represent the closure and subsequent re-opening of a mechanical vent entry connected to a pump sump or holding tank.

### Fan Boundary Condition

As stated previously, mechanical fans are installed in LUL station vent systems to provide venting for low level appliances and collection sumps.

The boundary condition developed to represent the fan/atmosphere interface, and hence enable the calculation of the air pressure at the first node downstream of the fan ($p_1$), is based on the following equation :

$$p_1 = p_0 + p_f \tag{8}$$

where $p_0$ is atmospheric pressure and $p_f$ is the fan total pressure, which is a function of the user specified fan characteristic.

In order to simulate the effects of changes in fan speed, the model utilises the following non-dimensional fan coefficients :

- Fan flow coefficient : $\frac{Q}{ND^3}$ (9)

- Fan pressure coefficient : $\frac{\Delta p}{\rho N^2 D^2}$ (10)

For a single fan the flow density ($\rho$) and fan diameter ($D$) are constant. Therefore, the fan delivery flow ($Q$) and associated pressure rise ($\Delta p$) at any speed ($N$) may be related, via the non-dimensional coefficients shown above, to fan reference conditions ($Q_{ref}$ . $\Delta p_{ref}$ . $N_{ref}$ ). From equations (9) and (10), the required relationships may be expressed as :

$$Q_{ref} = Q\left(\frac{N_{ref}}{N}\right) \tag{11}$$

$$\Delta p = \Delta p_{ref}\left(\frac{N}{N_{ref}}\right)^2 \tag{12}$$

In addition, any fan characteristic may be expressed in the following form :

$$\Delta p_{ref} = K_1 + K_2 Q_{ref} + K_2 Q_{ref}^{\ 2} + K_4 Q_{ref}^{\ 3} \tag{13}$$

where $K_1, K_2, K_3$ and $K_4$ are fan dependent coefficients.

Manipulation of equations (11), (12) and (13) yields the following expression for the fan characteristic at any speed :

$$\Delta p = \left(\frac{N}{N_{ref}}\right)^2\left(K_1 + K_2\left(\frac{N_{ref}}{N}\right)Q + K_3\left(\frac{N_{ref}}{N}\right)^2 Q^2 + K_4\left(\frac{N_{ref}}{N}\right)^3 Q^3\right) \tag{14}$$

By defining fan speed as a function of time within the model, it is therefore possible to simulate the effect of changes in fan speed. This enables the effects of fan start up/shut down, intentional variations in fan speed (variable speed fans) and fan breakdown conditions to be simulated.

**Flow Balancing Subroutine**

As the mechanical vent systems installed within LUL stations are often complex, multi branched arrangements served by one fan, it is common to install adjustable valves immediately downstream of the fan to regulate the flow through each branch of the system. The flow balancing subroutine incorporated into the mechanical vent model enables the effects of these valves, termed volume control dampers, to be simulated. This is achieved by introducing loss coefficients into each of the network branches intersecting at the first junction upstream of the fan. The magnitude of each loss coefficient, which can be equated to the position of the volume control damper, may be altered individually until the desired flow balance is achieved.

### Pump Sump Boundary Condition

As shown in Figure 1, a pump sump is a low level, unsealed collection sump which receives appliance (not W.C's) and pump discharges. To prevent build up of odour in and around pump sumps, they are always connected to a mechanical vent system.

The boundary condition developed to represent a pump sump in the model is based on the fact that the air pressure in a pump sump is always equal to the air pressure at the entrance to the mechanical vent pipe. Using this relationship, in conjunction with the user specified sump data (initial free air volume, water inflow, water outflow, venting loss coefficient) and an iterative technique, allows the air flow conditions within a pump sump to be calculated.

The use of a variable, user specified venting loss coefficient, whose magnitude can be equated to the degree of air entrainment into a sump from the surrounding area, enables any type of pump sump configuration to be modelled.

### Holding Tank Boundary Condition

As shown in Figure 2, a holding tank is a low level, sealed collection sump which receives appliance discharges (mainly W.C's). In order to prevent the accumulation of foul odour and the depletion of appliance trap seals during pump operation, a holding tank is always connected to a mechanical vent system. An additional vent pipe (e.g. pipe 2 in Figure 2), normally terminating at an air admittance valve, is also installed to prevent appliance trap seal depletion due to the action of the fan.

The boundary condition developed represents a holding tank as a junction with a storage capability, an approach which yields expressions for the air inflow and outflow from a holding tank. When combined with the equation defining tank air pressure, these expressions enable the flow conditions within a holding tank to be calculated. As with pump sumps, the user specified holding tank data (initial free air volume, water inflow, water outflow) enables the effect of variations in the tank free air volume to be simulated.

### Appliance Discharge Boundary Condition

The boundary condition developed to represent an appliance discharge to a pump sump, holding tank or a manhole is based on the following equation :

$$p = p_0 + p_w \tag{15}$$

where $p$ is the air pressure at the end of the pipe conveying the appliance discharge, $p_0$ is atmospheric pressure and $p_w$ is the air pressure induced by the appliance discharge, which has been shown (Campbell, 1992) to be a function of the air and water flow rate.

In addition to normal flow conditions, the model may, by specifying an airpath stoppage, be used to simulate the effect of full bore flow within the pipe conveying the appliance discharge.

### Mechanical Vent Entry Closure/Opening Boundary Condition

In the event of pump failure, sump level sensor failure or excessive inflow, the entry to a mechanical vent pipe connected to a pump sump or holding tank may become submerged. This would result in the propagation of large air pressure transients through

the system and, as a submerged vent entry acts as a dead end, a change in the system steady state operating conditions. The air pressure transients generated or the change in the system operating point may well result in the depletion of appliance trap seals throughout the system.

The boundary condition developed to represent an instantaneous vent closure, based on the Joukowsky expression for the pressure change accompanying an instantaneous flow stoppage, is given by :

$$\Delta p = -\rho c v_0 \tag{16}$$

where $\Delta p$ is the pressure change due to the air flow stoppage, $\rho$ is air density, $c$ is the acoustic velocity in air and $v_0$ is the local velocity destroyed by the air flow stoppage.

The negative sign in equation (16) indicates that, as the air is being drawn from the sump to the fan, the expected pressure change on vent closure is negative.

In many cases the geometry of the vent to sump connection will result in a less rapid closure of the vent entry. The model represents slower vent closures by introducing a variable closing loss coefficient ($K_c$) to equation (16), given by :

$$K_c = \frac{K_{max}}{T_c^n} \Delta T_c^n \tag{17}$$

where $K_{max}$ is the maximum loss coefficient achieved during closure (0 for a fully open entry, 60000 for a fully closed entry), $T_c$ is the total time for vent closure, $\Delta T_c$ is the time into the closure and $n$ is an index to represent the mode of closure.

When the sump water level drops, a submerged vent entry will re-open, allowing the re-establishment of the air flow from the sump. This scenario, which will again result in the propagation of large air pressure transients and a change in the system operating point, may lead to the depletion of appliance trap seals.

The model treats an instantaneous re-opening of a vent entry in an identical manner to an instantaneous closure. The only difference is that as the air flow is re-established the pressure at the vent entry will increase, hence the negative sign in equation (16) is neglected.

A slow opening of the vent entry is also treated in the same manner as a slow closure, the variable opening loss coefficient ($K_o$) being given by :

$$K_o = K_{max}\left(1 - \left(\frac{\Delta T_0}{T_0}\right)^n\right) \tag{18}$$

where $K_{max}$ is the maximum loss coefficient achieved prior to the re-opening of the vent entry (0 for a fully open entry, 60000 for a fully closed entry), $T_0$ is the total time for vent re-opening, $\Delta T_o$ is the time into the re-opening and $n$ is an index to represent the mode of opening.

## VALIDATION OF MECHANICAL VENT MODEL

In order to validate the model, site tests were carried out on the mechanical vent system installed at Green Park Underground Station. This system, a schematic of which is shown in Figure 3, was selected as it was considered representative of LUL station vent

systems in general and because the exposed vent pipes greatly simplified the installation of the monitoring equipment.

### System Instrumentation and Test Methods

Fifteen pressure transducers, located regularly throughout the system, were used in conjunction with a P.C based data acquisition system to record air pressures within the vent pipes. In addition, a pitot static tube/pressure transducer arrangement was used in a number of different locations to monitor the air flow rates within the system.

To enable a wide variety of both steady and unsteady conditions to be monitored in a short time, events were artificially initiated.

### Comparison of Measured and Predicted Conditions

The air pressures and air flow rates predicted by the mathematical model compared very well to those measured on site. Two examples of this good agreement are shown in Figures 4 and 5.

Figure 4 shows the measured and predicted variation in air flow rate, through the mechanical vent pipe connected to pump sump number 1, as a result of the fan slowing down from maximum speed via a series of intermediate speed settings. As can be seen, the predicted variation in flow rate compares very well to that measured. In both the measured and predicted cases, the relatively slow fan transition time (approximately 20 seconds) results in smooth changes in the air flow rate.

Figure 5 illustrates the measured and predicted variation in air pressure, immediately downstream of pump sump number 1, as a result of the instantaneous closure of the mechanical vent entry connected to pump sump number 1. As shown, the model accurately predicts the steady state air pressures occurring before and after the closure event. Figure 5 also shows that the measured and predicted peak positive and negative pressures are of the same order of magnitude, the minor differences being due to the inability to replicate an instantaneous vent closure on site.

## DRAINAGE MODEL

### IDENTIFICATION AND DEVELOPMENT OF ADDITIONAL BOUNDARY CONDITIONS

Following consultations with LUL drainage engineers and consultants employed by LUL, it was determined that the following additional boundary conditions were required to accurately simulate the operation of the drainage networks installed within LUL stations :

- Interceptor trap boundary condition.
- Pump delivery to gravity drain boundary condition.

### Interceptor Trap Boundary Condition

Interceptor traps are installed in all LUL station drainage networks immediately upstream of the local authority sewer connections. They are used to prevent the ingress

of foul air into the station drainage network and the transportation of greasy compounds into the local authority sewer.

To develop the interceptor trap boundary condition, flow depth measurements, utilising the experimental test rig shown in Figure 6, were taken at a variety of discharges and pipe slopes. The presence of the interceptor trap was seen to result in a region of subcritical flow at the trap inlet, the transition from normal, supercritical flow being via a hydraulic jump and a backwater profile. Analysis of the experimental data yielded an equation, relating the flow depth at the trap inlet ($h_i$) to the flow critical depth ($h_c$), of the form :

$$h_i = K_1 + K_2 h_c + K_3 h_c + K_4 h_c \qquad (19)$$

where $K_1$, $K_2$, $K_3$ and $K_4$ are experimentally determined coefficients.

The model utilises the flow depth calculated from equation (19) in conjunction with standard rapidly varied flow theory to determine the position of the upstream hydraulic jump. Gradually varied flow theory is then used to determine the backwater profile.

Flow depth measurements downstream confirmed that the flow depth at the trap exit could be assumed to be the critical flow depth.

**Pump Delivery to Gravity Drain Boundary Condition**

As a consequence of the operating characteristics of LUL station drainage networks, where large quantities of water collect in low level collection sumps, the arrangement whereby pump delivery lines discharge into gravity drains is very common.

To develop the required boundary condition, flow depth measurements, utilising the experimental test rig shown in Figure 7, were taken at a variety of discharge combinations and pipe slopes, and for five different junction configurations (90° in-line top entry, 45° in-line top entry, 45° perpendicular top entry, 90° level entry and 45° level entry). The combining flows were seen to result in a region of forced subcritical flow in the gravity drain immediately upstream of the junction, the transition from normal, supercritical flow being via a hydraulic jump and a backwater profile. Analysis of the experimental data yielded an equation, relating the depth at the junction ($h_j$) to the critical depth of the gravity drain flow ($h_{gc}$) and the critical depth of the combined gravity and pump flow ($h_{cc}$), of the form :

$$\left(\frac{\left(h_j - h_{gc}\right)}{h_{gc}}\right) = a\left(\frac{\left(h_{cc} - h_{gc}\right)}{h_{gc}}\right)^b \qquad (20)$$

where $a$ and $b$ are experimentally determined coefficients dependent on junction configuration.

The model utilises the flow depth calculated from equation (20) in conjunction with standard rapidly varied flow theory to determine the position of the upstream hydraulic jump. Gradually varied flow theory is then used to determine the backwater profile.

Flow depth measurements downstream of the junctions confirmed that the depth could be assumed to be the critical flow depth of the combined gravity and pump discharges.

## VALIDATION OF DRAINAGE MODEL

In order to validate the model, site tests were carried out on the drainage networks installed in the Central Line upper machine chamber area of Bank Underground Station. These networks, a schematic of one of which is shown in Figure 8, were selected as they were considered representative of LUL station drainage networks in general and because the exposed pipework greatly simplified the installation of the monitoring equipment.

### System Instrumentation and Test Methods

The data acquisition system used to monitor the mechanical vent system installed at Green Park Underground Station was also used to monitor the flow conditions at Bank Underground Station. The only difference was that the transducers, instead of being used to measure pipe air pressures, were used to measure the pressure variations within an air buffer located in the tubes connecting the pipe inverts to the transducer ports. Pre-determined calibration coefficients were then used to convert the measured air pressures into flow depth values.

To enable a wide variety of both steady and unsteady conditions to be monitored in a short time, events were artificially initiated.

### Comparison of Measured and Predicted Flow Conditions

In general, the flow depths predicted by the mathematical model compared very well to those measured on site. The minor differences that did occur were due to inaccuracies in the appliance/pump discharge data used in the model, which had to be estimated.

An example of the agreement obtained is given in Figure 9, which shows the measured and predicted variation in flow depth with pump operation. As shown, the model accurately predicts the sudden increase in flow depth as the pump starts up, the stabilisation of flow depth as the pump reaches its normal operating discharge and the gradual decrease in flow depth as the pump stops.

## CONCLUSIONS

Previous work at Heriot-Watt University has led to the development of computer based numerical models capable of simulating the operation of multi-storey building drainage networks and their associated vent systems. This paper has described the development of the additional boundary conditions and model subroutine required to accurately simulate the operation of the drainage networks and mechanical vent systems installed within London Underground stations.

In the case of the vent model, boundary conditions have been developed to allow accurate representation of mechanical fans, which drive London Underground station vent systems, pump sumps, holding tanks and appliance discharges to pump sumps, holding tanks and manholes. In addition, a flow balancing subroutine has been incorporated into the vent model to enable the effect of flow regulating valves to be simulated. The model developed, having been validated against data obtained from site tests, is now suitable for use as an aid to the design of London Underground station mechanical vent systems.

In the case of the drainage model, boundary conditions have been developed to allow accurate representation of interceptor traps and pump delivery lines discharging into gravity drains. The model developed, having been validated against data obtained from site tests, is now suitable for use as an aid to the design of London Underground station drainage networks.

## ACKNOWLEDGEMENTS

The research reported in this paper was funded by London Underground Limited.

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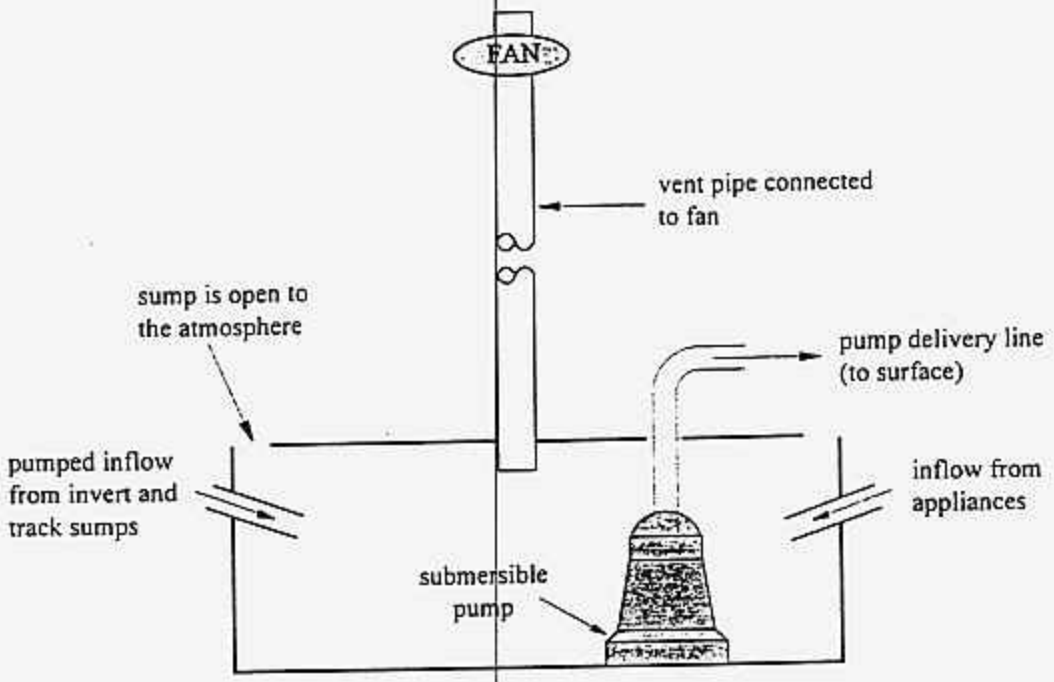



**Figure 1 : Typical Pump Sump Arrangement**

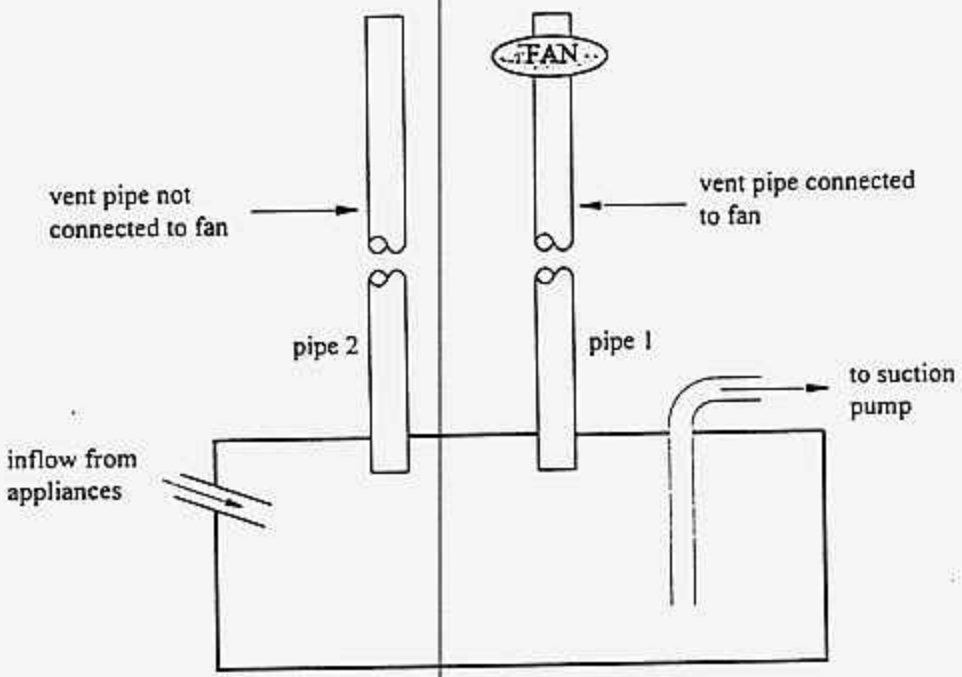



**Figure 2 : Typical Holding Tank Arrangement**

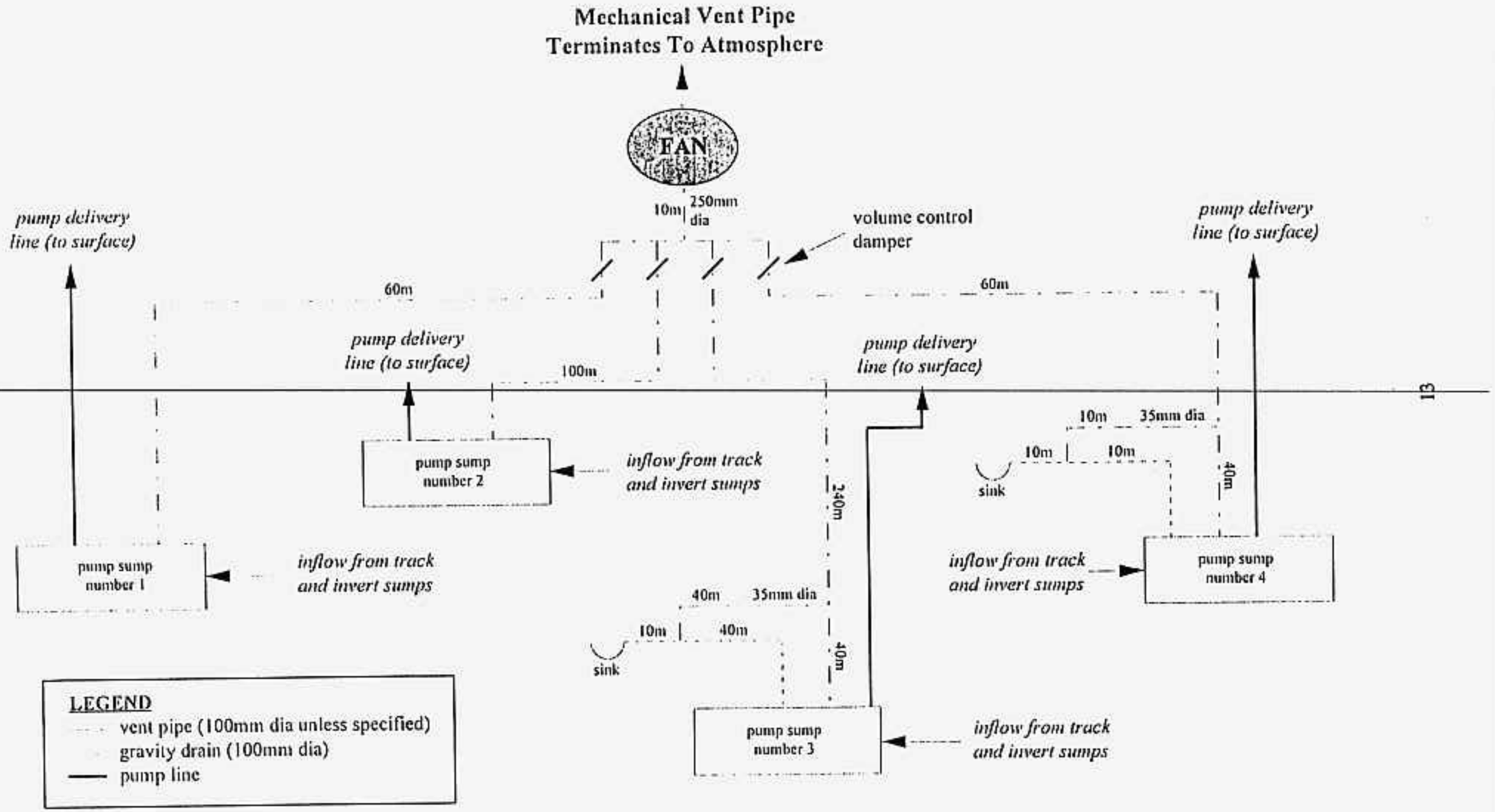



Figure 3 : Green Park Mechanical Vent System

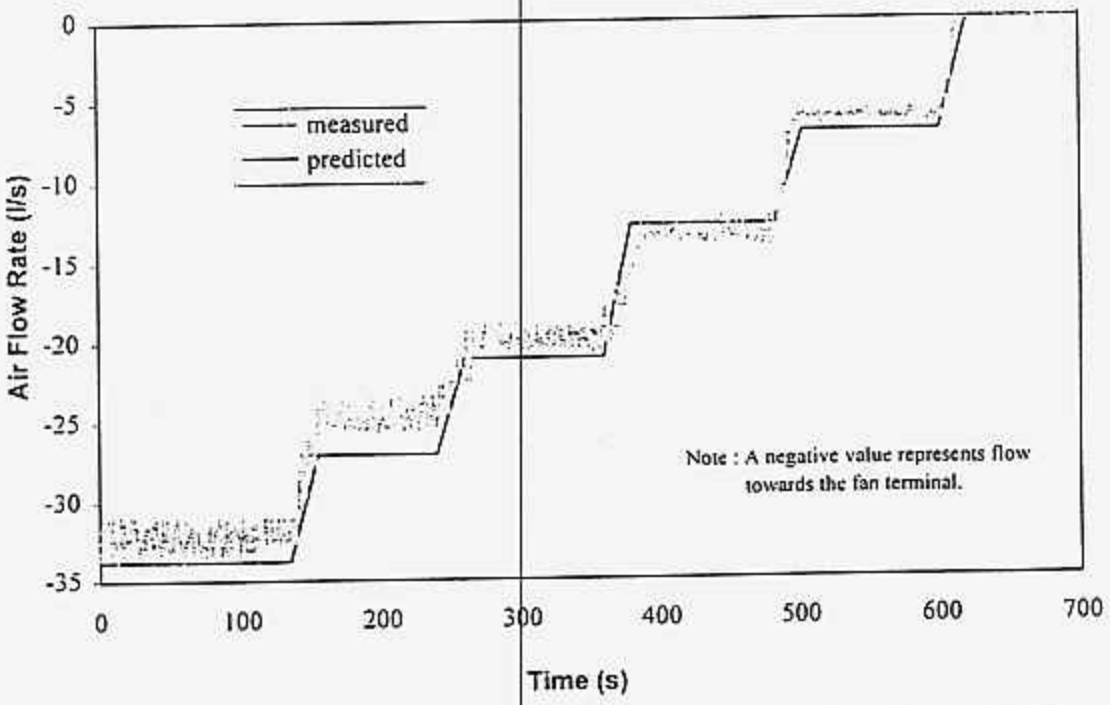



**Figure 4 : Measured and Predicted Variation in Airflow Rate with Fan Speed**

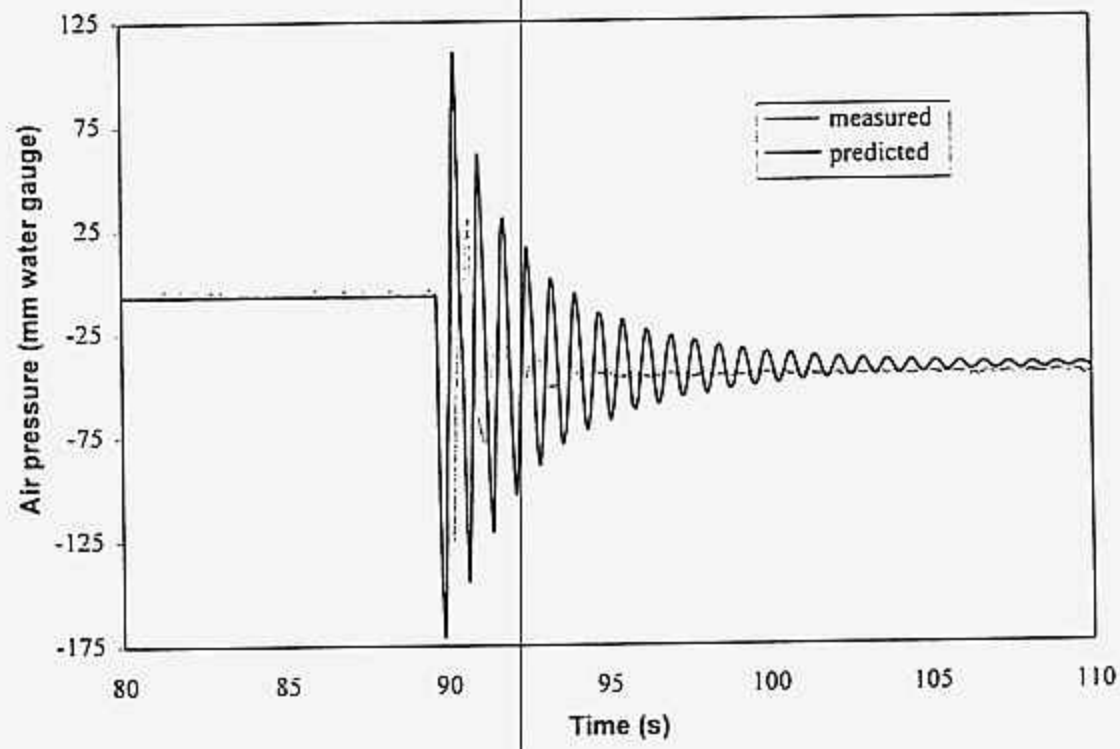



**Figure 5 : Measured and Predicted Variation in Flow Depth with Pump Operation**

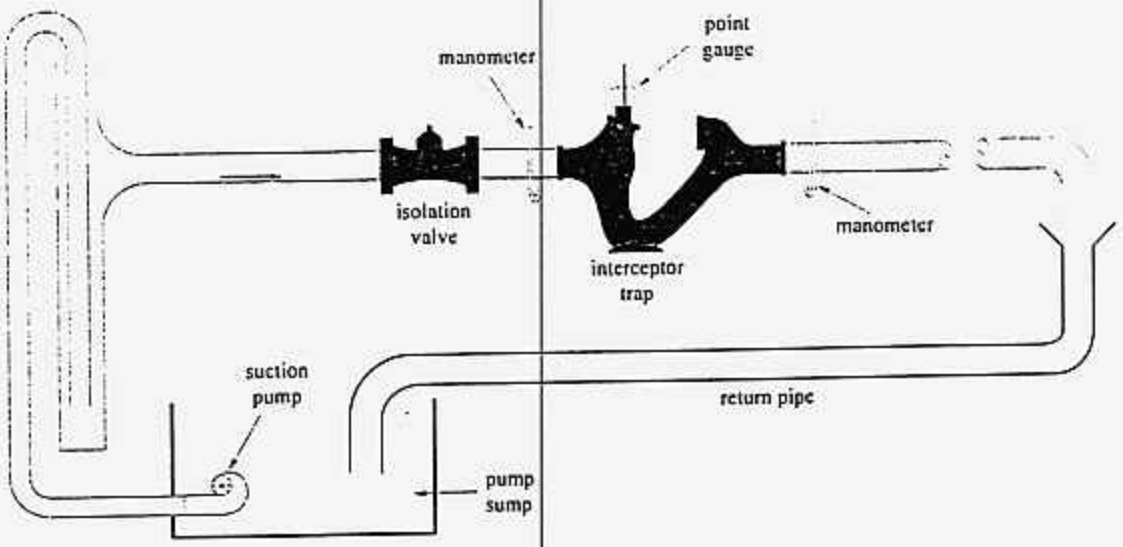



**Figure 6 : Interceptor Trap Experimental Test Rig**

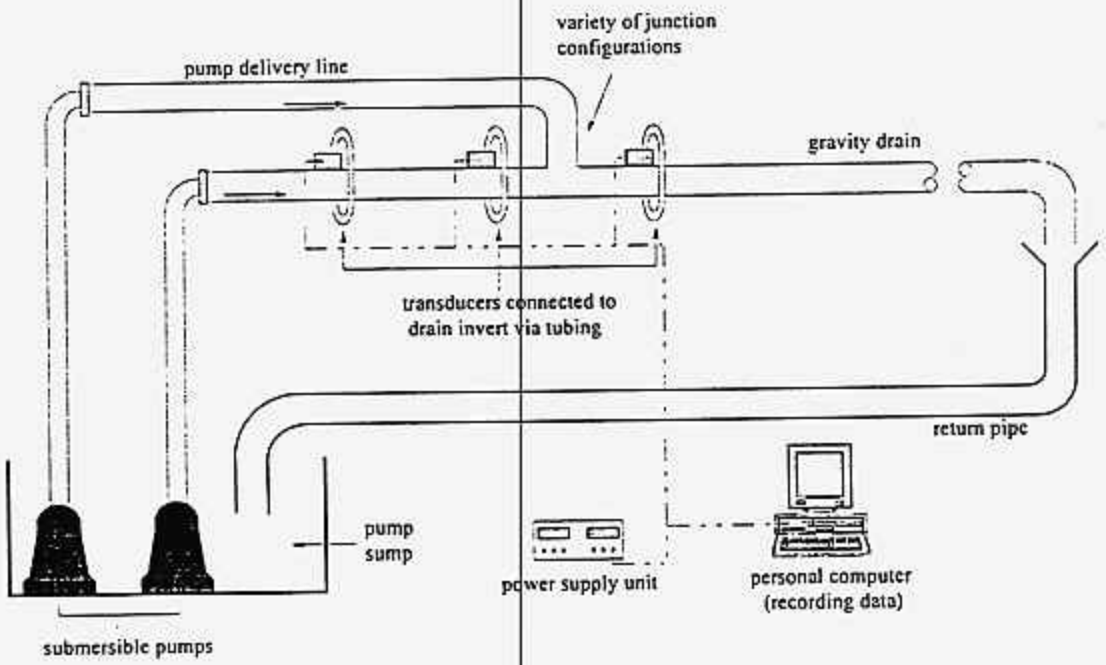



**Figure 7 : Pump Delivery to Gravity Drain Experimental Test Rig**

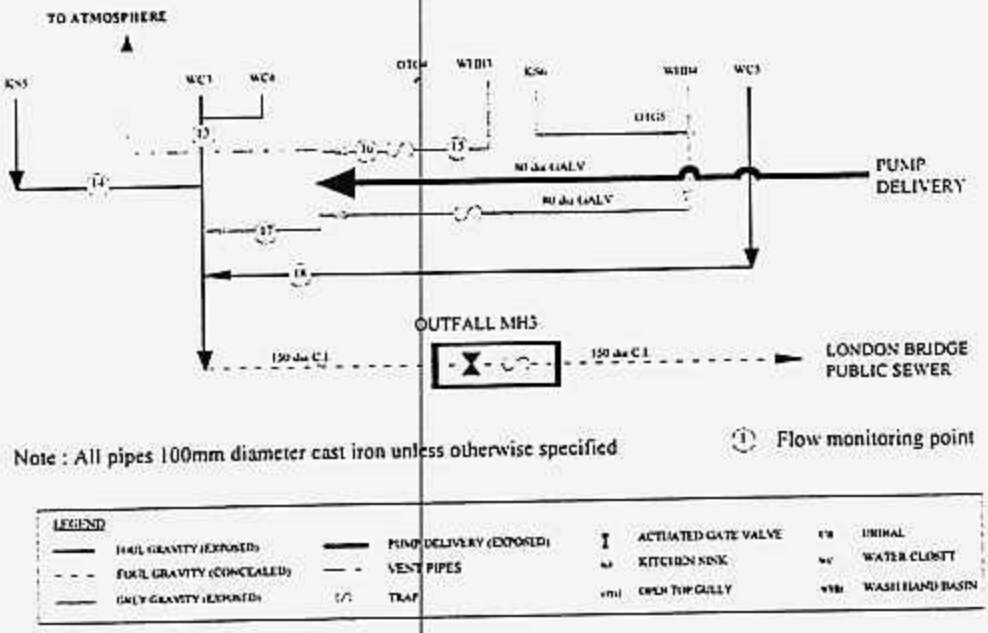



**Figure 8 : Drainage Network Installed at Bank Underground Station**

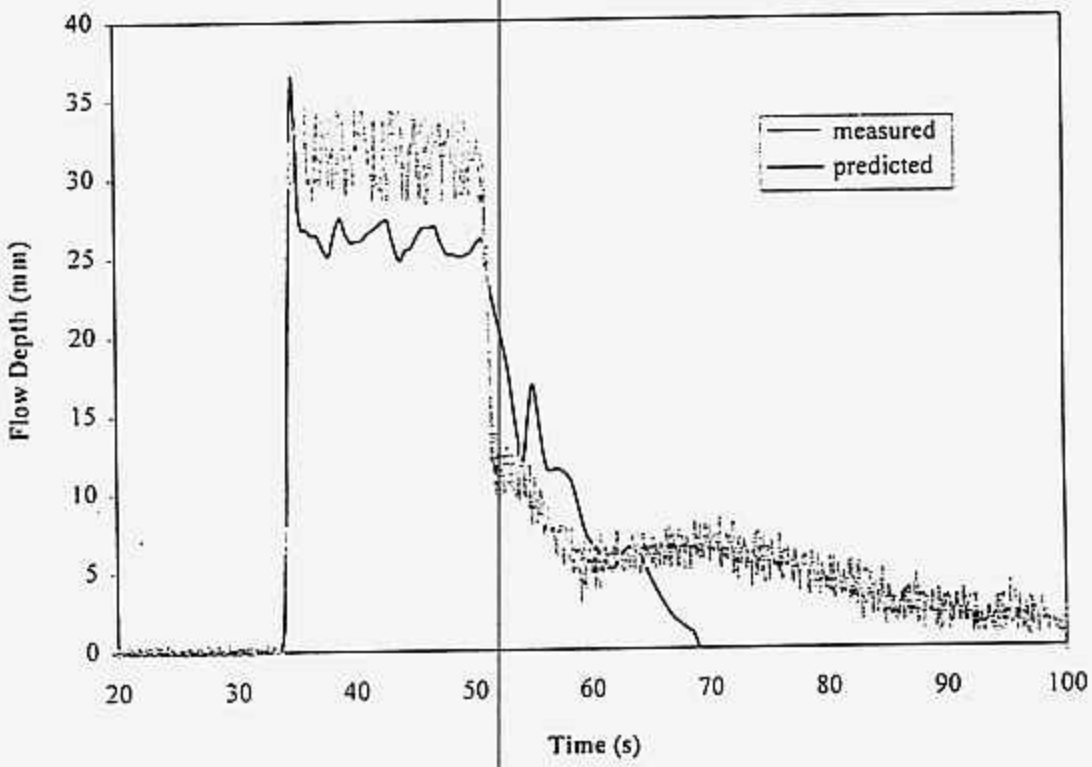



**Figure 9 : Measured and Predicted Variation in Flow Depth with Pump Operation**

# Topic B3

## Computer Simulation as Aid to the Design of Building Drainage Networks

Prof. J. A. Swaffield, Dr. J. A. McDougall

# COMPUTER SIMULATION AS AN AID TO THE DESIGN OF BUILDING DRAINAGE NETWORKS

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The transient flow conditions within a building drainage system may be simulated by the numerical solution of the defining equations of momentum and continuity, coupled to a knowledge of the boundary conditions representing either appliances discharging to the network or particular network terminations. While the fundamental mathematics has long been available, it is the availability of fast, affordable and accessible computing that has allowed the development of the simulations presented in this paper.

A drainage system model for unsteady partially filled pipeflow will be presented. This model is capable of predicting flow depth and rate, and solid velocity, throughout a complex network. The ability of such models to assist in the decision making and design processes will be shown, particularly in such areas as appliance design and water conservation.

## UNSTEADY FLOW ANALYSIS IN BUILDING DRAINAGE SYSTEMS

The water flows within a building drainage network as a result of appliance discharge are inherently unsteady. The local flow at any point in the network is determined by the usage pattern of the appliances, and the attenuation imposed upon any discharge during its passage through the network. While the unsteady nature of such flows was always appreciated (Hunter, 1940), it was not practical to address the numerical simulation of such flow conditions until the advent of modern digital computing. Therefore, in order to design building drainage systems to effectively remove waste water and solids, a series of quasi-steady flow and probability based techniques were developed in the 1940s, and these remain the basis for drainage design up to the present time. Such design methods are based on a range of empirical data, much of which is now outmoded due to fundamental changes in the usage pattern of appliances, changes and innovations in appliance design and the introduction of the new design criteria, particularly those concerned with water conservation.

In order to allow system design, these methodologies have become the basis of prescriptive design codes. Due to the empirical nature of the basic data utilised to develop these design codes, the current situation is that each national code may be viewed as an attempt to describe, based on empirical and steady flow concepts, the fundamental underlying unsteady flow fluid mechanics that defines drainage system operation.

The introduction of water conservation raises design issues not necessarily covered by the steady state empirical data used to generate current design guides. Rapid changes in the water consumption of appliances, water conservation and future metering and costing strategies require that improved modelling methods be developed. This would ensure that systems are not over-designed, thus avoiding the enhanced likelihood of solid deposition and maintenance costs.

The term 'unsteady' has an accepted definition that, at any location in the pipe network, the flow rate and depth will vary with time. This clearly applies to building drainage systems fed by a random selection of appliance discharges.

An appliance discharge generates a wave that propagates down the drain towards its termination at a vertical stack or at a junction with other pipes, which may naturally be carrying their own discharges. In these waves, the deeper zones tend to move faster than the shallower, effectively redistributing the water mass in the wave forward, steepening the leading edge and spreading the tail of the wave. Friction reduces the range of flow velocities along the wave, so that not all waves 'break'. The wave attenuates, lowering the peak flow depth and rate as the wave moves through the network, and increasing the flow duration at any location. These effects, which cannot be predicted by the current design methods, provided the impetus for the development of the simulations presented.

The degree of attenuation experienced by any appliance discharge is dependent upon pipe diameter, roughness and slope, the shape of the initial flow vs time profile and the baseflow over which it must pass, Figure 1. The driving force for attenuation is the difference in depth and velocity within the wave itself; these differences decrease due to attenuation thus reducing the tendency to further attenuation. Far downstream, the wave becomes 'almost' a steady flow; the summation of many such attenuated waves leads to conditions that approximate to steady free surface flows.

While the flow conditions within building drainage systems may appear at first sight to be complex, they belong to a well understood category of unsteady flows within the wider field of fluid mechanics. The necessary solution techniques have been available for some time, awaiting the arrival of reliable, fast computing. The research required to allow the development of drainage simulation models has been summarised by Swaffield and Galowin (1992). Such simulations allow the local flow conditions in a drainage network to be predicted. These flow conditions are governed by the usage pattern of the connected appliances, the form of individual appliance discharge profiles and the design of the drainage network.

## THE MODELLING OF UNSTEADY FLOW CONDITIONS

The water flows within building drainage systems belong to a family of unsteady flows described by the full equations of continuity and momentum. The solution of these equations was first investigated by d'Alembert in the 1750s. The defining equations are quasi-linear hyperbolic partial differential equations whose numerical solution is made possible by use of the method of characteristics (Lister, 1960).

**Free surface wave propagation in unsteady flows**

The equations of continuity and motion defining transient flow conditions may be combined using the method of characteristics into a pair of total differential equations in flow depth, h. and flow velocity, V, suitable for finite difference treatment -

$$\frac{dV}{dt} \pm \frac{g}{c}\frac{dh}{dt} + g(S - S_0) = 0 \qquad (1)$$

provided that

$$\frac{dx}{dt} = V \pm c \qquad (2)$$

where the wave speed, $c$, is defined in terms of the flow area, $A$, and the surface width, $T$, as

$$c = \sqrt{gA/T} \qquad (3)$$

and S and $S_0$ are the friction and pipe slopes respectively (Swaffield and Galowin, 1992).

The finite difference expressions given in equation (1) only exist if the dx/dt relationship given in equation (2) is adhered to, this being the Courant criterion which links simulation time step to internodal lengths. The Courant criterion depends upon flow velocity and wave speed; for free surface flows these are comparable, commonly less than 5m/s. Equation 2 defines lines, known as characteristics, drawn in the x-t plane. These characteristic lines may be thought of as the mode of communication of information from one location in the flow at the current time step to another location one time step in the future.

As a result of a co-ordinated research programme at Heriot-Watt University, funded both by SERC (now EPSRC) from 1983-1998 and the US Department of Commerce National Institute of Standards and Technology from 1981-1987, suitable simulations have now been developed and are described below. These computing models are capable of predicting the flow rate and depth at any time within a multi-level building drainage network subjected to user-defined appliance discharge patterns.

At the boundaries to any drain only one characteristic can exist and the boundary must be defined by an equation linking flow depth to flow rate and/or time. Boundaries now developed for these simulations include:

- w.c. discharge to a drain;
- pipe junctions, including displaced hydraulic jumps;
- entry to vertical stacks;
- the transformation of the stack annular flow back into free surface flow at entry to the lowest level collection drain;
- solid transport within a pipe network.

The model is also capable of representing the effects of slope, both accurate and defective, and joint obstructions on both wave attenuation and solid transport. The

solid transport model is a 'velocity decrement' scheme and has been extended to cover solid diameter, mass and specific gravity, as illustrated in Figure 2 (Swaffield and McDougall, 1996).

## THE DRAINAGE SIMULATION MODEL

The numerical model described above, based on the method of characteristics, has been developed with a user-friendly graphical interface for use under Windows on PCs. The model is capable of representing unsteady flow within building drainage networks, including the possibility of multiple appliance diacharges to a network and multi-level building configurations. It accurately simulates the attenuation of appliance discharges through complex networks and also includes the validated representation of the transport and deposition of solids within such attenuating flows. The relationship between the solid parameters of mass, diameter and specific gravity, the pipe parameters of slope, diameter and roughness, and junction characteristics are accommodated by basing the solid transport model on a velocity decrement approach where the solid velocity is determined from the locally predicted flow velocity. The numerical solutions are effectively driven by the discharge profiles of the various appliances connected to the network and a user-defined pattern for such appliances. The appliance discharge profiles are empirical, the remainder of the simulation is based on a full solution of the unsteady wave equations.

Figure 3 illustrates the application of the model to a bank of five 6-litre w.c.s connected to a single drain line. All pipes are of length 2 metres, diameter 100mm, slope 0.01 (1:100) and are of coated cast iron, and all five w.c.s operate at time zero in the simulation. The embedded graph shows the combined flow rate against time at the downstream end of the system.

Figure 4 shows the model being used to simulate a single 6-litre w.c. connected to a 40 metre long, 100mm diameter coated cast iron pipe at a slope of 0.01. The w.c. operates three times at 25 second intervals, starting at time zero in the simulation. The embedded graph shows the velocity of a solid, initially discharged 2.5 seconds into the first flush, as it is deposited and then re-transported by the subsequent flushes.

The third simulation, shown in Figure 5, shows a three-level network, each level having a bath, basin and w.c. The w.c.s are all flushed at time zero in the simulation, the basins are emptied 20 seconds later, and the baths have been assumed not to be emptied during the simulation. The embedded graph shows the combined flow rate against time at the base of the stack.

## MODEL APPLICATIONS

The model has a wide range of applications, which include drainage design, code formulation, water conservation proposal assessment, reduction of drainage maintenance costs and w.c. design to meet solid deposition criteria.

**Building drainage design and national codes.** The first area where this simulation would be applicable is in assessing current code recommendations for the design of drainage networks for a range of building types, particularly in the areas of pipe sizing and water conservation. The use of this simulation would also allow the assessment of the contribution of a particular building type to the drainage network outwith the

building boundary. This is equivalent to reducing the building to an 'effective appliance' loading the network with a predicted flow-time profile. Changes in pipe sizing suggested by such modelling would affect drainage design codes.

**Water conservation.** The use of the model to re-assess building drainage codes as described above would naturally lead to the inclusion of water conservation as a parameter in the simulation.

**Maintenance costs.** By balancing pipe size reductions against water conservation proposals, and by utilising the solid transport simulation, it will be possible to use the model to assess the effects on drainage maintenance within the building.

**W.c. design.** The obvious corollary to the water conservation case above is that w.c. design guidance could be derived from the application of the solid transport model / water conservation assessment to the determination of w.c. discharge profiles likely to give acceptable transport performance. This could lead to system designer specification of w.c. discharge profile necessary for any particular type of installation.

Figure 6 shows the model being used to determine the effect on solid transport of changing the w.c. profile. These simulations are similar to those shown in Figure 4 and described above.

The two upper simulations show a w.c. with a flush volume of 6 litres discharging into a 40 metre long, 100mm diameter coated cast iron pipe at a slope of 1:100 (0.01). The w.c. on the left has a gravity cistern with a flush duration of 6 seconds and a peak flow rate of 1.2 litres/second, while that on the right has a pressure cistern with a flush duration of 3 seconds and a peak flow rate of 4 litres/second. In each case, the solid is discharged when the flow rate from the w.c. reaches a level of 1 litre/second. It can be clearly seen that the peak solid velocity on the first flush is much higher for the pressure cistern than for the gravity cistern, while the reverse is true for subsequent flushes. This is due to the much more rapid attenuation of a pressure cistern because of its 'peaky' nature, i.e. its lack of a plateau which is a feature of a gravity cistern.

The two lower simulations are similar to the previous two, but the w.c.s have a flush volume of 3 litres, and the pipe has been changed to 75 mm diameter at a slope of 1:50 (0.02). The peak solid velocities are higher than with a 6 litre flush volume and a 100mm diameter pipe at 1:100.

The solid travel distances are summarised in the following Table.

| Flush volume (litres) | 6 | | 3 | |
|---|---|---|---|---|
| Pipe diameter (mm) | 100 | | 75 | |
| Pipe slope | 0.01 | | 0.02 | |
| Cistern type | Gravity | Pressure | Gravity | Pressure |
| Travel distance - flush 1 (m) | 10.4 | 15.0 | 14.4 | 16.7 |
| Travel distance - flush 2 (m) | 4.1 | 2.0 | 7.9 | 5.8 |
| Travel distance - flush 3 (m) | 3.3 | 1.6 | 7.2 | 5.5 |
| Total travel distance (m) | 17.8 | 18.6 | 29.5 | 28.0 |

**Table 1. Travel distances for the simulations illustrated in Figure 6.**

This table clearly illustrates the following:

1. Pressure cisterns are more effective on the first flush than gravity cisterns.
2. The reverse applies to subsequent flushes, i.e., gravity cisterns are more effective on subsequent flushes than pressure cisterns.
3. The travel distances for a 3 litre flush can be greater than for a 6 litre flush, provided the pipework is re-designed to suit the lower flush volume. This clearly illustrates that a large reduction in w.c. flush volume will not necessarily cause solid transport problems.

From points (1) and (2) above, it can be inferred that high peak discharge cisterns perform better than low peak discharge cisterns where the total travel distance to the main sewer is relatively short, while the reverse is true where the travel distance is greater.

**Networks outwith the building boundary.** Once the building has been established as a 'pseudo-appliance' in terms of its discharge pattern, by application of the model to assess the drainage flow attenuation and combination, it will be possible to apply the model, in all the application areas defined above, to at least the smaller bore drainage networks linking buildings on a particular site. The considerations of water conservation, pipe sizing and solid transport would be carried into these studies and could lead to recommendations for change in codes in this area, in addition to those dealing with the in-building system.

## CONCLUSIONS

This paper has outlined the application of numerical simulation techniques to the design of both drainage systems and appliances. In doing so it has drawn on the output of a concerted and planned research programme, whose objective was to introduce soundly based fluid mechanics analysis techniques to the design of building drainage systems. These proposals offer a new approach to the design and evaluation of building drainage networks that emphasises a user-defined appliance usage profile as the basic data required to drive the simulation. This is a departure from the probability based approach previously employed in system design. It is stressed that the current probability / steady flow design limits approach cannot by its very nature address the problems solved by this paper.

## ACKNOWLEDGEMENT

The work reported in this paper was supported by SERC (now EPSRC) and US Department of Commerce research awards. This support is gratefully acknowledged.

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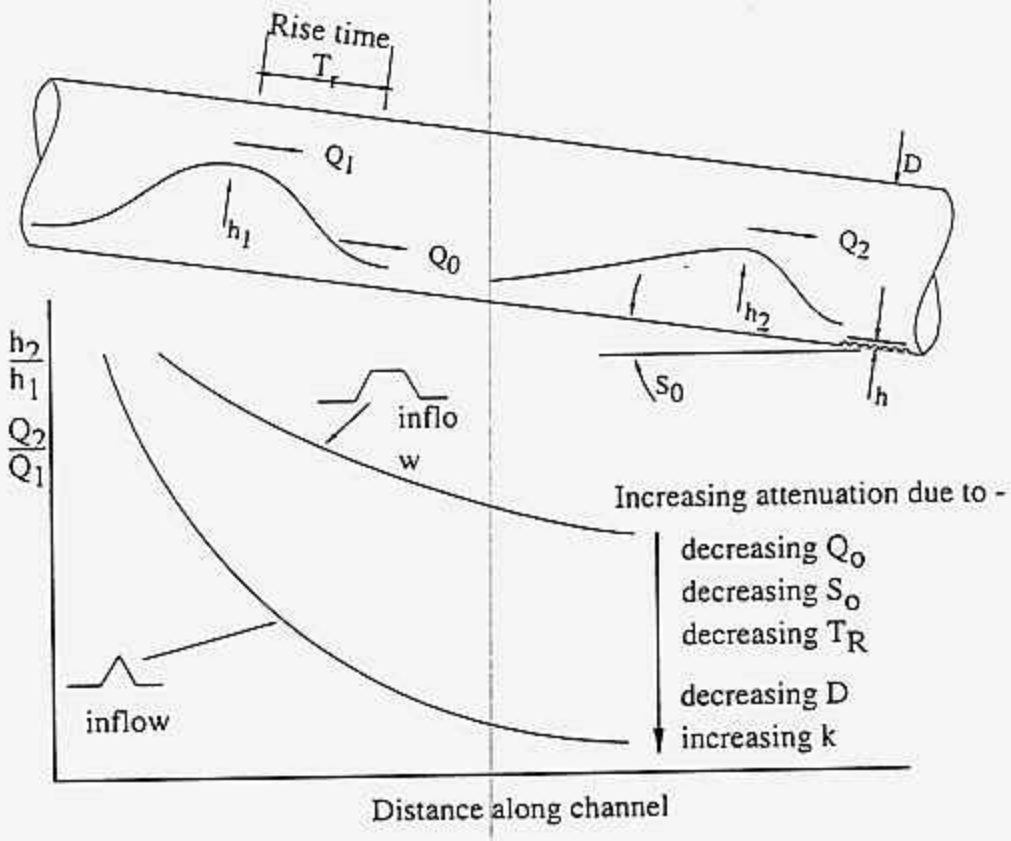



**Figure 1 Dependence of wave attenuation on pipe and slope parameters**

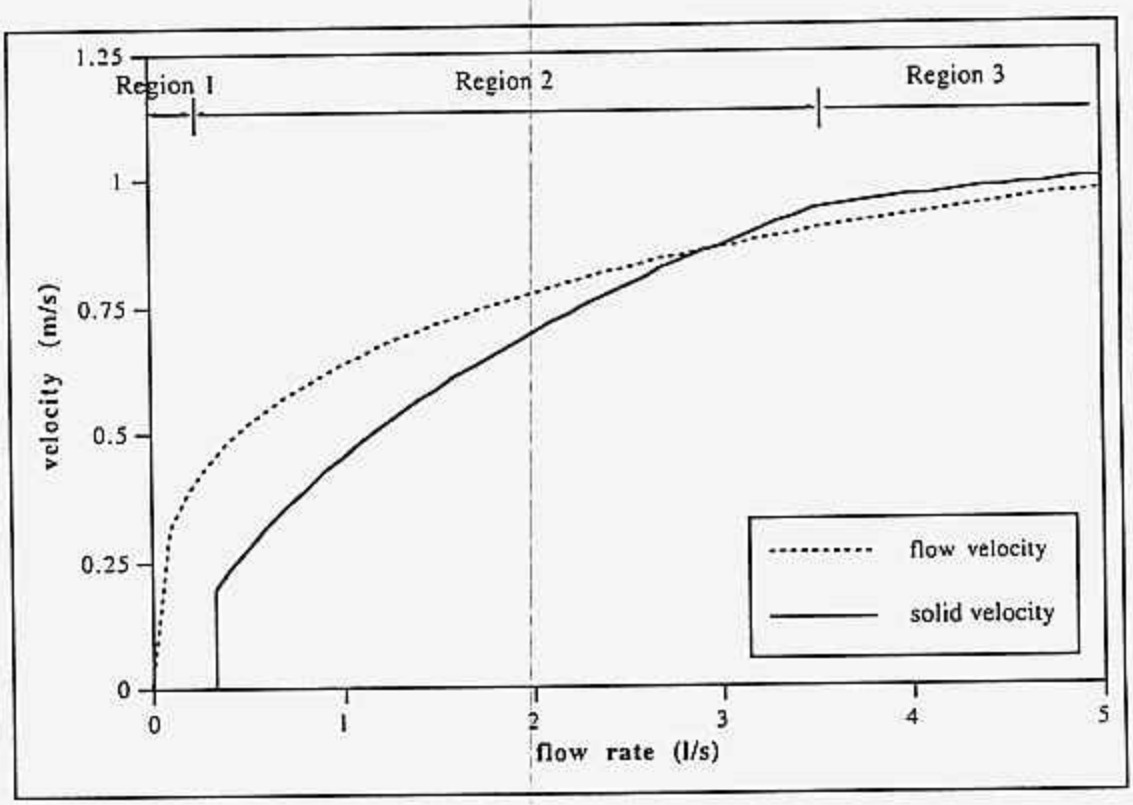



**Figure 2 An illustration of the solid velocity model for 100mm diameter coated cast iron pipe at a slope of 1:100 (0.01)**

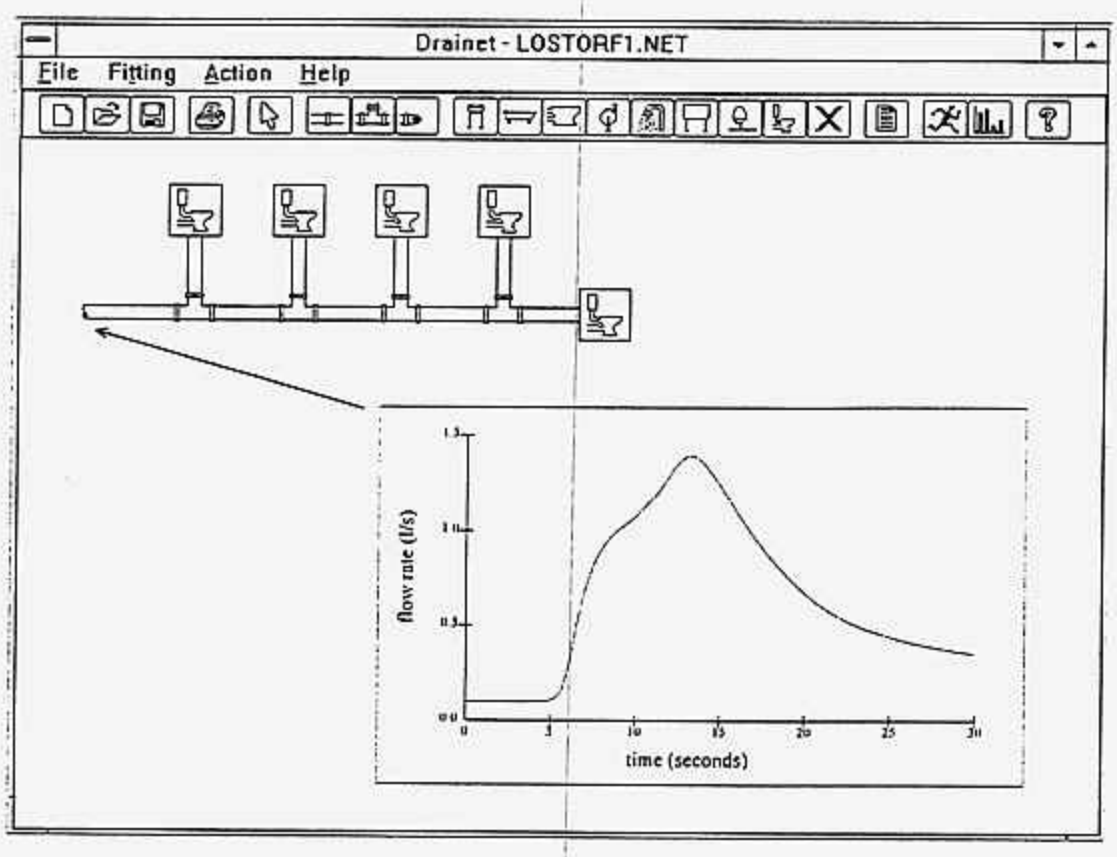



Figure 3. A single-level network with 5 w.c.s connected to a single drain line, showing the flow rate vs time at the end of the system.

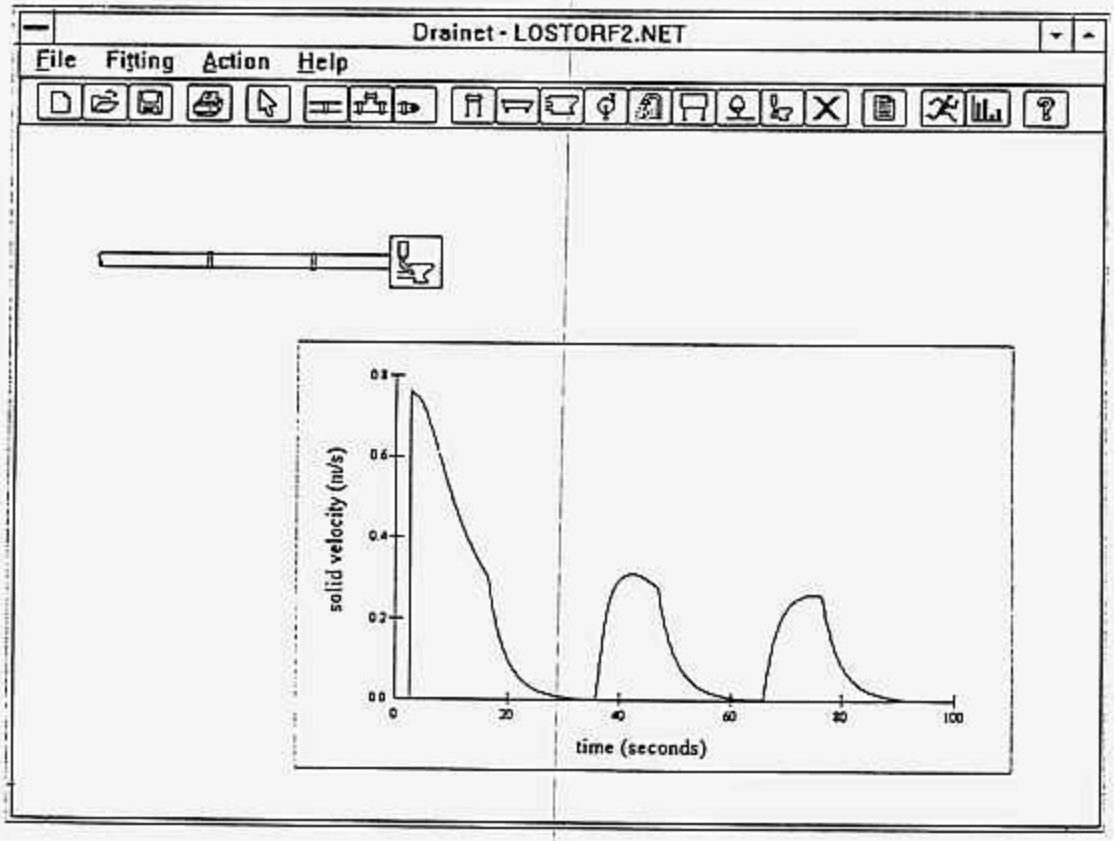



Figure 4. A single-level network with one w.c. connected to a 40 metre long drain, showing the solid velocity vs time for a solid flushed from the w.c. at the peak of the flush profile.

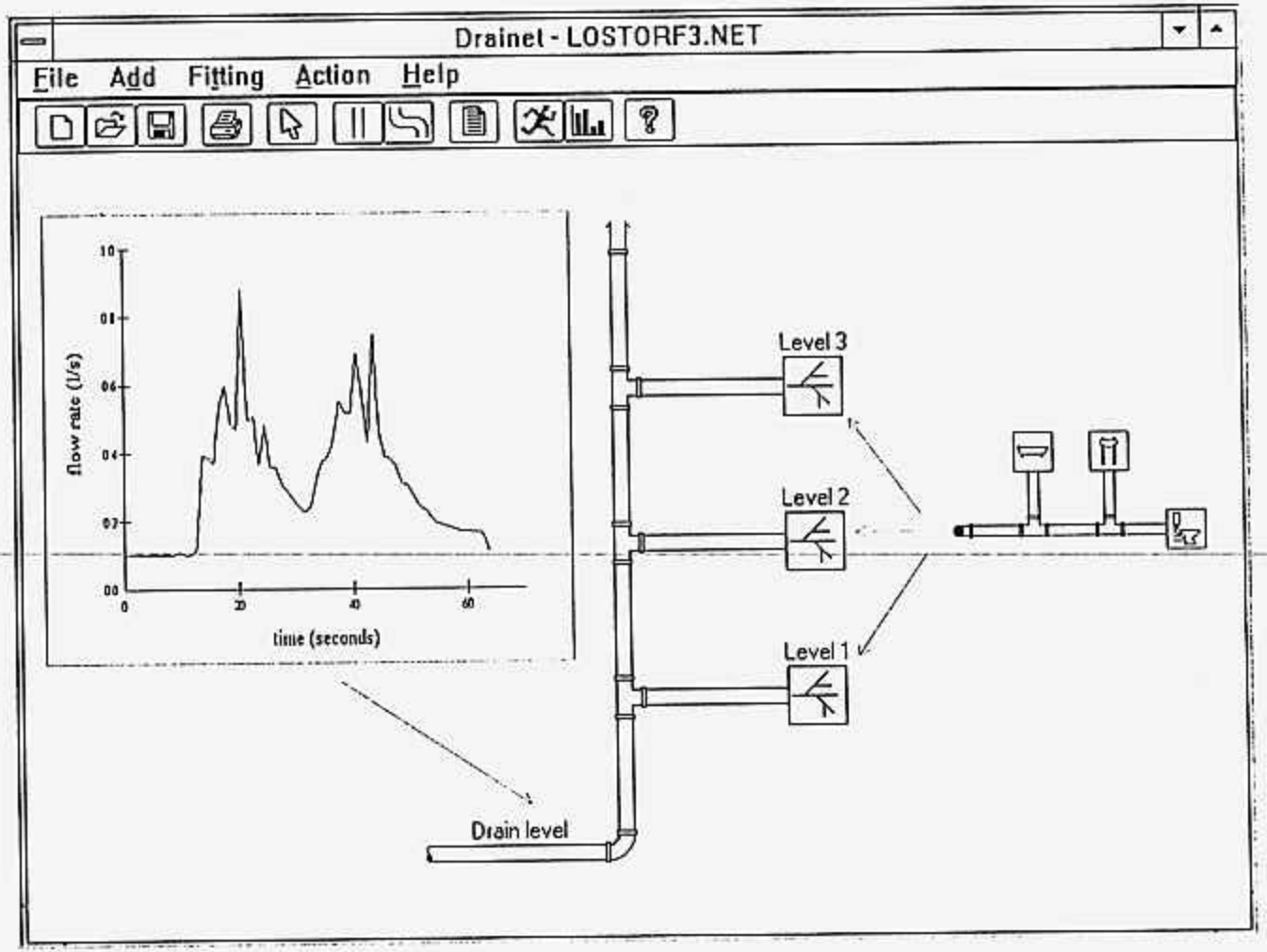



Figure 5. A multi-level network with three levels, each having a bath, basin and w.c. The w.c. flushes at time zero in the simulation, the basin 20 seconds laterand the bath is assumed not to be emptied during the simulation.

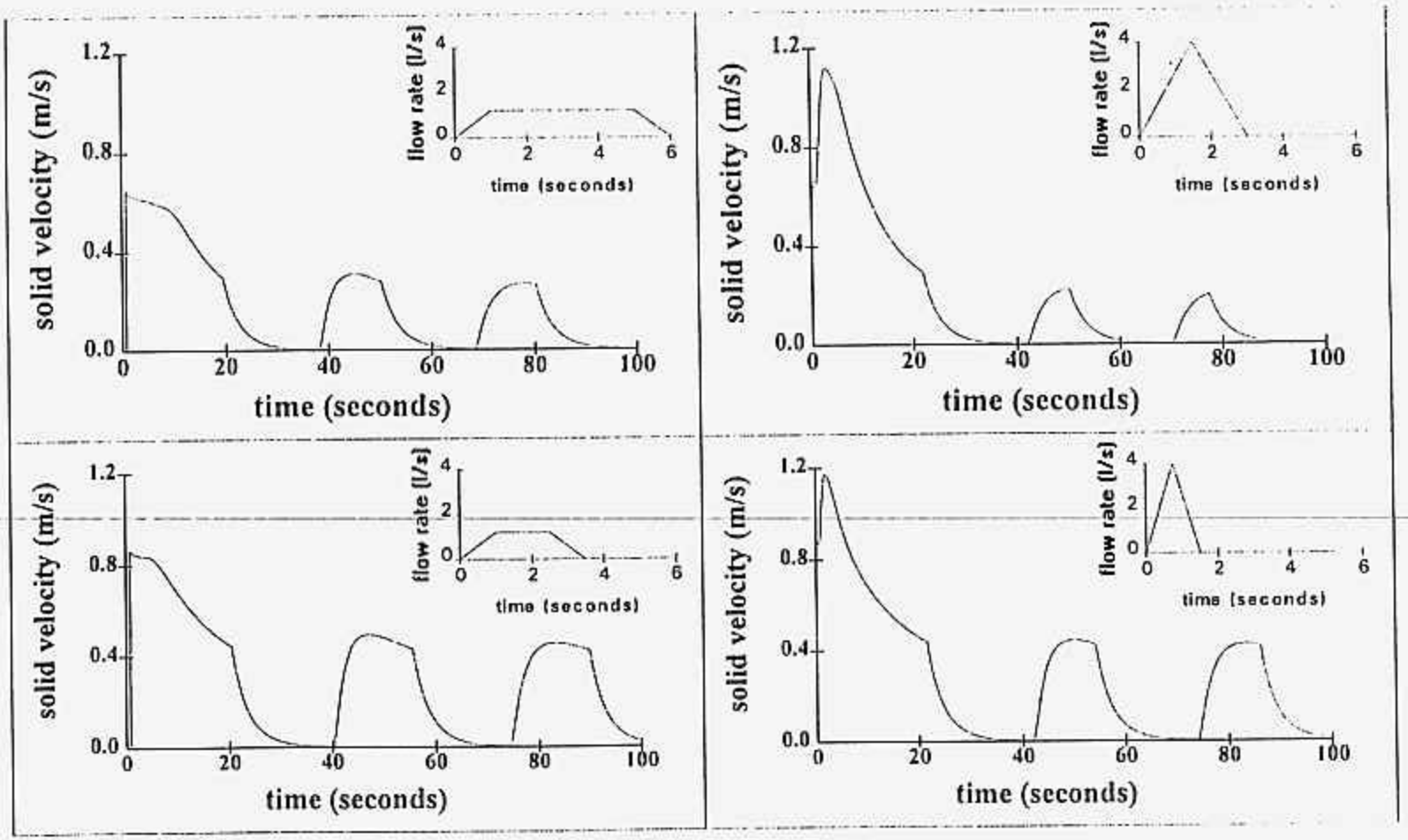



Figure 6. Four simulations showing the effect of variations in flush profile on solid transport. The upper two simulations show a 6 litre w.c. flushing into a 100mm diameter pipe at 1:100, the lower two a 3 litre w.c. flushing into a 75mm diameter pipe at 1:50. The left two simulations show gravity cisterns while the right two show pressure cisterns.

# Topic B4

## Study on Pressure Distribution of Drainage Stack in High-Rise Apartment Houses

Ch. Cheng, Japan

concentrate loss.
friction loss

CIB-W62 Paper

# Study on Pressure Distribution of Drainage Stack in High-Rise Apartment Houses
## --prediction method in case of single-point discharge--


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## Abstract

In order to simulate actual water discharge of high-rise residential buildings, systematic full scale model experiments were performed using a 100m high experiment tower. Preliminary experiments showed that high level of discharge entry leads not only large peak negative pressure but also peak position being apart from the discharge floor, which has not been observed in the 30m high tower experiments. In case of single-point steady discharge, we assembled a full numerical prediction method of air pressure distribution of drainage stack, which includes the prediction of peak negative pressure and air flow rate in stack vent pipe. Furthermore, we propose a numerical prediction method that can be applied to any discharge height in case of single-point discharge.

# Study on Pressure Distribution of Drainage Stack in High-Rise Apartment Houses

--prediction method in case of single-point discharge--

By

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## 1. Introduction

### *1.1 Background*

To ensure proper drainage, the gravity system without any energy supply is commonly used in building all over the world at present, and a trap with simple structure is also preferred because of its easy elimination of stench and vermin. A full volume discharge in the stack of the gravity drainage system is prohibited to protect seal water inside a trap at the time of discharge. An actual discharge may consist of water, air and/or solids. The energy of air flow rate is created by air mixed with the falling water as well as the friction between air and the falling water.

On the other hand, hydraulic jump and other complex currents, which may occur at the points where water flows from a branch pipe into a drainage stack, or from a drainage stack into a building drain pipe, make the cross-sectional area of air flow change greatly in a very short distance. Therefore the same kind of pressure loss occurs in these parts as in the sections where the size of pipes broadens or narrows abruptly. Some friction stress related to the velocity difference between water and air may also occur, but this operates mainly as the ventilation resistance in the stack. In this way the intra-pipe currents of the gravity drainage system take the form of complex stream that is greatly influenced by the force of gravity, making it difficult to simulate a model experiment. For this reason, the analysis of current phenomena in high-rise building is yet to be performed. In fact, designing of drainage systems at present is mainly performed by the calculation method based on experience.

As an overseas research on this topic, a steady discharge experiment had been conducted in a 32-floors high building by Dr. Pink in U.S.A.. One of the most important conclusions of Dr.

Pink's research[5] is that the air flow rate in the stack vent pipe increases in according to the height of water discharge floor. That is to say the water discharge height is an important factor in establishing a prediction method of air pressure distribution of drainage stack system.

In Japan, a discharge experiment using a 30m high experimental tower (equivalent to 10-story building) was conducted by Ohtsuka et al[6~8], and a prediction method of air pressure distribution of drainage stack was proposed. In this study, application to high-rise building was considered and the results were compared with those of Pink's. However, a systematic full scale experiment simulating the drainage system of high-rise building was not performed then.

Concerning this topic, authors of this paper obtained a chance of using a 100m high experiment tower to simulate actual water discharge of high-rise residential buildings. This paper presents new information revealed through our experiment, and outlines a new prediction model of air pressure distribution of drainage stack applicable to high-rise building.

In order to simulate and verify a complex current phenomenon of drainage system at any given heigh such as in a high-rise building, we simplified our model to meet the following condition:

1.) The kind of drainage system used is stack vent system.
2.) Only single-point steady discharge from one branch pipe connected to the drainage stack is considered.
3.) Only water and air are included in discharge; no solids and detergent is used.

The fundamental principles below were established to facilitate a model-making of the observed phenomenon:

1.) Only values such as average air velocity are considered. The simulation of actual air and water flow is not performed.
2.) The pressure loss at the points where water flows from a branch pipe into a drainage stack, or from a drainage stack into a building drain pipe are regarded as similar to the resistance due to the changes in the shape of ducts.
3.) The energy of air current in stack is considered mainly to be caused by the friction stress due to the difference in velocity between water and air; the effect of air mixed with the falling water is thought to be minimal.

### *1. 2 Relation to Former Research*

The first research concerning the current phenomenon of gravity drainage system was conducted by R.B. Hunter[1] in 1940's. For the lack of appropriate equipment, however, his work is limited to qualitative considerations. Even at the CIB W-62 seminar, which is the only international symposium held every year at present, very few studies presented are dealt quantitatively and analytically. As for experimental design, R.J. Pink's was the only one which utilized a 100m tower.

In recent papers published in Japan, Dr. Ohtsuka, Nezime, et al. proposed a prediction

method of air pressure distribution of drainage stack. Although several attempts had been made by Otsuka to apply the method to the case of high-rise building, his studies are based on the experimental data obtained from a 30m tower, and full attention is not given to the phenomena peculiar to high-rise buildings.

In this study, we deal with the current phenomenon of gravity drainage system of high-rise residential buildings utilizing a full scale experimental facility to simulate the various factors involved in the phenomenon. We also make models for each factor and attempt to construct a prediction method applicable to a drainage stack at any height.

## 2. Experiment and Elementary Results[9,10]

### *2.1 Abstract of Experiment and Procedures*

To simulate high-rise and middle-high residential buildings, we used the 108m high experiment tower which belongs to the Research Institute of the Housing and Urban Development Corporation in Hachioji and a 30m high experiment tower which belongs to the Meiji University and performed various water discharge experiment. Fig. 2.1 shows the layout and view of the 108m high experiment tower, and Fig. 2.2 shows the drainage system and the device of experiment in the tower (108m ).

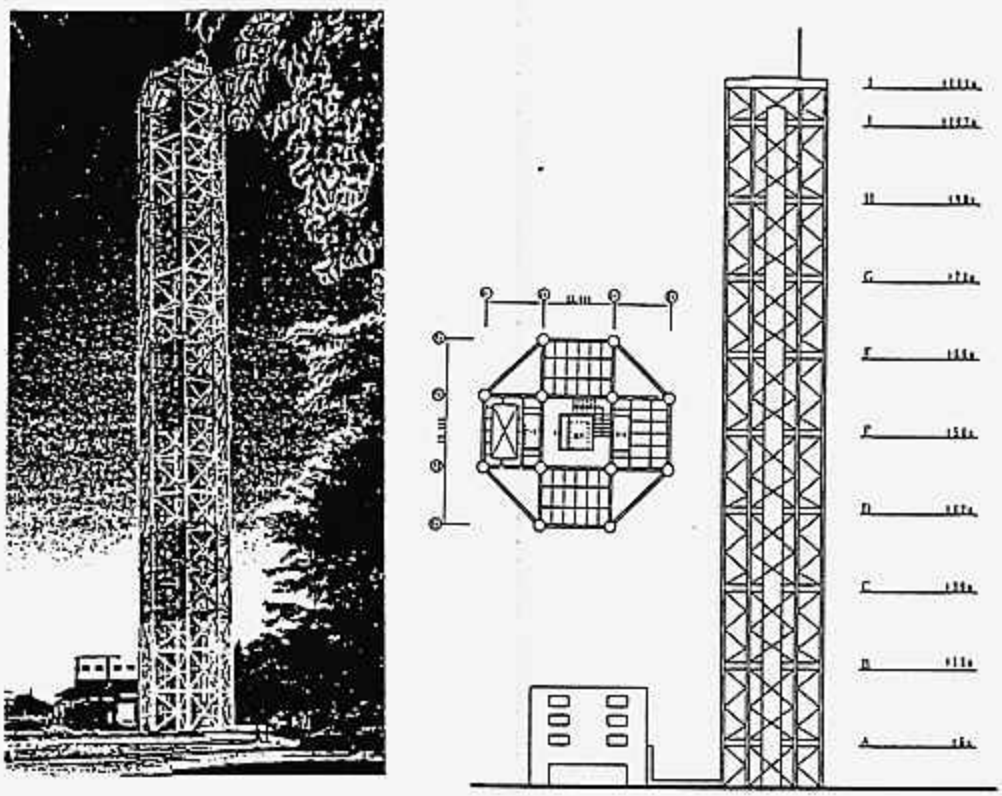


Fig. 2.1 Layout and view of the 108m high experiment tower

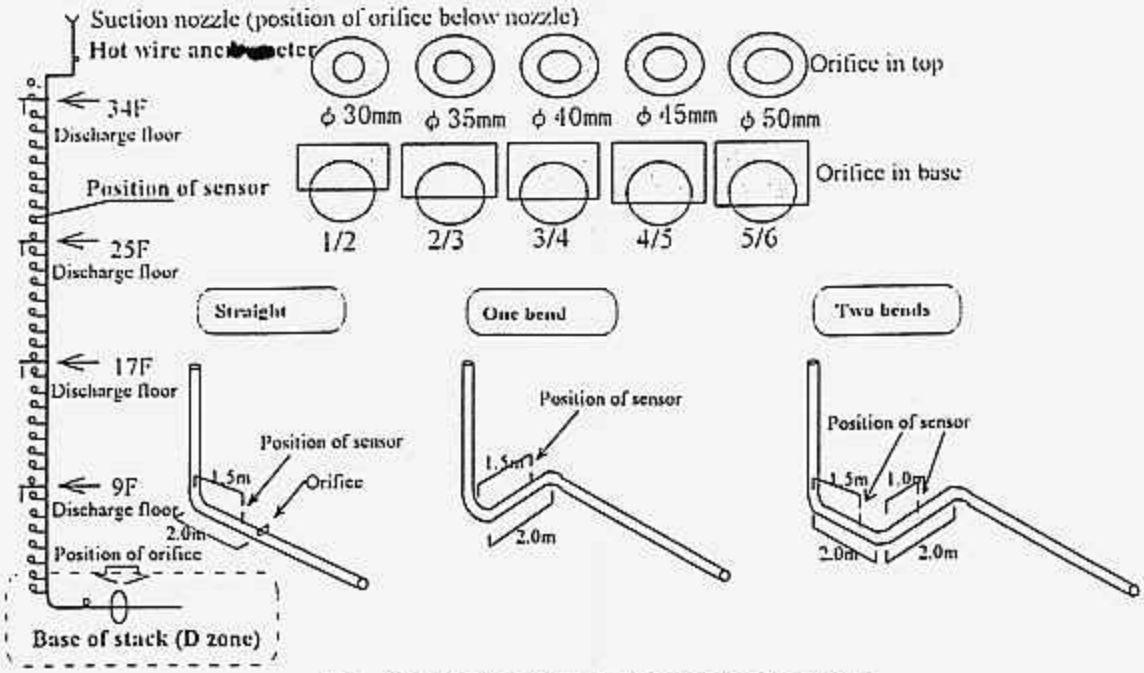



Fig. 2.2. Device of high-rise experiment tower

The diameter of stack pipe was ϕ 100mm (using JIS-DT joint), the building drain pipe was ϕ 125mm, and the horizontal fixture drain branch (branch pipe) was ϕ 75mm. The measurement of air pressure was made by using a small diffuse semiconductor of air pressure transductor, 35 points were measured in each branch pipe, and 2 points were measured in the building drain pipe. Assuming that the air flow in the pipe has a normal distribution, air flow velocity was measured by a hot wire anemometer in the central position of ventilation stack, and translated to air flow rate (Qa). The conditions of the experiment is shown in Table 2.1.

Table 2.1 Experiment condition of high-rise tower

| Building drain pipe | Condition of orifice | | Discharge floor | Flow rates |
|---|---|---|---|---|
| Straight | No orifice | | 34 F<br>25 F<br>17 F<br>9 F | 1.0(l/s)<br>2.0(l/s)<br>3.0(l/s)<br>4.0(l/s) |
| | Orifice in top | 30.35.40.45.50 mm | | |
| | Orifice in base | 1/2.2/3.3/4.4/5.5/6 | | |
| One bend | No orifice | | | |
| Two bends | No orifice | | | |

The building drain pipes were prepared as follows: straight, one bend, two bends, and straight with orifices of five different sizes (1/2, 2/3, 3/4, 4/5, 5/6 of pipe's sectional area) inserted. Orifices of five different sizes (with the diameter of 30, 35, 40, 45, 50mm) were also inserted in stack vent pipe to change air resistance.

The following Fig. 2.3 shows the device of a middle-high (30m) experiment tower. The drainage system and equipment were almost the same as for the high-rise experiment tower, but only a straight building drain pipe was used. On the top of the stack vent pipe, a fan with controllable running velocity was set. It is turned on when air flow rate needs to be increased, and

air flow rate can be decreased by adjusting the sucking damper. In this way, a wide range of air flow rate was simulated.

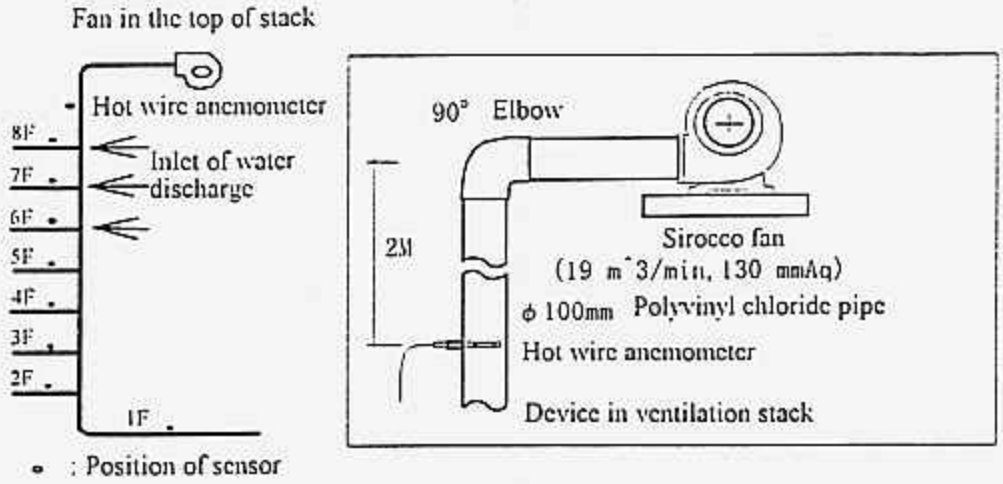



Fig. 2.3 Device of middle-high experiment tower

*2.2 Elementary Experiment Results*

*1). Condition of High-rise (108m) Tower*

Fig. 2.4 and Fig. 2.5 show the elementary results of air pressure distribution in drainage stack which were measured without orifice. Fig. 2.4 shows the air pressure distribution when single-point steady discharge was made from the floors 9F, 17F, 25F, and 34F. Fig. 2.5 shows the results when flow rate was varied in the range of 1.0 ~ 4.0 l/s.

These figures clearly indicate that the larger peak negative air pressure was observed in the high-rise setting than in the middle-high experimental tower (30m). Futhermore, the distance between the discharge floor and the positions where the peak negative pressure was observed tends to increase as the discharge floor gets higher. This has not been observed in the 30m tower, either. On the other hand, if we insert the orifice to decrease the air flow rate, we find the tendency that the peak negative air pressure position approachs to the water discharge floor. The results with the orifice inserted are shown in Fig. 2.6 and Fig. 2.7.

*2). Condition of middle-high (30m) Tower*

Fig. 2.8 shows the experimental results with different water flow rates of 1.0 l/s to 4.0 l/s using a middle-high (30m) experiment tower. The other results that were enforced to adjust the air flow rate by using a fan on the top of stack vent pipe are shown in Fig. 2.9. The observation of these figures brings us to the second point that the constant pressure gradient at final stack length is very closely related to the air flow rate, which corresponds with the results of former research.

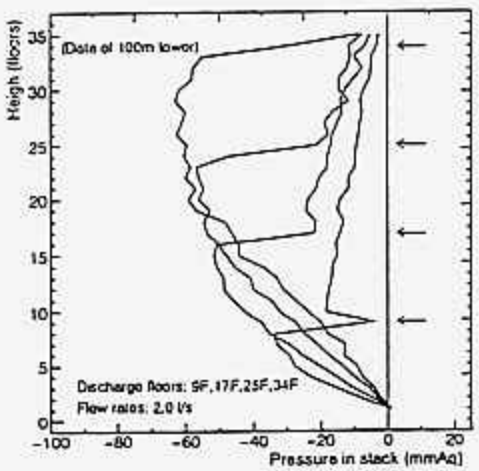



Fig. 2.4 Pressure distribution due to discharge height

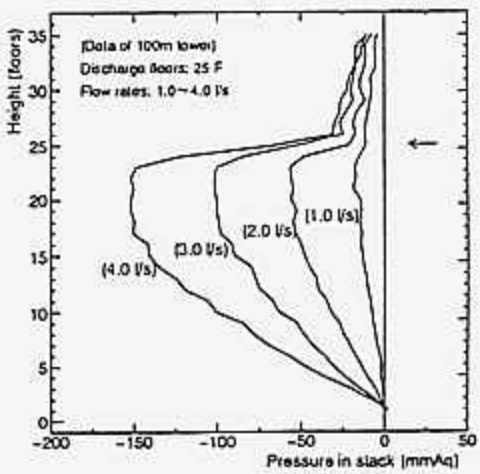



Fig. 2.5 Pressure distribution due to flow rates

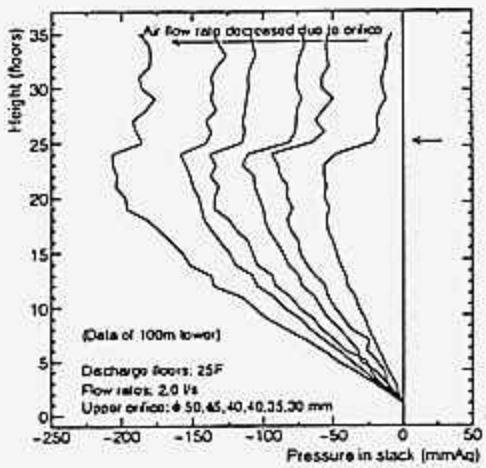



Fig. 2.6 Pressure distribution due to upper orifice

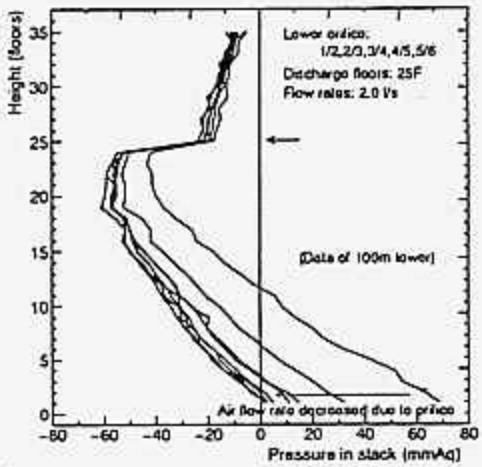



Fig. 2.7 Pressure distribution due to lower orifice

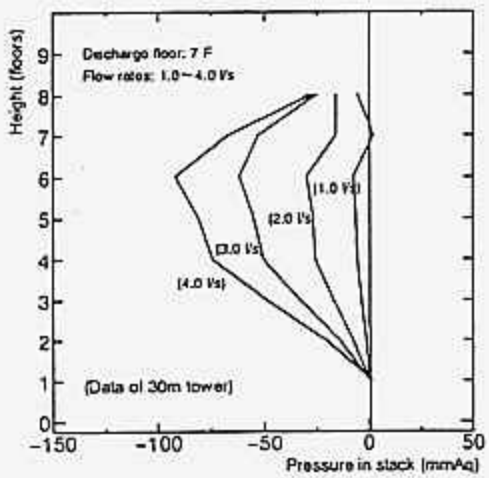



Fig. 2.8 Pressure distribution due to flow rates

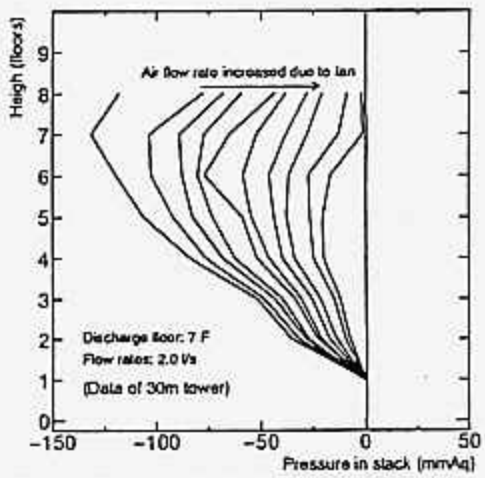



Fig. 2.9 Pressure distribution due to upper orifice

## 3. Principle of Prediction Model[11~18]

In order to study and modify the air pressure distribution which occurs in the drainage stack, we divided the profile of drainage stack into four zones, as shows in the following diagram (Fig. 3.1).

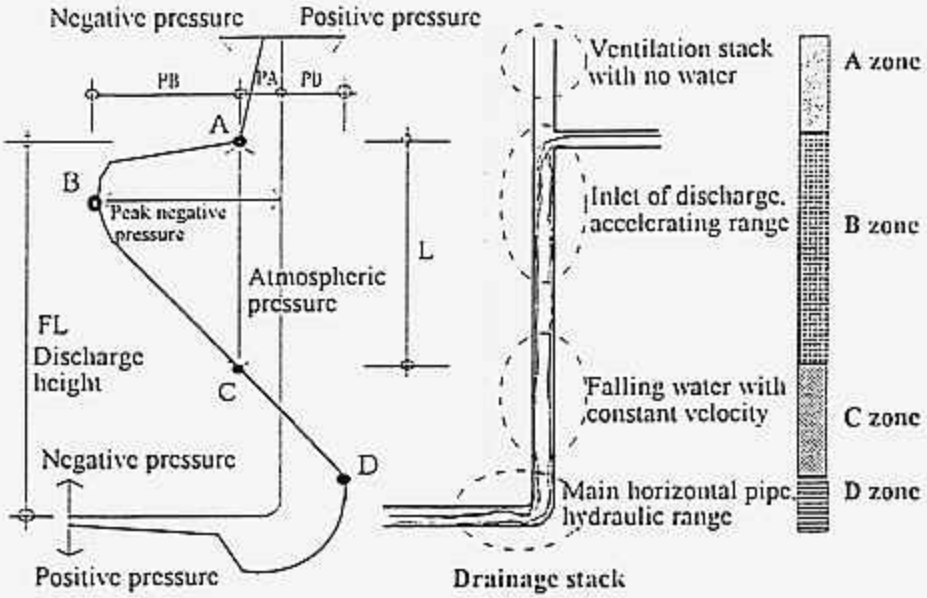



Fig. 3.1 Profile of air pressure distribution zones in drainage stack

We defined these zones of drainage stack as the following; A zone is from the top of the ventilation stack to the discharge floor, and there is only air flow. B zone is from the branch pipe to the point where air pressure recovered after it reached its negative peak and discharged water operated as ventilation resistance. The vertical distance between the branch pipe and this point is defined as L. C zone is from the lower position of B zone to the base of the drainage stack, and here the air flow is caused by the falling water and the constant pressure gradient occured in this range. And D zone is the area of the building drain pipe which hydraulic jump and air flow resistant occured.

### *3.1 Formula of $P_A$, $P_B$, $P_D$*

#### *1). A zone*

A zone consists only of air flow in pipe, therefore, as in the research of Dr. Ohtsuka, we can deal the phenomenon of this range as a general duct, and use the following formula (1) to calculate the air pressure $P_A$ of A zone.

$$P = \xi \times \left(\frac{\gamma}{2g}\right) \times v_a^2 \quad \cdots\cdots (1)$$

Fig. 3.2 shows the change of resistant coefficient $\xi_A$ in the stack vent pipe in the range above the water discharge floor. This diagram indicates that the length of a drainage stack is roughly proportional to the function of the resistant coefficient $\xi_A$. In this study, we used the regression line in Fig. 3.2 to calculate the drag coefficient $\xi_A$ and air pressure distribution in the stack vent pipe.

*2). B zone*

Concerning B zone, we at first regarded that above-mentioned formula (1) appropriate, and the drag coefficient $\xi_B$ is independent of air flow rate, being only the function of water flow discharge. Fig. 3.3 shows the relations between air pressure $P_B$ of B zone and square of air flow rate ($Qa^2$), and we find that $Qa^2$ is almost proportional to $P_B$.

However as shown in Fig. 3.4, we checked the same relation in both logarithm axes, and found that $Qa^2$ is not exactly the function of $P_B$. Furthermore, Fig. 3.5 which shows the relation between the drag coefficient $\xi_B$ and air flow rate Qa indicates that although there is a few disparities, the drag coefficient $\xi_B$ decreases as the air flow rate Qa increases. At this point, we regarded the air flow rate Qa as the function of the drag coefficient $\xi_B$ which was used in above formula (1) as Ohtsuka et al. did.

The reasons for the disparities of the drag coefficient $\xi_B$ were considered below. First, $\xi_B$ was calculated by the measurement valves of Qa and $P_B$, thus the error of measurement would influence the result of calculation due to the expression of ($P_B/Qa^2$), and second, that the peak negative pressure did not occur exactly on the same floor on which the measurement was made. In order to express the $\xi_B$ by the function of Qa, we used approximation of the regression equation in Fig. 3.6 to estimate $\xi_B$ by Qa. Futhermore, we tried to use the regression equation in the case where air flow rate is very small, however, further experimental data need to be collected on this matter.

*3). D zone*

Owing to the hydraulic jump in the building drain pipe, D zone shows the same phenomenon of air resistance as in A zone. Here, we also regarded that the formula (1) appropriate, and if we plot the data of experiments as in Fig. 3.7, the diagram tells us that the drag coefficient $\xi_D$ of D zone in some conditions of main horzontal pipe is only related to water flow discharge. As the result, we confirmed that $\xi_D$ is independent of air flow rate, and we also used the formula (1) to calculate the air pressure $P_D$ of D zone in the present paper.

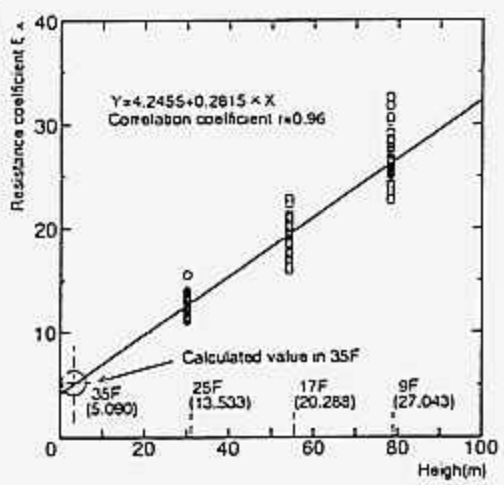



Fig. 3.2 Resistance coefficient of A zone

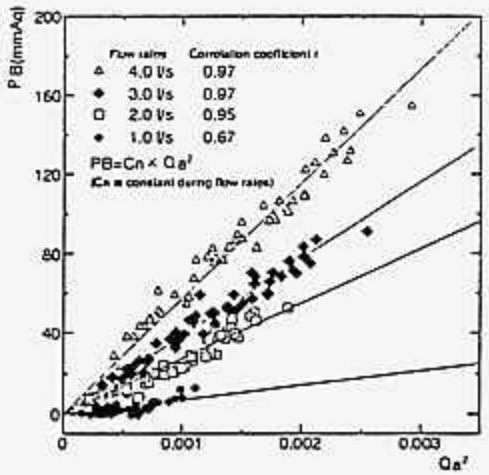



Fig. 3.3 Relation between P B and $Qa^2$

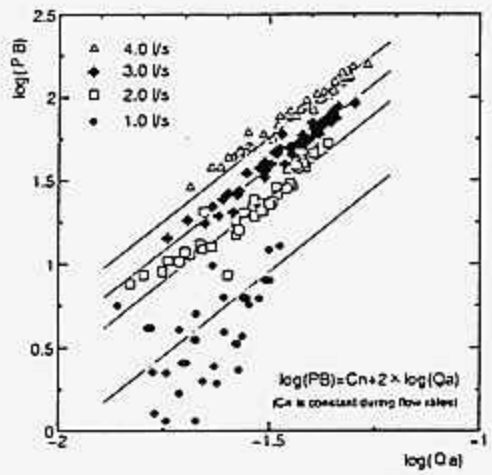



Fig. 3.4 Logarithmic relation between PB and Qa

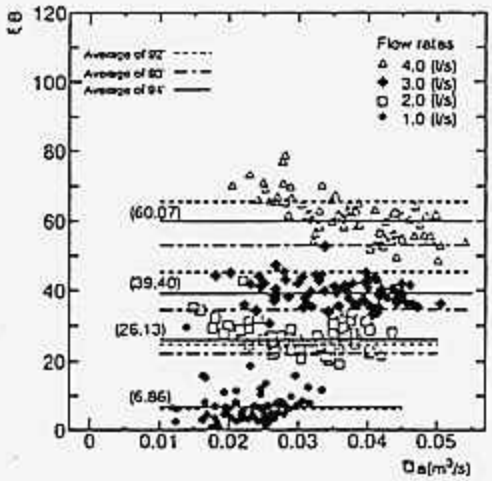



Fig. 3.5 Relation between Qa and ξ B

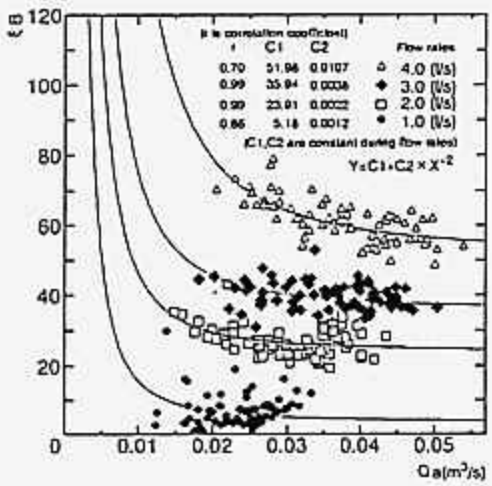



Fig. 3.6 Correlation between Qa and ξ B

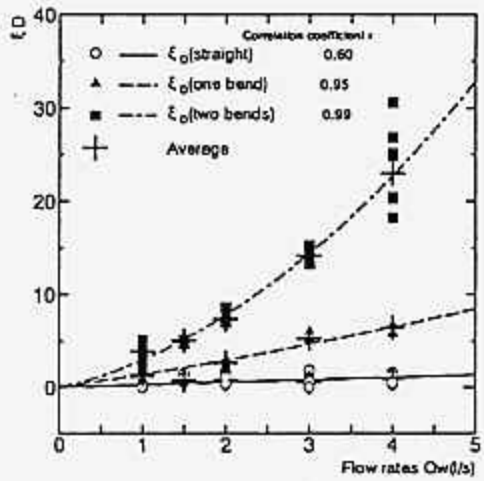
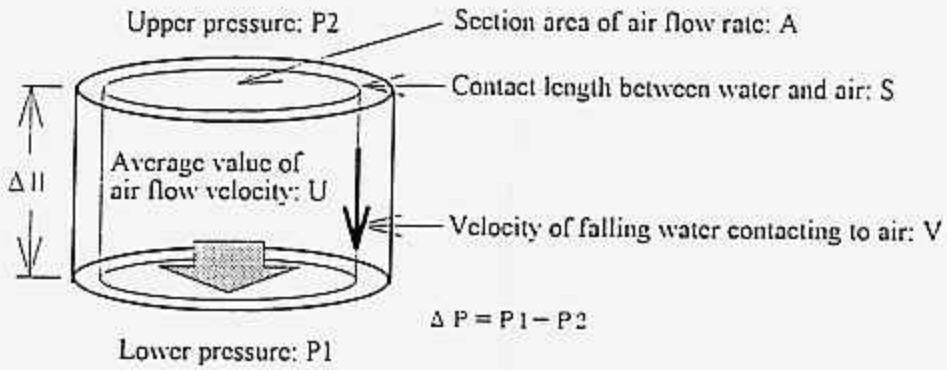



Fig. 3.7 Relation between ξ D and flow rates

*3.2 Formula of Constant Pressure Gradient of C Zone*

Concerning the constant pressure gradient of C zone, we considered the mutual operation between water and air in the drainage stack as sketched in Fig. 3.8 to express the calculation model. Fig. 3.8 shows a model element $\Delta H$ which is a profile of short period of drainage stack.




Note : In spite of the assumption of annular flow in this model, we used the revised non-annular flow to practice the actual calculation.

Fig. 3.8 Profile the constant pressure gradient in C zone

As the diagram indicates, if we consider the vertical balance of stress, the interface of water and air bears the friction stress caused by the velocity difference between V of falling water and U of average air flow. By the same friction stress, the air flow bears the descending stress, and at the same time, the falling water bears the ascending stress which is caused by air flow. However the specific weight ratio between water and air is about 1:1000, and the influence of air flow to falling water could be ignored in some range of air flow rate.

Therefore, we assumed that the cross-sectional area of air flow rate A, the contact length between water and air S, and the velocity of falling water which contact the air flow V are all independent of air flow rate Qa in the present paper. Here we did not deal with the detail of the properties which occurs in the drainage stack, thus we regarded V as a representive velocity which is in the contact face between water and air. To take into consideration the influence of falling water on air flow, we regard $\tau$ as the friction stress per contact area, and S as the average contact length, then the friction stress of air flow is $\tau S \Delta H$ in the model element.

On the other hand, for a continuing property in drainage stack, air flow rate is constant, and the force mentioned above acts on the force which is caused by the balance of pressure difference in the range of model element. Here we regard the cross-sectional area of air flow rate in pipe as A, the pressure of upper part and lower part as $P_1$ and $P_2$, thus it could be expressed as $(P_1 - P_2)A$. That is to say we get the balance equation of force as following:

$$\tau S \Delta H = (P_1 - P_2) A = \Delta P \cdot A \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

If we change the form of equation (2), we get another equation as below;

$$\frac{\Delta P}{\Delta H} = \frac{S}{A}\tau \qquad (3)$$

That is the constant pressure gradient is relative to contact length, cross-sectional area of air flow, and friction stress. According to the above function, it is natural to consider that the friction stress $\tau$ could be expressed by product of the dynamic pressure which is caused by the relative velocity between air and water and the friction coefficient $\varsigma$, thus we assumed the equation below;

$$\tau = \varsigma \frac{\gamma}{2g}(V-U)^2 \qquad (4)$$

Strickly speaking $\varsigma$ in equation (4) is the function of roughness and relative velocity V-U, which is expressed by Reynolds number, and postulated from the analogy of the flow in the drainage stack. The roughness on the interface of falling water is very large as far as the amount of water is sufficient, and as a general rule Reynolds number is very large, therefore, $\varsigma$ is actually regarded as constant. Accordingly, let us substitute equation (3) for equation (4), then we get the following equation.

$$\frac{\Delta P}{\Delta H} = \frac{\varsigma\gamma}{2g}(V-U)^2\frac{S}{A} \qquad (5)$$

Equation (5) indicates that, if the average velocity of air flow is equal to the falling water flow, the constant pressure gradient will be zero. Later, we will use this explanation to calculate the velocity of falling water flow. Here we regarded the air flow rate as Qa, the cross-sectional area of air flow as A, and we get the equation (6) below:

$$\frac{\Delta P}{\Delta H} = \frac{\varsigma\gamma}{2g}\left(V-\frac{Q_a}{A}\right)^2\frac{S}{A} \qquad (6)$$

Next, we could change the form of equation (6) to equation (7 )as below;

$$\frac{\Delta P}{\Delta H} = \frac{\varsigma\gamma}{2gA^2}\cdot\frac{S}{A}(AV-Q_a)^2 \qquad (7)$$

Furthermore, we used the parameter of $\alpha$ and $\beta$ defined below to replace the above equation.

$$\alpha^2 = \frac{\zeta\gamma}{2gA^2} \cdot \frac{S}{A} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (8)$$

$$\beta = AV \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (9)$$

Where parameters $\alpha$ 、$\beta$ are the function of water flow discharge, and are independent of air flow rate as mentioned above. Then equation (7) will take the form as following;

$$\frac{\Delta P}{\Delta H} = \alpha^2(\beta - Q_a)^2 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (10)$$

Therefore, if we could decide the parameters $\alpha$ 、$\beta$ of every discharge of water flow rate from experiments, then it is possible to connect the constant pressure gradient with air flow rate. Finally, we used the equation (11) to verify the result of experiment data per liter of water flow rate.

$$\sqrt{\frac{\Delta P}{\Delta H}} = \alpha(\beta - Q_a) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (11)$$

We use the constant pressure gradient as based on the length L in the present paper. and we calculated the constant pressure gradient by connecting point C and point D in Fig. 3.1 with a straight line.

The relation between the square root of constant pressure gradient and the air flow rate is shown in Fig. 3.9 and Fig. 3.10. Fig 3.9 shows the data of the middle-high (30m) experimental tower, and the data of the former research of Dr. Ohtsuka were ploted in the same diagram. Fig 3.10 shows the data of the high-rise (108m) experimental tower. Let us take notice that the data of the present and former research have the same disparity range as shown in Fig 3.9. This diagram tells us that there is no great influence on the data due to different measurement equipment, in other words, the data of the present paper can be generalized.

In the measurement of the middle-high experiment tower, we performed a large range of air flow rates (about 0～0.03 $m^3/s$) by using orifice and fan. As a result, the data of air flow rate using a high-rise tower shown in Fig 3.10 have the same tendency as the data shown in Fig 3.9 in range from 0.02 $m^3/s$ to 0.03 $m^3/s$. It indicates the possibility that we could simulate the constant pressure gradient in a high-rise tower by using the data of middle-high tower. Actually, when we ploted the data of the high-rise tower and middle-high tower together, they seem correspondently as shown in Fig 3.11.

Comparing of the data of high-rise tower and middle-high tower, we find that the square root of pressure gradient at the discharge flow rate of 2.0 liter per second or less declines constantly, roughly in accordance with the increase in air flow rate. However, in the same condition the decline in the pressure gradient is more gradual when flow rate is 3.0 liters per second or more. The reason for this is that the velocity of falling water is influenced by the change in air flow rate. In the prediction model in the present paper, we used the approximation of regression straight line from Fig 3.11 and the parameters of $\alpha$ 、$\beta$ shown in table 3.1 and Fig 3.12 to calculate the constant pressure gradient.

This brings us to another point. According to the equation (11) and diagram above-mentioned, we could get the value of parameter $\beta$ from the intersection of congression straight line and the axis of air flow rate Qa. As the definition of equation (9), $\beta$ is the product of cross-sectional area of the air flow rate A and the representative velocity of falling water V in the contact surface with air flow.

If we assume that the representative velocity V is near to the average velocity of falling water $V_w$, then the cross-sectional area of air flow rate could be expressed as equation (12), and table 3.1 shows the results of calculation which is in accordance with the relation mentioned above.

$$A = A_p - Q_w / V \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (12)$$

Table 3.1 Experimental constant $\alpha$ , $\beta$ and presumption velocity of falling water

| Water flow rates (l/s) | Experimental constant $\alpha$ | Experimental constant $\beta$ | Presumption velocity of falling water V(m/s) |
|---|---|---|---|
| 1.0 | 42.60 | 0.043 | 5.61 |
| 2.0 | 51.93 | 0.062 | 8.15 |
| 3.0 | 63.54 | 0.069 | 9.17 |
| 4.0 | 75.09 | 0.073 | 9.81 |

However, we must be careful about the result of the calculation since the assumptions on which the calculation is based is not known clearly. In the previous studies it was assumed that the terminal velocity of drainage stack could be determined from water flow rate of discharge and ratio of cross-sectional area of water to cross-sectional area of stack, and the influence of air flow rate was ignored.

However, according to the observation of experiments of high-rise tower which was performed in this study, it is obvious that the generation of a great mount of air flow rate is possible in high-rise buildings, and that may influence the terminal velocity of drainage stack as mentioned above. Therefore, as making a theoretical formula of velocity of falling water in drainage stack in future studies, it is necessary to consider the influence of air flow rate on the velocity of water in case of high-rise buildings.

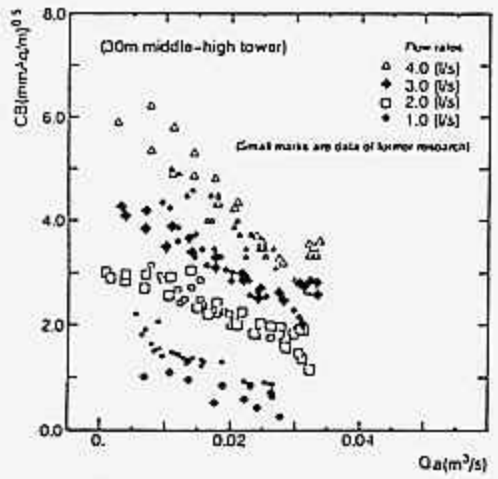



Fig. 3.9 Relation between CB and Qa

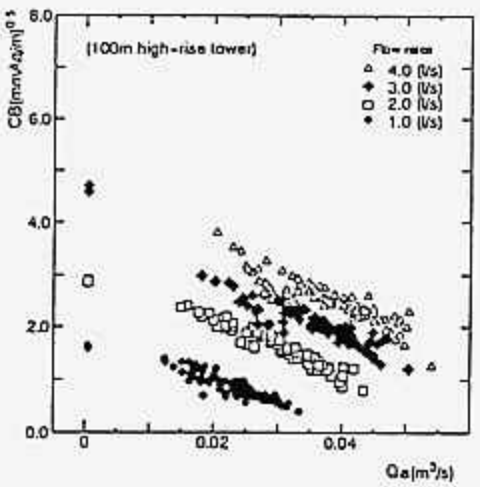



Fig. 3.10 Relation between CB and Qa

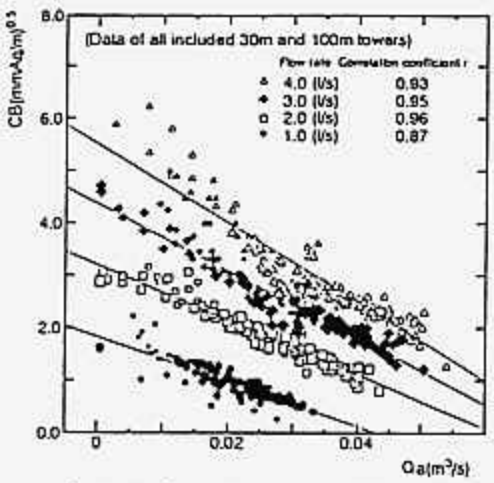



Fig. 3.11 Correlation between CB and Qa

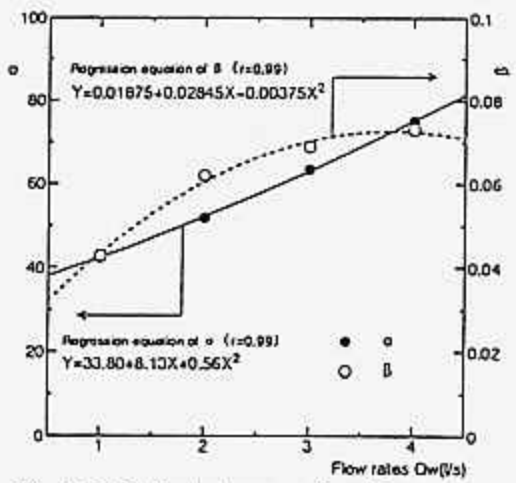



Fig. 3.12 Relation between α, β and flow rates

## 4. Prediction Method of Qa and Pressure Distribution

If we regard the actual water flow in drainage stack from point A to D as shown in Fig 3.1 as a kind of operation fan, then the air flow rate in stack is an air flow phenomenon caused by the sucking force of falling water. In this study, we used the air flow rate as a representative parameter of flow phenomenon in drainage stack, thus the loss of air pressure in every zone of drainage stack would be balanced by the pressure due to the constant pressure gradient in stack, and the prediction model is completed by doing a loop calculation at this balance condition.

*4.1 The Prediction Method*

According to the result of a mount of study, we find the relation between the air flow rate Qa and parameter L which is shown in Fig. 4.1. The diagram indicates that L is the function of Qa, and that is to say the B zone has a simular profile as if the condition of Qa is the same. Fig. 4.2 shows some cases of experiment with a nearly Qa, and the area covered with lines in Fig. 4.2 indicate the same result as above-mentioned.

According to the regular relation between Qa and L, we can be certain that L is the function of pressure $P_B$ , and the relation between L and $P_B$ is shown in Fig. 4.3 with logarithm axis. Therefore, we find that $L^{0.7}$ is the function of $P_B$ regardless of the mount of water discharged. At this point, when we divide the resistant coefficient $\xi_B$ by $L^{0.7}$ , we find that ( $\xi_B/L^{0.7}$) is more strickly relative to Qa shown in Fig. 4.4 than Fig. 3.6.That is to say $\xi_B$ could be expressed by the facter of ($C/Qa^2$), here C is a constant according to the water flow discharge. Thus we get the equation as below:

$$\xi_B = C \times L^{0.7} \times Q_a^{-2} \quad \cdots\cdots (13)$$

( $C$ is a constant according to the water flow rates )

If we substitute equation (13) for equation (1), then we get a very simple equation as following:

$$P_B = C \times L^{0.7} \quad \cdots\cdots (14)$$

( $C$ is a constant according to the water flow rates )

In other words, we could predict $P_B$ only by using the function of $L^{0.7}$ . Accordingly, the prediction of $P_B$ becomes more accurate in practice by using the parameter L.

As a result of the above mentioned study, it is possible to predict the air pressure distribution in drainage stack by the following process shown in Fig. 4.5 and Fig. 4.6. First of all, we have to set the discharge floor height FL, water flow rate $Q_w$, and the condition of the building drain pipe. Secondly, adequately to take an assumption of Qa, and use Fig. 3.6, Fig. 3.7, Fig. 3.13, equation (1) and equation (11) to calculate $\xi_B$ , $P_D$, L, $P_B$ and constant pressure gradient, then we could get one pressure of A zone as $P_{A1}$. On the other hand, using equation (1) with the assumption of same value of Qa, we could obtain another pressure of A zone as $P_{A2}$ . Generally, $P_{A1}$ could not be equal to $P_{A2}$ , thus we revise the value of Qa, and do a loop calculation to the end until the condition of $|P_{A1} - P_{A2}| \leq \varepsilon$ was matched. At the end of above loop calculation, we could obtain the exact air flow rate of Qa which is under this condition.

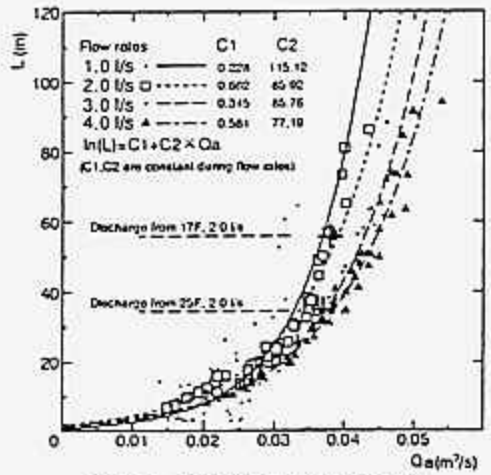



Fig. 4.1 Relation between Qa and L

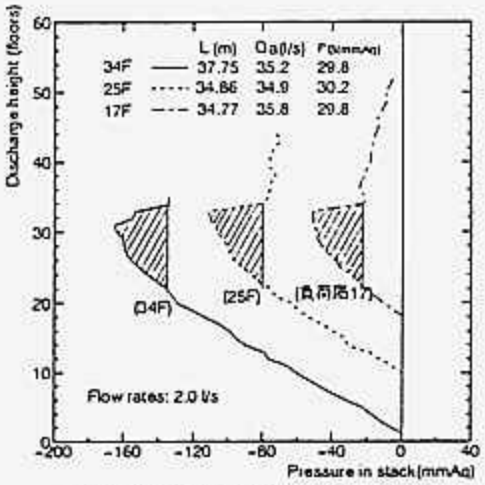



Fig. 4.2 Examples of experiment result

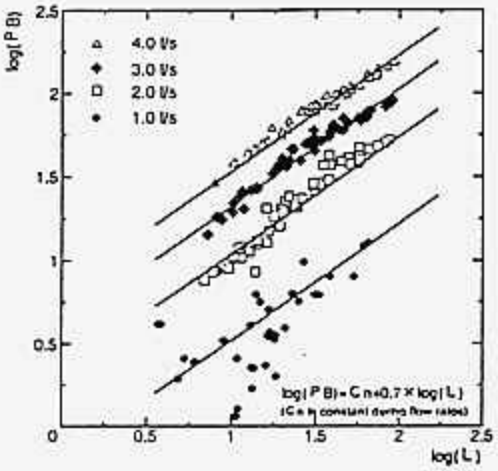



Fig. 4.3 Logarithmic relation between PB and L

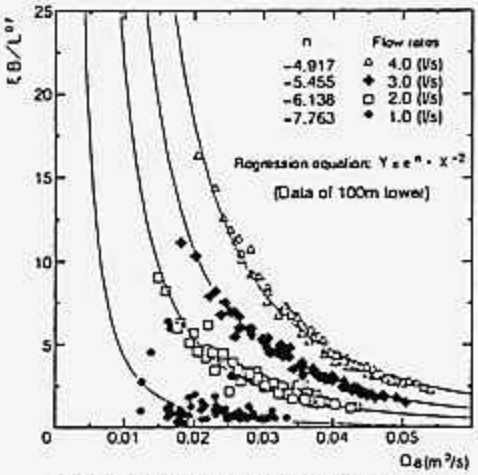



Fig. 4.4 Relation between Qa and ξ B/L^n

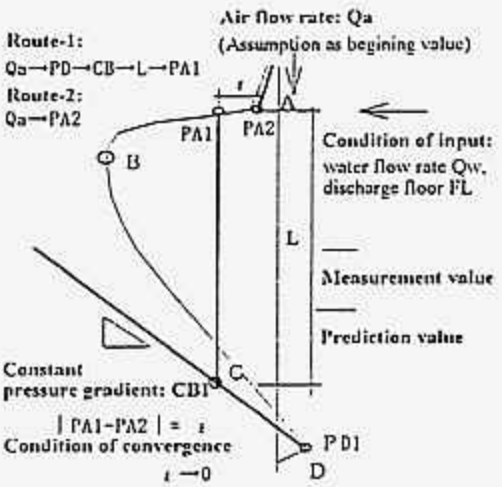



Fig. 4.5 Model of prediction

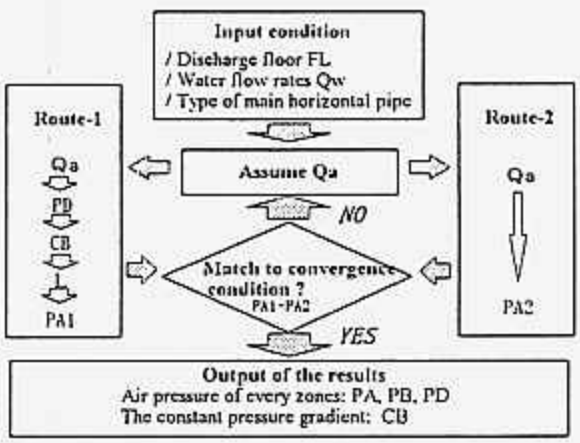



Fig. 4.6 Flow chart of prediction process

*4.2 Expansion of Prediction Model*

The profile of air pressure distribution in a drainage stack is characteristic as mentioned in paragraph 3.1, therefore, as shownin Fig. 4.7 we expanded the model to develope the study of prediction method.

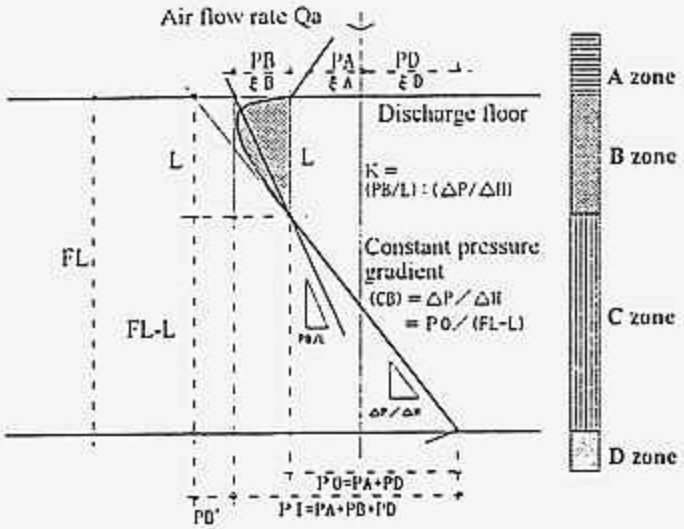



Fig. 4.7 Model of air pressure prediction method in drainage stack

In every zone of the stack, there is geometrical relation among these parameters shown in Fig. 4.7, thus we can express the constant pressure gradient CB by the equation (15) as below;

$$CB = \frac{\Delta P}{\Delta H} = \frac{P_A - P_D}{FL - L} = \frac{P_O}{FL - L} \quad \cdots\cdots (15)$$

$$(X = P_O / P_I, \qquad CB = \Delta P / \Delta H)$$

According to the conclusion of this study mentioned in paragraph 3.3, if we fix the value of Qa, then $P_B$, L, CB will be obtained. That is to say PB/L and CB will be in proportion as shown in Fig. 4.7 in the condition of the same Qa, and the function was expressed by equation (16) as below;

$$K = \frac{P_B / L}{CB} \quad \cdots\cdots (16)$$

($K$: Ratio of $P_B$/L and CB, CB is the constant of pressure gradient)

The relation between constant K and Qa obtained as a result of the experiment is shown in Fig. 4.8. This diagram indicates that the value of K is from 0 to 1, and if we exclude the extreme condition, K will be a constant value about 0.4 in average. Concerning parameter L, there is a definitive property, as if $P_A$=$P_D$=0, then L will be equal to discharge heigh FL, on the contrary, if $P_A$ and $P_D$ are very large compared to $P_B$ , L will be near to 0. At this point we used the geometric relation to express the dimensionless number of X($P_O$/$P_I$) and Y(L/FL) as following;

$$X = \frac{P_o}{P_i} = \frac{CB(FL - L)}{P_B + CB(FL - L)} \quad \cdots\cdots (17)$$

$$(X = Po / P_I, \qquad CB = \Delta P / \Delta H)$$

Here we subsitute K above for equation (16), and we get the equation (18) as below;

$$X = \frac{P_o}{P_i} = \frac{CB(1 - Y)}{\frac{P_B}{L} \cdot Y + CB(1 - Y)} = \frac{(1 - Y)}{K \cdot Y + (1 - Y)} \quad \cdots\cdots (18)$$

$$(X = Po / P_I, \quad Y = L / FL, \quad CB = \Delta P / \Delta H), K = P_B / (CB \cdot L)$$

$$\therefore Y = 1 \Rightarrow X = 0 \Leftrightarrow Y = 0 \Rightarrow X = 1$$

The equation (18) indicates that, if X is equal to 0, then Y will be 1, that is L is equal to the discharge heigh FL. On the contrary, if X is equal to 1, then Y will be 0.That has been verified by the results of the experiment. Therefore, it is clear that dimensionless number of X and Y have some dependent relation.

Furthermore, due to K is relative to dimensionless number of X and Y, the relation of K-Y and K-X was shown in Fig. 4.9 and Fig. 4.10, and the regression line would be expressed as equation (19) as below;

$$K = \frac{Y}{1 + Y} \quad \cdots\cdots (19)$$

Here we substitute equation (19) for equation (18), then we get the equation (20) as below;

$$X = \frac{(1 - Y)}{K \cdot Y + (1 - Y)} = \frac{(1 - Y)}{\frac{Y}{1 + Y} \cdot Y + (1 - Y)} = 1 - Y^2 \quad \cdots\cdots (20)$$

$$(X = Po / P_I, \quad Y = L / FL, \quad K = P_B / (CB \cdot L)$$

In the equation (20), we expressed the function of X and Y as in Fig. 4.11 to show the relation of the two dimensionless numbers. We ploted the data of the experiment to in Fig. 4.11, and it is clear that the function of X and Y is comparable to the experiment as shown in Fig. 4.12. According to the conclusion given in paragraph 3.3 above, the calculation method of parameter L is derived from the function of Qa. The question is, if the prediction is beyond the scope of experiment, then we can not obtain the solution by the regression function reasonably.

Therefore, we used equation (20) as the function for the prediction model. We found that the prediction model will be satisfactorily applicable to any heigh of water discharge.

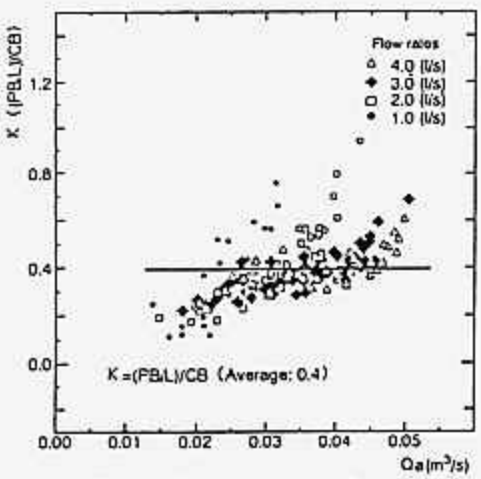



Fig. 4.8 Relation between Qa and K

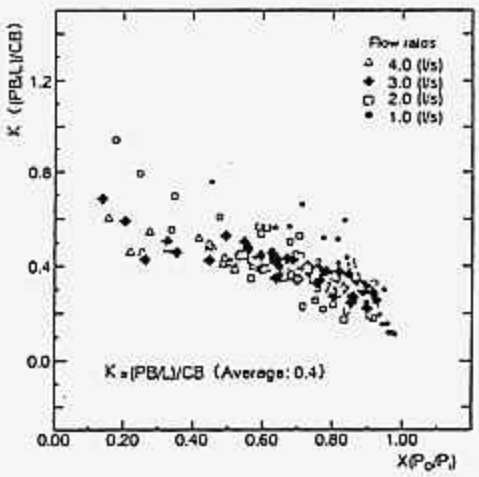



Fig. 4.9 Relation between $X(P_o/P_j)$ and K

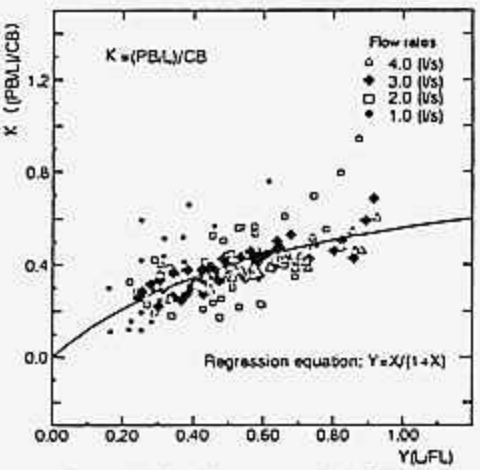



Fig. 4.10 Relation between Y(L/FL) and K

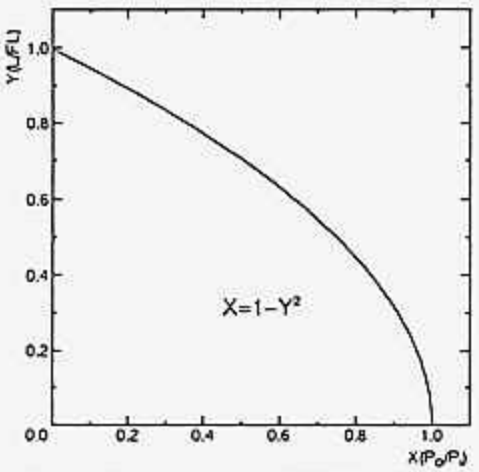



Fig. 4.11 Presumption curve of $X(P_o/P_j)$ and Y(L/FL)

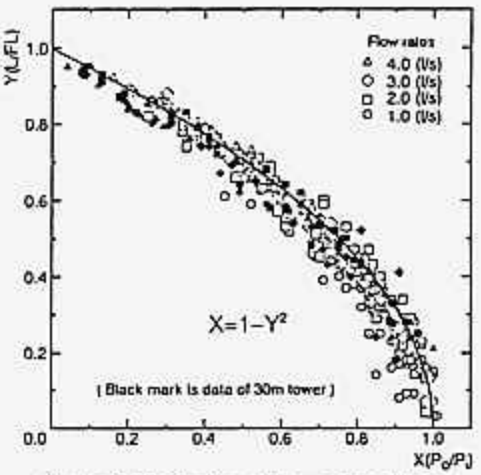



Fig. 4.12 Verification with experiment data

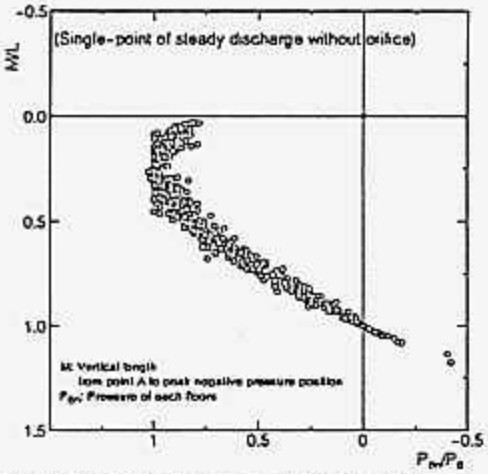



Fig. 4.13 Profile of pressure distribution in B zone

*4.3 Prediction of the Curve of Air Pressure Distribution in B Zone*

In this study, it is important to predict the peak negative pressure in B zone as practicality, and the peak negative pressure position is the crux of this prediction model.

Therefore, it is nessary to predict the curve of air pressure distribution in B zone.At this point, we find the relation between dimensionless number of $P_{Bn}/P_B$ ($P_B$ of every floor divided by $P_B$ in peak negative pressure position) and $L_n/L$ (distance from discharge position to every floor divided by L), and we ploted the data of experiment in Fig. 4.13. This diagram indicates that the pressure distribution in B zone is almost similar. We divided the curve into two parts in the point M which is about 0.235L from the discharge floor.

However, here we must pay attention to the assumption the K is independent of Qa and it is not strickly satisfactory in extreme condictions as shown in Fig. 4.8. It may be worth to study this more deeply in the future. Anyway, according to the observation above, we offer a similar profile to predict the curve of air pressure distribution of B zone in general condition.

Fig. 4.14 shows the outline of the calculation model from point A to point C. Here we regarded point M as a base point of the profile, and the upper part from point M to A can be expressed by the equation as below;

$$P = P_B - \left(\frac{y}{0.235L}\right)^n \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (21)$$

By the method of least squares, we could obtain the value of n in equation (21), and then prediction formula of the upper part of profile is obtained.

Therefore, the equation of the lower part of the profile from point B to point C can be satisfactorily applicable to four boundary conditions. We obtained a cubic equation to predict this part of the profile. Using the above mentioned method, we can predict the curve of air pressure distribution of B zone from point A through point B to point C.

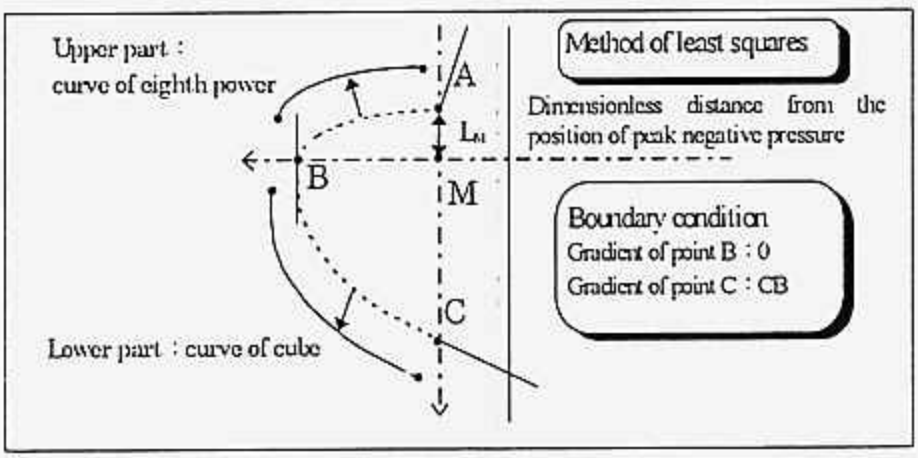



Fig. 4.14 Prediction method of air pressure distribution curve in B zone

*4.4 Prediction of Air Pressure Distribution*

Here we plot the profile of air pressure distribution in the results of both calculated value and measurement data, Fig. 4.15 ~ Fig. 4.18 show the comparison profile in the high-rise building. These figures indicate that the calculated results are comparable to the experiment. Furthermore, we compared the calculated results with all kind of experiments in this study excluded the data of very small air flow rate, and the comparison data are shown in Fig. 4.19~Fig. 4.24. In spite of a few disparities in the middle-high tower, as a total observation of the comparation, this model can satisfactorily to recapture the results of experiment.

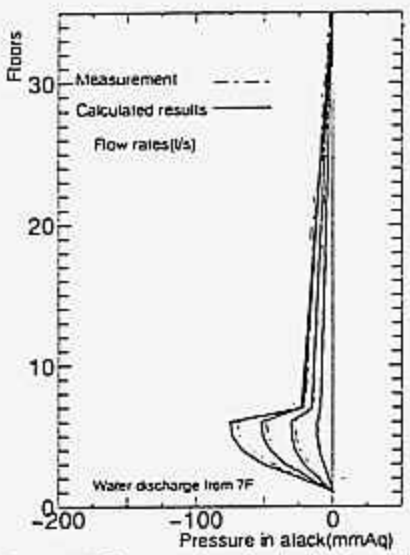


Fig. 4.15 Comparation of calculated results

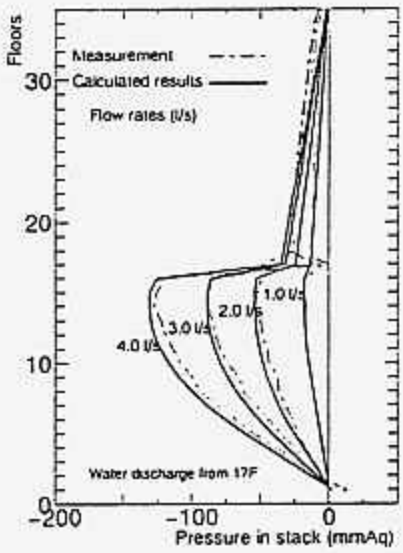


Fig. 4.16 Comparation of calculated results

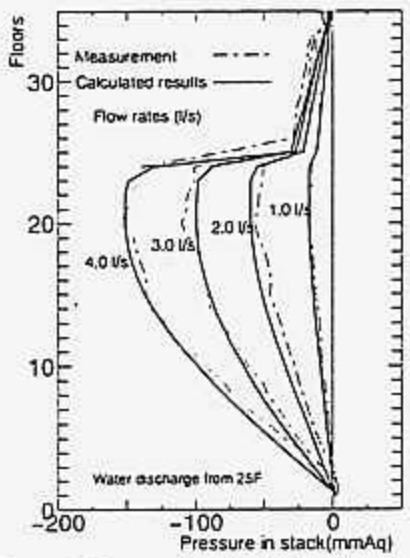


Fig. 4.17 Comparation of calculated results

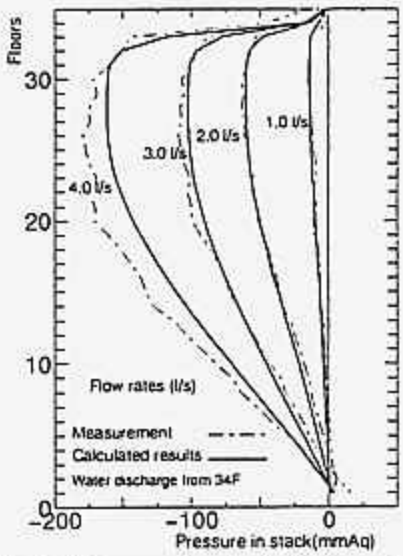


Fig. 4.18 Comparation of calculated results

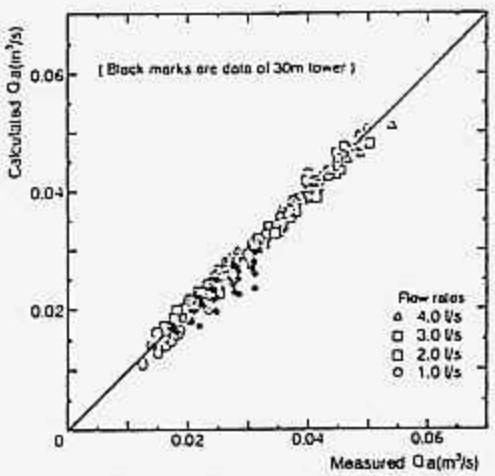



Fig. 4.19 Calculated results of Qa

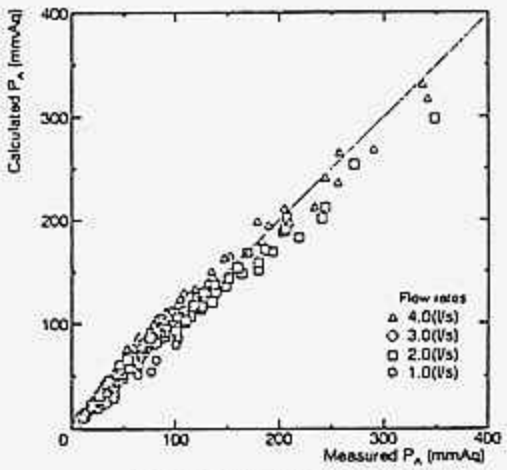



Fig. 4.20 Calculated results of $P_A$

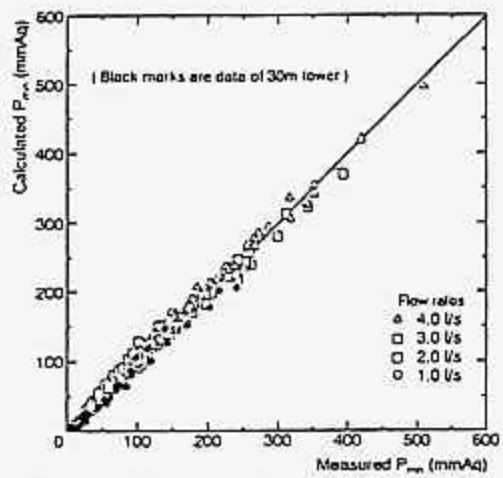



Fig. 4.21 Calculated results of peak negative pressure

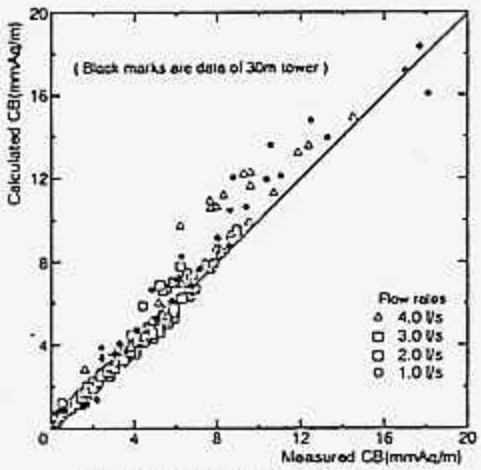



Fig. 4.22 Calculated results of CB

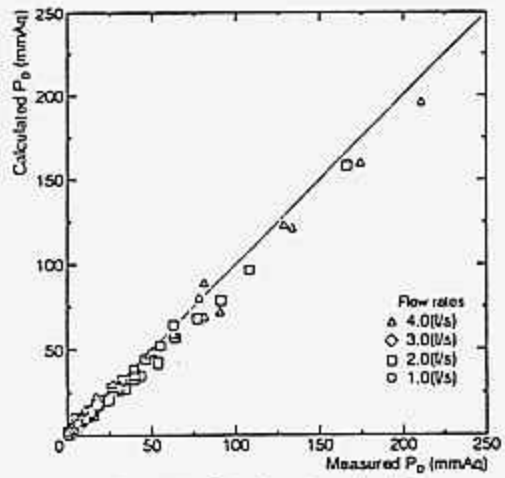



Fig. 4.23 Calculated results of $P_D$

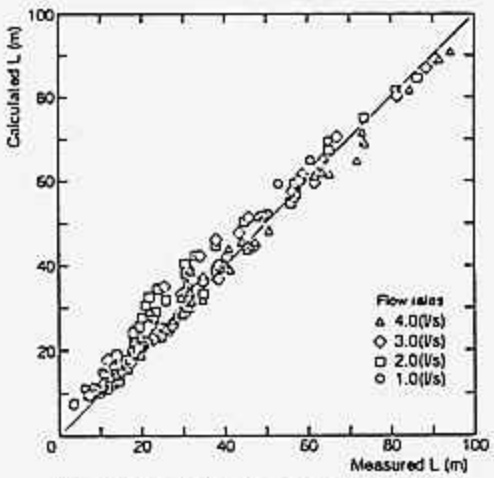



Fig. 4.24 Calculated results of parameter L

## 5. Conclusions

Concerning the study of air pressure distribution of drainage stack using JIS joint (DT joint) when water discharge is up to 4.0 l/s, in case of single-point steady water discharge, we reached the following conclusions;

1). Larger peak negative air pressure was observed in the high-rise buildings than in the middle-high buildings using 30m high experimental towers.

2). The distance between the floor on which the peak negative pressure was observed and the discharge floor increases in proportion to the increase in air flow rate. This also has not been observed in the 30m high experimental towers.

3). $P_A$ can be expressed by a value obtained from multiplying the coefficient $\xi_A$ by the dynamic pressure of air velocity. $P_D$ is expressed likewise $\xi_D$ multiplied by the dynamic pressure of air velocity. Here $\xi_A$ is determined by the drainage system, and $\xi_D$ is by the drainage system and water flow rate.

4). According to the prediction model postulated in this paper, the square root of constant pressure gradient in C zone can be expressed in terms of a linear equation of air flow rate. It matches the results of the experiment fairly well.

5). The air pressure distribution of a drainage stack is a function of Qa, and we offered a similar profile to predict the curve of air pressure distribution of B zone in general.

6). The prediction model of air pressure distribution of a drainage stack presented in this paper is satisfactorily applicable to any discharge height, which includs high-rise and middle-high buildings.

Table of symbols and Units :

| | |
|---|---|
| P : Pressure in stack (mmAq) | $\xi$ : Drag coefficient |
| $P_A$: Pressure of A zone | $\xi_A$ : Drag coefficient of A zone |
| $P_B$: Pressure of B zone | $\xi_B$ : Drag coefficient of B zone |
| $P_D$: Pressure of D zone | $\xi_D$ : Drag coefficient of D zone |
| $\gamma$ : Specific weight of air | g: Acceleration of gravity |
| $V_a$: Velocity of air flow in stack vent (m/s) | $V_w$ : Velocity of falling water (m/s) |
| Qa:Air flow rate in stack vent ($m^3$/s) | A: Section area of air flow rate ($m^2$) |
| S: Contact length between water and air (m) | U: Average velocity of air in C zone(m/s) |
| V: Velocity of falling water contacting to air (m/s) | $\varepsilon$ : Allowable error in convergent condition |
| $\Delta$H : Length of model element of stack (m) | $\Delta$P: Pressure difference of in model element(mmAq) |
| $\tau$ : Friction stress (mmAq) | $\varsigma$: Friction factor |
| L: Vertical length of B zone (m) | FL: Discharge height (m) |
| $\alpha$ 、 $\beta$ : Experimental constant of the constant pressure gradient model | |
| CB: The constant pressure gradient $\Delta P/\Delta H$ (mmAq/m) | |

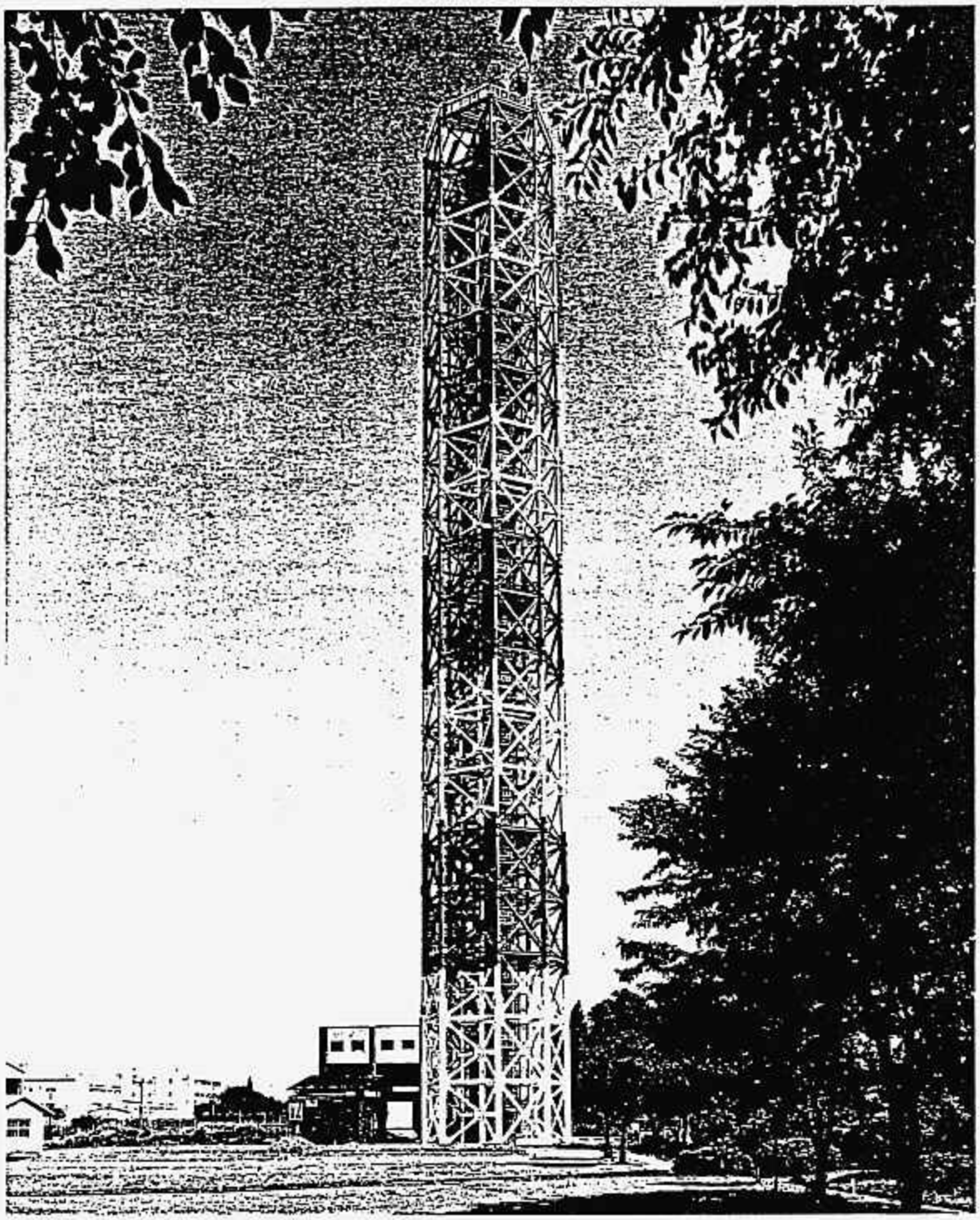
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# 超高層住宅実験タワー



住宅都市整備公団
Corporation (HUDC)

The original photograph of Fig. 2.1

# Topic B5

## Septic Tank Drainage Fields- an Investigation into the Applicability of Percolation Testing

J. Griggs, J. Powell, Dr. J. Hall, United Kingdom

# CIB W62 Paper

SSIV Bildungszentrum, Lostorf, Switzerland, September 1996.

## Field trials of percolation tests for septic tank drainage fields

**JC Griggs BSc, J Hall BEng PhD and JJM Powell MSc CEng MICE**

This paper is to be presented at the CIB W62 symposium on water supplies and drainage by John Griggs

Building Research Establishment

## CIB W62 symposium at SSIV Bildungszentrum, Lostorf, Switzerland, September 1996.

# Field trials of percolation tests for septic tank drainage fields

by J C Griggs BSc, J Hall BEng PhD and J J M Powell MSc CEng MICE

**Summary**

In England and Wales there are estimated to be over 800,000 cesspools, septic tanks and small sewage treatment works. Of these, the most common are septic tanks. The outflow from a septic tank is a low grade material, it has only been subject to settlement and some degree of anaerobic digestion, and its disposal can create contamination problems and pollution leading to health risks.

An assessment of the soil into which the proposed discharge will be made is by a percolation test which determines if it is suitable. Such assessments may be required by relevant authorities including building inspectors. In 1995, BRE sought the views of local authority building control departments in England and Wales on percolation tests. From the information gathered there was no consistent approach. There was a diversity of opinion over which percolation test specification should be used and what tolerances on measurement were applied.

Trials, discussed in this paper, were conducted at a site in central England to compare various percolation test procedures and specifications. The results from the tests performed were very varied and often ambiguous.

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# Field trials of percolation tests for septic tank drainage fields

by J C Griggs BSc, J Hall BEng PhD and J J M Powell MSc CEng MICE

## 1 Introduction

In England and Wales there are estimated to be over 800,000 cesspools, septic tanks and small sewage treatment works. Of these, the most common are septic tanks. The outflow from a septic tank is a low grade material, it has only been subject to settlement and some degree of anaerobic digestion, and its disposal can create contamination problems and pollution leading to health risks.

A percolation test may be used to determine the suitability of the ground into which effluent is to be discharged. The percolation rate for septic tank discharges must be large enough to allow the effluent to pass through without causing ponding on the surface, but be low enough to effect effluent cleansing and pollutant attenuation by physical, chemical and biological processes.

There is a diversity of ground evaluation methods that determine the suitability of soils for discharge from septic tanks by means of a percolation test. The percolation tests specified vary considerably in their complexity, duration and ease of performing.

In 1995, BRE sought the views of local authority building control departments in England and Wales on percolation tests. It was found that the application and test procedures for percolation tests were not consistent amongst the local authorities and, hence, a standard test with clearer procedures should be developed.

## 2 Current Percolation tests

Table 1 summarises the tests most commonly used in the UK and Ireland. Other countries are known to have a variety of test methods and specifications.

TABLE 1

| Publication date and country | Publication name and field trial test number | Key points of test specification | Test criteria or use of results from test |
|---|---|---|---|
| 1952 UK | BS code of practice CP 303 Surface water and subsoil drainage[1] | Dig trial pits and measure rate at which water soaks away. Spacing of subsoil drains dependant on soil classification and based upon War Office publication 'Military Engineering' Vol 5. | The test is used 'Where any doubt exists as to the suitability of the ground...' There are no test criteria. |

| | | | |
|---|---|---|---|
| 1972 UK | BS code of practice CP 302 Small sewerage treatment works[2]<br><br>TEST 2 | Dig 300mm square hole 600mm deep. Fill with water and allow to drain overnight. Next day fill to at least 250mm and observe time for water to seep away completely. After three tests, calculate average water level drop in time per mm. | For each second to fall 1mm a land area of 0.5m$^2$ per person is required. |
| 1973 UK | BRE Digest 151 Soakaways[3] (now withdrawn)<br><br>TEST 8 | Dig 150mm dia hole at 1 and 2m deep, use 300mm of water, 2 or 3 times to get average time to completely drain | Times up to 4800 minutes and areas up to 400m$^2$ are specified. The time obtained, in minutes, is used along with a graph of six curves ( one for each diameter of soakaway from 1 to 3.5m, ) plotted against the area to be drained. Guidance is given on the selection of size of soakaways. In soils with low permeability it is suggested that multiple small soakaways are used. |
| 1983 UK | BS 6297 Design and installation of small sewage treatment works and cesspools[4]<br><br>TEST 3 | 300mm square hole 250mm deep below the proposed invert level of the land drain ( or if deep, a 300mm dia hole may be used). Fill with water and allow to drain overnight. Next day repeat and observe time for water to seep away completely. After three tests, calculate average water level drop in time per mm. | The percolation value must be less than 140 seconds. For values from 140 to 100seconds underdrains are desirable. Guidance is given on the construction of soakaway pits in porous soil and subsurface irrigation systems in less porous soils. The percolation value obtained is used in the equation<br>A = PxVx0.25<br>where A = floor area of drainage trench, P = number of persons and V is the obtained percolation rate. |
| 1985 UK | BS 8301 Code of practice for Building Drainage[5] | Referred to Digest 151 and BS 6297 for specifications | |
| 1991 Ireland | National Standards Authority of Ireland (NSAI) Standard Recommendation (SR) 6 Septic tank systems Recommendations for domestic effluent treatment and disposal from a single dwelling house[6]<br><br>TEST 1 | Site suitability test:<br>Dig one (or two holes) 1m X 1m X 2m deep. Fill hole with water, cover and leave for at least 48 hrs. Measure depth of water left in hole. There shall be no more than 1m of water left in the hole.<br><br>Percolation test:<br>Dig at least two holes approximately 0.3m X 0.3m X at least 0.4m deep. Score bottom and sides with blade of a knife. Fill to at least 300mm until subsoil is swollen and saturated. Record the time taken for the water level to drop 100mm. Divide by 4 to obtain time (T) for 25mm drop in level. T must not be less than 5 seconds or greater than 60 seconds. | Suitability test:<br>There shall be no more than 1m of water left in the hole.<br><br>Percolation test:<br>T must not be less than 5 seconds or greater than 60 seconds. Values less than 5 seconds may indicate a percolation rate that is too fast, possibly leading to pollution of the groundwater. Values greater than 30 seconds may indicate a percolation rate that is too slow, possibly leading to ponding of effluent at the site of the percolation area. |
| 1991 UK | BRE Digest 365[7] (BRE Digest 151 withdrawn)<br><br>TEST 5 | Dig trial pit same depth as full-sized soakaway (normally 1.5 to 2.5m), 0.3 to 1m wide and 1 to 3 m long, trimmed square. Fill pit rapidly and allow to drain 3 times on the same or consecutive days. Calculate infiltration rate (f) for water to fall from 75% to 25% of the pit's effective storage depth. | Design procedure uses I-O=S where I = inflow, O = outflow and S = required storage, I=AxR where A = impermeable area drained and R = rainfall and O=axfxD where a = effective area, f = determined infiltration rate and D = duration of storm. |

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| | | | |
|---|---|---|---|
| 1992 UK | NHBC Standards[8] chapter 5.3 "Drainage below ground"<br><br>TEST 4 | Referred to BRE Digest 151 test for specifications | Times up to 4800 minutes and areas up to 400m$^2$ are specified. The time obtained, in minutes, is used along with a graph of six curves ( one for each diameter of soakaway from 1 to 3.5m, ) plotted against the area to be drained. Guidance is given on the selection of size of soakaways. In soils with low permeability it is suggested that multiple small soakaways are used. |
| 1995 UK | NHBC Standards[9] chapter 5.3 "Drainage below ground" | **Septic tank installations**<br>Simplified version of unamended BS 6297 test<br>**Surface water soakaways**<br>Referred to BRE Digest 151 test or Digest 365 specifications | See respective tests above. |

This is the situation that currently exists in England and Wales. In other countries percolation tests are performed for similar reasons but are different to the current UK and Irish test specifications and requirements.

The test procedure in National Standards Authority of Ireland (NSAI) Standard Recommendation 6:1991 is very comprehensive. It specifies a percolation test hole, similar to that in BS 6297, but it is preceded by a large trial hole test to determine any effects associated with the water table. It is the only test procedure examined in this study to specify minimum percolation rates to ensure that cleansing of the effluent occurs.

## 3 Percolation tests proposed in other documents

The test in British Standard BS 6297 has been in use for twelve years (and in its amended form for five of those years), and its suitability has been questioned by the UK users of the Standard. A proposal was recently made, by a member of the BSI committee B/505/40/1 responsible for the Standard, for a revised percolation test and sizing calculation[10]. In this draft test, holes four times the area, but ten times the volume, of those in BS 6297 were specified, along with a test procedure based upon that given in BRE Digest 365, with the exception that only two fillings of water were used. The test is summarised in table 2.

Table 2

| Publication date | Publication name and field trial test number | Key points of test | Use of results |
|---|---|---|---|
| 1995 | **Rees proposal for revision to BS 6297** Based upon BS6297 DIN4261 SR6 & BRE digest 365<br><br>TEST 7 | Create trial hole(s) 0.6 X 0.6m X 0.6m deep (below pipe). Fill with water and allow to drain. Refill to depth of 0.6m. Time fall in water level from 0.45m to 0.15m in all holes. Longest time (T) to be used in calculation. | The percolation rate T, in hours, is used in the equation **L = 0.75TxP** where L= required length of trench and P= number of people. |

Previously, a different approach had been proposed by researchers at HR Wallingford[11] at the end of 1991. This procedure does not specify a particular hole size but a hole is progressively enlarged and flowrates are recorded that enable constant water levels (heads) to be maintained. By solving simultaneous equations infiltration coefficients can be obtained. The test procedure is set out in table 3.

Table 3

| Publication date | Publication name and field trial test number | Outline test procedure | Use of results |
|---|---|---|---|
| 1991 | The hydraulic design and performance of soakaways HR Wallingford, extract from conclusions and recommendations<br><br>TEST 9 | A soakage pit is excavated and a soakage test conducted.<br>This involves filling the pit with water and keeping it full for a period of time. The flow rate to maintain a constant water level is found by:<br>either noting the average rate at which water needs to be added, or, by periodically measuring the time taken for the water level to fall by a small amount.<br>Once steady conditions are established, the soakage pit can be allowed to drain and the falling levels may be monitored. Subsequently, the soakage pit excavation is increased in size and the test is repeated. | By using simultaneous equations for two sets of results infiltration coefficients can be obtained. This data is then to be used in guidelines which are to be developed for designers of soakaways. |

The current test specified in Digest 365 is considered to be effective and comprehensive by UK experts. To perform the test a mechanical digger and water bowser are generally required. Thus it may be expensive, and not easy to carry out on restricted sites or where there are limited water supplies.

A CIRIA report[12] on infiltration drainage recommends an infiltration, or percolation, test for soakaways which is based upon BRE Digest 365. The test procedure in this CIRIA report is summarised in table 4.

Table 4

| Publication date | Publication name and field trial test number | Key points of test | Use of results |
|---|---|---|---|
| 1995 | Infiltration drainage CIRIA Funders Report IP/5 Section 4.3.5<br><br>Based upon BRE Digest 365<br><br>TEST 6 | **Location:**<br>If any dimension of the system is >25m then a test pit is required every 25m (if the soil is fissured, the distance between test pits should be reduced to 10m).<br>Size of pits:<br>The depth of the anticipated system and:<br>a) if the area to be drained is <100m$^2$ the water volume must be at least 0.5m$^3$, or<br>b) if the area to be drained is >100m$^2$ the water volume must be at least 2m$^3$<br>Fill (*) with water, record the water level against time.<br>Repeat the test two or more times, preferably on the same day.<br>[(*) However, do not completely fill the hole if not enough water can be supplied or it is anticipated that infiltration will only occur at the lowest layers.] | As in BRE digest 365 |

## 4 Practical comparison of percolation test results

### *4.1 Trials at Gloucestershire, England 1996*

In the Spring of 1996, BRE conducted trials in Gloucestershire to compare the specifications and requirements of various percolation tests. Tests were compared with each other on the same plot of land over a period of four days. A test devised by BRE's Geotechnics Division was also compared, this is summarised in table 5. The details of the other tests are given in sections 2 and 3.

Table 5

| Publication date | Publication name and field trial test number | Key points of test | Use of results |
|---|---|---|---|
| - | BRE Geotechnics test<br><br>TEST 10 | **Dig test hole 0.3m X 0.3m X 0.3m** below the proposed level of the invert of the inflow pipe. Fill with water and record the rate of fall of the water level to within about 10mm of the base.<br>Remove soil of about 0.5m depth and repeat test at the lower level. Continue to remove soil and repeat test until the base of the test hole is at least 600mm below the proposed invert level of any distribution pipe or possible underdrain.<br><br>Such test holes should be dug at various points over the proposed site. | The progressive nature of this test enables a profile of the percolation rates of the soil to be made. This can be used to determine the best distribution layout arrangement for the drainage field. |

The percolation rates determined using the test procedures are expressed in various ways and in different units. The results of the field trials are shown in figure 1. For ease of comparison all the resulting percolation rates have been converted to metres per second.

The trials revealed wide inconsistencies in results between the various tests which would lead to different size drainage fields. In general, the variation in percolation rate was less for the greater depths of hole, however the least variation was a factor of about 20 (at 2m) rising to around 100 just below 0.5m. The tests were all conducted in the same time period and thus the variation in results does not take into account seasonal variations which are likely to be significant. Such variations show the limitation of site percolation tests and the results obtained confirm experience in the USA[13] where considerable variation in percolation test results within single sites has also been found.

Examination of individual tests performed at different depths reveals considerable differences, but may reflect the local variations of the soil profile. Whilst the BRE Digest 151 test produced identical percolation rates at 1m and 2m below the surface, both the CIRIA and BRE Geotechnics tests showed lower percolation rates below 1m than those above 1m. The difference could be due to different ground formations or the effects of the auger used in the Digest 151 test modifying the surface of the test hole by smearing the soil particles. The large deep pits produced the lowest percolation rates. It is possible that this was due to the soil structure and type around 2m below the surface, or that the soil was saturated by the larger volume of water used in the test.

In the current study, the scatter of the results in figure 1 may be explained, to some extent, by the structure of the ground. Figure 2 shows the soil in a well-weathered trench, scaled against a 1m rule, nearby the trial site. It clearly shows fissures and various porous layers within the top one metre. Below 1m the soil structure appears to be more consistent.

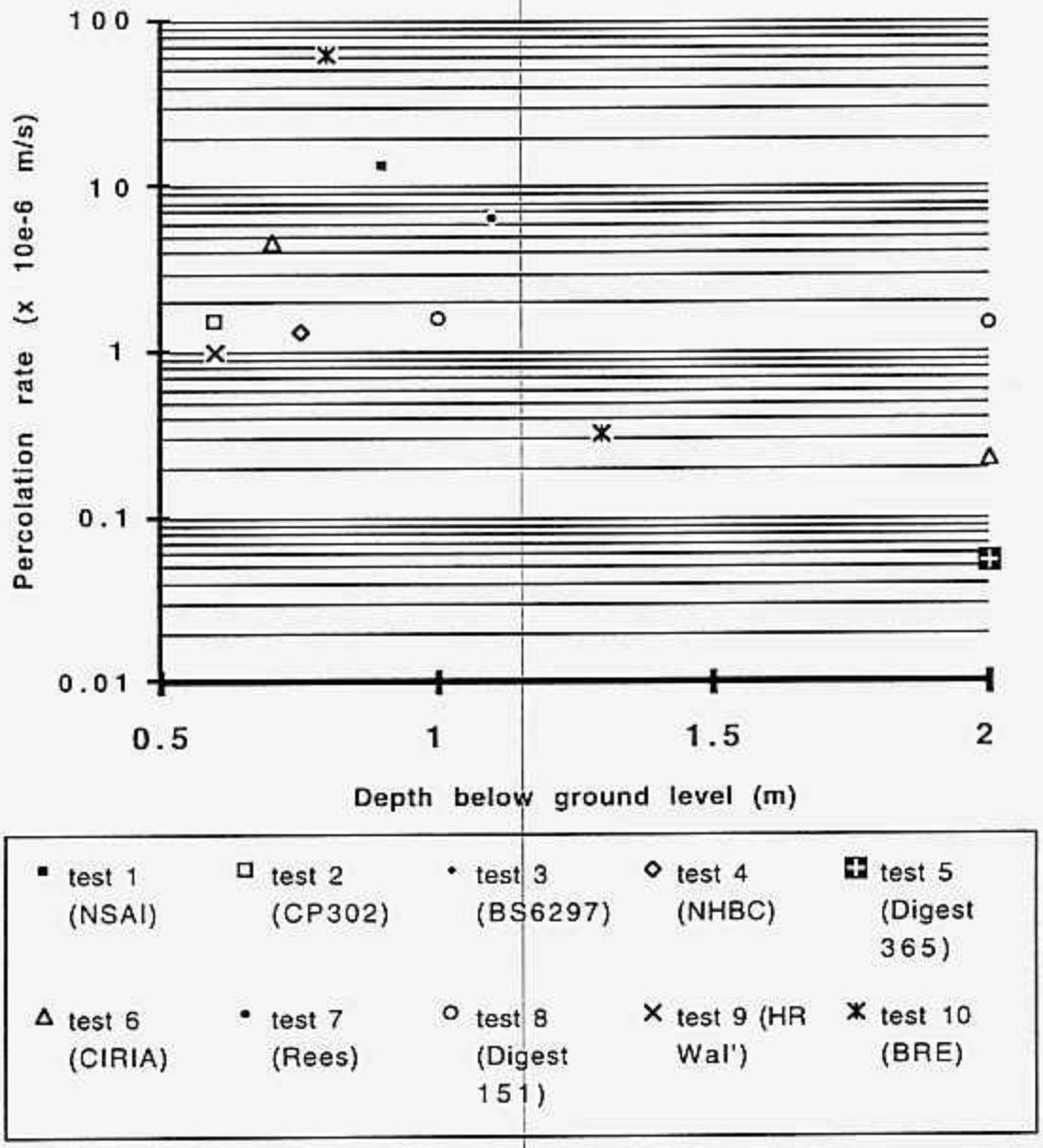



**Figure 1**
Percolation rates for site at various depths using different test methods (logarithmic scale)

**Note** The reason for the values of the BS6297 result (test 3) and NHBC result (test 4) being the same are that it was one test. The two documents deal slightly differently with the results at the design stage.

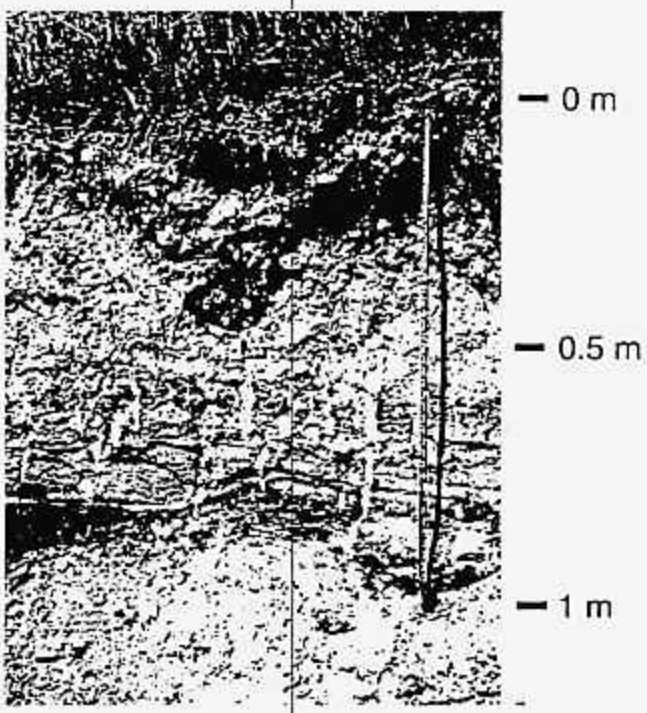



**Figure 2**
Soil structure at test site (length of rule =1m)

*4.2 Work in the USA*

Comparison of different test procedures with identically sized holes in the same soil has shown that surface preparation and filling techniques can affect percolation rates by a factor of up to ten[14]. Techniques for testing developed by J T Winneberger[15] use paper insets to reduce inaccuracies introduced by water filling.

Tests conducted in California in the 1950s showed that, after about three months of continuous application of wastewater in soils of varying permeability, the infiltration rates were essentially the same[16]. This was due to the biomat film (formed by the deposited solids from the effluent and colonised by bacteria and other micro-organisms which metabolise and encourage conversion reactions as the thickness of the boimat increases), at the soil and wastewater interface, becoming the limiting factor once equilibrium had been established. The only exceptions to this occurred in soils of very coarse gravel or those with significant amounts of clay. Values obtained in the 1980s for the long-term hydraulic capacity of the biomat film, termed as Long Term Acceptance Rate (LTAR), ranged from 12 to 20 $l/m^2$day depending on the hydraulic head [15, 17, 18]. These values approximate to those that would be expected for a loamy clay soil.

## 5 Discussion of errors in percolation tests

The units for percolation rate are stated in millimetres per second but generally they cannot be measured to such an implied accuracy; metres per day would imply the accuracy normally obtained. The reasons for the variations in results may be due to many factors :

**Method of hole production** Depending on the soil type and structure, the way in which the holes are formed may influence the results. When hand digging a hole, if a fork is used in clay soil types the walls of the hole produced may be rough but if a spade is used the blade may smooth or smear the surface. A smeared surface may resist the penetration of water more than a roughened surface. If a mechanical digger is used high compression and shearing forces on the ground may be produced which can influence the percolation of water. If an auger is used the head has a smearing and polishing effect on the soil as it is withdrawn, inserted and rotated to remove the extracted soil and deepen the hole.

In sandy soils it may be impossible to form a test hole without the addition of shuttering and an aggregate filling.

**Surface preparation** Before the hole produced is filled with water the surfaces to be tested may be conditioned as part of the test procedure. Preparations may require scoring of the surface to roughen it, the tearing away of soil to enlarge the hole and the removal of any compacted soil, or the addition of newspaper linings to prevent damage to the surface during filling with water. [Only the roughening of the surface was used in this current series of tests, the other preparations are used in American tests.]

**Water filling** The way in which water is introduced into the hole may affect the percolation rate. Most of the large holes tested had specifications that required 'rapid' filling with water, whilst the tests that had smaller holes required water to be filled to a specified level. If water is introduced forcefully the surface of the hole may be disturbed and the loosened soil may become suspended in the water or create a slurry.
The rate at which water is introduced may also be critical in saturating some soils. With porous soils, high rates of water flow may be needed to enable the hole to be filled.

**Number of fillings** If the hole is only filled once with water it is less likely that the surrounding soil will become saturated than if multiple fillings are used. With large test pits this is less of a problem due the larger quantity of water that is used.

**Duration of test** If the hole drains rapidly care is needed to judge the depth of the moving water level. However, if the test is long due to low flow rates and extends past normal working hours, the hole may empty during the night when it is unobserved and thus it is not possible to determine the percolation rate.

**Measuring range** It is easier to measure the time taken for the water level to fall past a specific depth than to decide when the water has completely drained away. Therefore, timing errors should be less when the former method is used.

**Soil type and structure** The form and type of soil may vary over the site of a proposed drainage field and with depth. Impervious layers, permeable regions and rocks are some of the possibilities that could affect the measured percolation rate.

If tests were conducted over a long period of time, weather and seasonal variations could be significant factors.

In addition to the above, some of the tests specifications introduce factors which contribute to uncertainties. The specification for the number of holes to be produced may not be clear or the way in which the final percolation rate is to be calculated is poorly specified. Where surface preparation is required it is not specified clearly how the preparation is to be carried out. Filling rates are often described as 'rapid' or 'slow' without any quantitative guidance; this is not acceptable for a test specification.

This work has emphasised that a percolation test is not be the only factor that should be considered in the siting of a septic tank drainage field. It is only one indicator of the suitability of a site. Other considerations should include the vegetation, the terrain and proximity of other buildings. Also, local knowledge of groundwater conditions and geological structure is very important.

## 6 Conclusions

Although basically the percolation test procedure is to dig a hole, fill it with water and time its discharge rate, there are considerable differences between commonly used tests. In general, small shallow holes are easy to create and fill with water and, if enough are used in the area proposed for the drainage field, they can provide shallow level information that can be used to design the arrangement of the discharge pipes. However, small shallow holes can give results that are very different to full size pit type soakaways. Therefore, large deep holes have better correlation with pit type soakaways but the tests are more involved and can be more costly.

Currently, there are two approaches to percolation testing. The first is that tests for septic tank discharges should be different from those for rainwater discharges because of the nature of the flow. In septic tank installations the inflow could be relatively continuous and the discharge almost instantaneous but for surface water soakaways the inflow will be irregular and the discharge delayed if there is storage in the soakaway due to a low soil permeability.

The second approach is that there is little difference in the requirements of the two situations. For example, the discharge from a bath could be considered equivalent to a period of rainfall. Much of the data, upon which the design assumptions for these installations have been made, were collected several decades ago. Due to changes in people's lifestyles and rainfall patterns it is not clear which approach to testing is the more appropriate; further consideration of the mechanisms involved is needed. Currently, BRE is carrying out research to determine drainage discharge patterns in domestic properties which will answer some of the uncertainties.

Whichever test philosophy is chosen, there are basic principles that should always be followed.

- The tests should take account of any seasonal variations of water table levels and rainfall.
- The tests should be straightforward, have clear and simple criteria for assessment, be as economic as possible and be practicable.
- The results obtained must be considered in relation to other information about the proposed site (such as location, water table and local geology).

## 8 Recommendations

The current test in BS 6297 is not satisfactory as it is poorly specified, for example, with regards to the number of holes to be dug, and it is imprecise. The percolation rate is calculated in seconds per millimetre which is misleading since the tests give only a rough estimation of the actual percolation rate and should be measured in metres per day.

The requirement in BS6297 to "... observe the time, in seconds, for the water to seep away completely." is too subjective. Determining, to the nearest second, the point at which water drains from a dug pit is impractical, in all but the fastest draining soils. Another major concern with the test procedure is that the current wording can be interpreted in many ways which may result in one or three holes being tested over two or four days- this is not acceptable as a specification. However, in some cases where repeat tests are required the procedure may take over 10 days. One of the problems cited by the local authorities was lack of resources and manpower, in general, and thus it is unlikely that such a test would be supervised by local authority inspectors. As '...underdrains are desirable.' if slow percolation rates are calculated, it is an omission in BS 6297 that no consideration is given to the percolation rate of the soil at the underdrain level.

In summary, from the current study the guidelines that can be applied to percolation testing are:

1 Useful information may be provided by progressively increasing the depth of the test holes thereby revealing the percolation profile for the plot of land. (Increments of 150mm revealed different percolation rates)

2 A large pit may simulate a soakaway pit installation very well but for sub-surface drainage fields, a series of small holes over the proposed area of the drainage field may provide more useful information.

3 In cohesive soils, such as clay, test holes can be produced to very fine tolerances on the dimensions i.e. within a few mm. However, in less cohesive soils shuttering and aggregate fills may be required and holes can only be made with low dimensional accuracy.

4 Hand augured holes are fast to make and produced consistent accurate holes with flat bases. Holes dug by a skilled operator using a mechanical digger are dependent on the size of bucket used. If the bucket is the width of the required hole a high degree of accuracy (in the order of ±1cm) may be obtained. Hand dug holes are the most variable. The effect on the walls of the hole of the digging mechanism must be considered to determine if it is suitable for the soil type.
**NOTE** Although the hand augers used produced flat based holes this would not be so with a powered auger as these usually have coarsely threaded noses to pull the blades into the soil.

5 If holes are to be spade dug by hand, they should not be deeper than their width. It is very difficult to extract soil from holes that are deeper than their widths

6 Where holes are to be dug in the floor of larger pits the area around the hole must be large enough to permit personnel to stand and climb in and out without displacing soil that can affect the measurements.

7 Large holes are generally more costly to dig, require more safety considerations and require more water for testing than small holes.

8 The degree of soil saturation greatly affects the determined percolation rate. For consistent results the soil must be completely saturated.

9 The percolation rate obtained from a site test is only one indicator as to the suitability of the ground for use as a drainage field.

10 Clear guidance is needed to cover all results of the tests, so that it is clear when to stop testing and how to extrapolate the results, if the ground is very slow draining.

## 9 Future Work

Work is required to determine the mechanisms that operate throughout the lifetime of a septic tank effluent disposal system in the UK climate. This information could be used to determine if such installations require different test procedures to those for surface water disposal systems and provide useful guidance for building inspectors and others.

Work is also required to determine definitive test methods to determine percolation rates and their applicability. Site trials, comparing the results of acceptable testing procedures, should be conducted in different locations at different times of the year to determine their suitability and repeatability.

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# Topic B6

## New SW-Modus for Siphonic Roof Drainage Systems

A. Schweizer, Switzerland

# New Software Modules for Siphonic Roof Drainage Systems

(grad. Plumbing Engineer Andy Schweizer, Geberit Technik AG, CH-8645 Jona, Switzerland)

## 1 Introduction

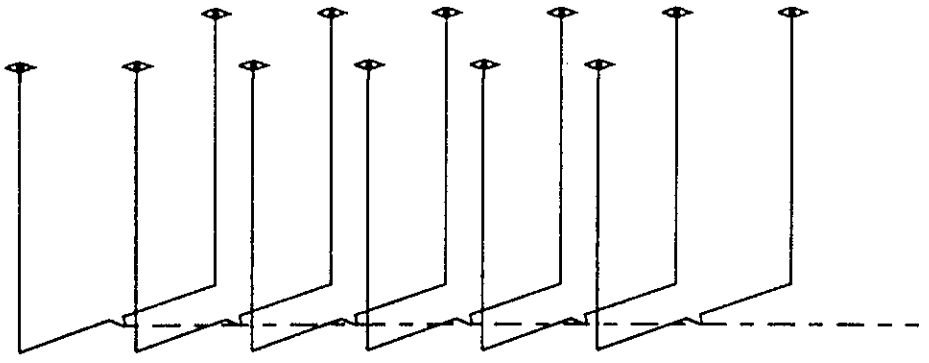
During the past few years, the advantages of siphonic roof drainage systems have become clear to engineers and builders all over the world. They have helped turn the system into a notable success. This success can be demonstrated in the large number of buildings where this system has been in service for years. The buildings in question include very large industrial facilities, airports, shopping centres and office buildings. These are exactly the type of building where the roof drainage system is subjected to exacting challenges as far as its functional reliability is concerned. The siphonic systems have been able to fulfil these requirements.

Most of the hydraulic calculations necessary for ensuring the function of the installed systems were performed with the help of PC-based software programs. This involved the system supplier providing the programs in question to the engineering offices and training the program users accordingly. Even today, there is neither an ISO standard nor other international standards for performing siphonic roof drainage system calculations. Consequently, the programs in use are not standardised either. Each system manufacturer has implemented their own defined hydraulic calculation in their program in the form of a specific algorithm. Equally, the manufacturers have also defined individual modes of using the programs. The result is that the programs differ greatly, principally as far as operating them is concerned.

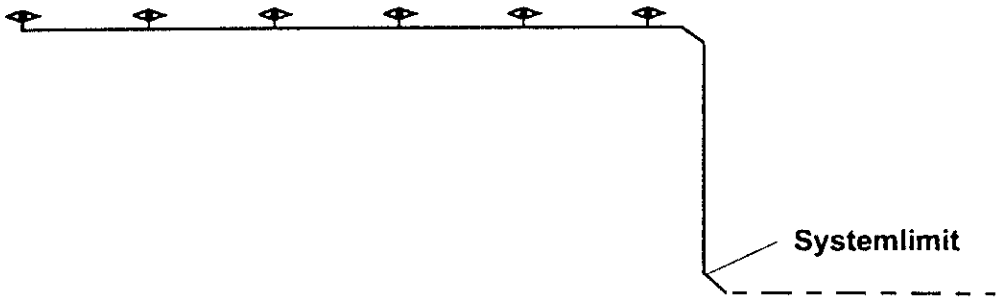
The general principles of performing work on the PC has been standardised by the use of modern operating systems such as Microsoft Windows. This graphical user interface is based on the intuitive perceptive faculties of the program operator. Care is taken to ensure that all programs contain the principal standardised objects and present them in a unified way on the screen. Compliance with these standards has been accepted by the software industry and this is influencing the ongoing development of all programs. Consequently, even the more technically oriented applications such as calculation programs for siphonic roof drainage systems have been developed in this direction. I would like to describe to you what consequences this has for the user and what the resulting advantages are. I shall explain aspects as appropriate by taking examples from the software which we have produced.

# 2 Survey of calculation procedures for roof drainage systems

## 2.1 Principle differences in the pipe layout

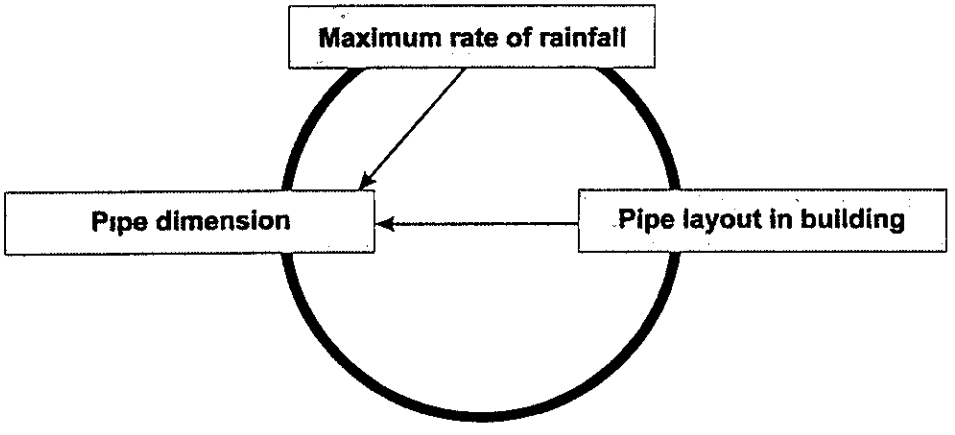


Conventional roof drainage system

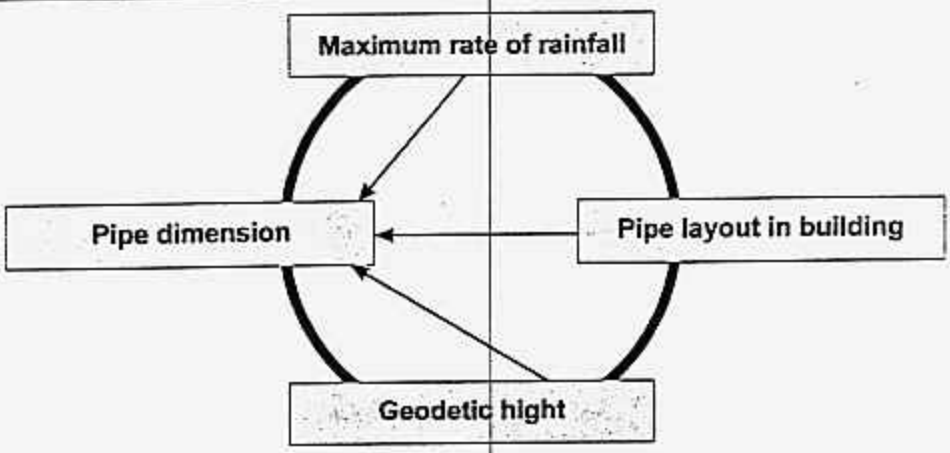



Syphonic roof drainage system

## 2.2 Fundametal values for the calculation of the dimensions




Conventional roof drainage system




Syphonic roof drainage system

This survey shows the principle components of the system which are relevant to the calculation. It presents a comparison between siphonic roof drainage systems and conventional drainage systems. In this context, the limits of the system are taken to be the transition point to the drains. In both processes, the objective is to determine the dimensions of the pipes depending on the local amount of rain and the specified routing of pipes in the building. In conventional non-pressure drainage, the applicable national standards specify calculation values in the form of a table. The basic values in the tables are either based on a roof area which can be connected to a horizontal or vertical pipe, or alternatively on the volumetric flow which has to be drained, which is calculated as a function of the amount of rain.

In calculations for siphonic roof drainage systems, the element of geodetic height also has a role to play as a fundamental value in the calculation. This value makes it difficult to use tables as a means of determining the pipe widths. A three-dimensional tables would be required. It would have a complicated structure and be difficult to interpret. Both systems require checking by the engineer if there is an alteration in the fundamental values (amount of rain, pipe routing or geodetic height) and must be adapted if required. All in all, it is clear that the existing interrelations make it more complicated to determine the pipe width for siphonic roof drainage systems as a result of the additional element in the calculation process represented by geodetic height. The following talk is intended to explain how to deal with this complexity.

## 3 Planning work when calculating siphonic roof drainage systems

### 3.1 Fundamentals

As already mentioned, the following parameters need to be worked out in order to perform the calculation for siphonic roof drainage systems:

- Amount of rain
  The amount of rain is dependent on the geographical location of the building. Generally speaking, the values are specified in the standards for the specific country. The units used vary from standard to standard (litres/m²) or gallons/minute/sq. ft.

- Pipe layout in the building
  The routing of the pipes is planned as a function of the specified portions of the construction and co-ordinating the pipes with other installations in the building.
- Geodetic height
  As in the case of pipe routing, this fundamental parameter is also dependent on the building which is to be drained. The significant feature for the calculation is the specific height from the roof outlet to the transition point to the drains (limits of the system).

In addition to these values, the roughness of pipe material used also affects the calculation. The values to be applied are generally integrated in the calculation programs and so the user does not need to consider them when determining the input values.

### 3.2 Preparations for planning and the calculation

It is necessary to define the distribution of the total amount of rain (derived from the fundamental parameters) between each individual roof outlet. The pipe dimensions have to be entered into the system in a three-dimensional way. To do this, it is necessary to use a sectional view to supplement the plan views which are normally two-dimensional. Entering the height of the pipe (the third dimension) is of decisive importance for the function of the siphonic roof drainage system.

### 3.3 Support from the PC program

The values worked out during the preparatory stage now form the basis for entering data into the system. It is now necessary to change the program and briefly explain the main elements of the user interface.

The application shown here possess all the elements of a Windows program. The application window can be opened and closed as well as moved around the screen.

As with any program running under Microsoft Windows, the application used here has a drop-down menu for accessing the commands. There is also a toolbar for the most frequently used commands in addition to the drop-down menu method of activating the commands.

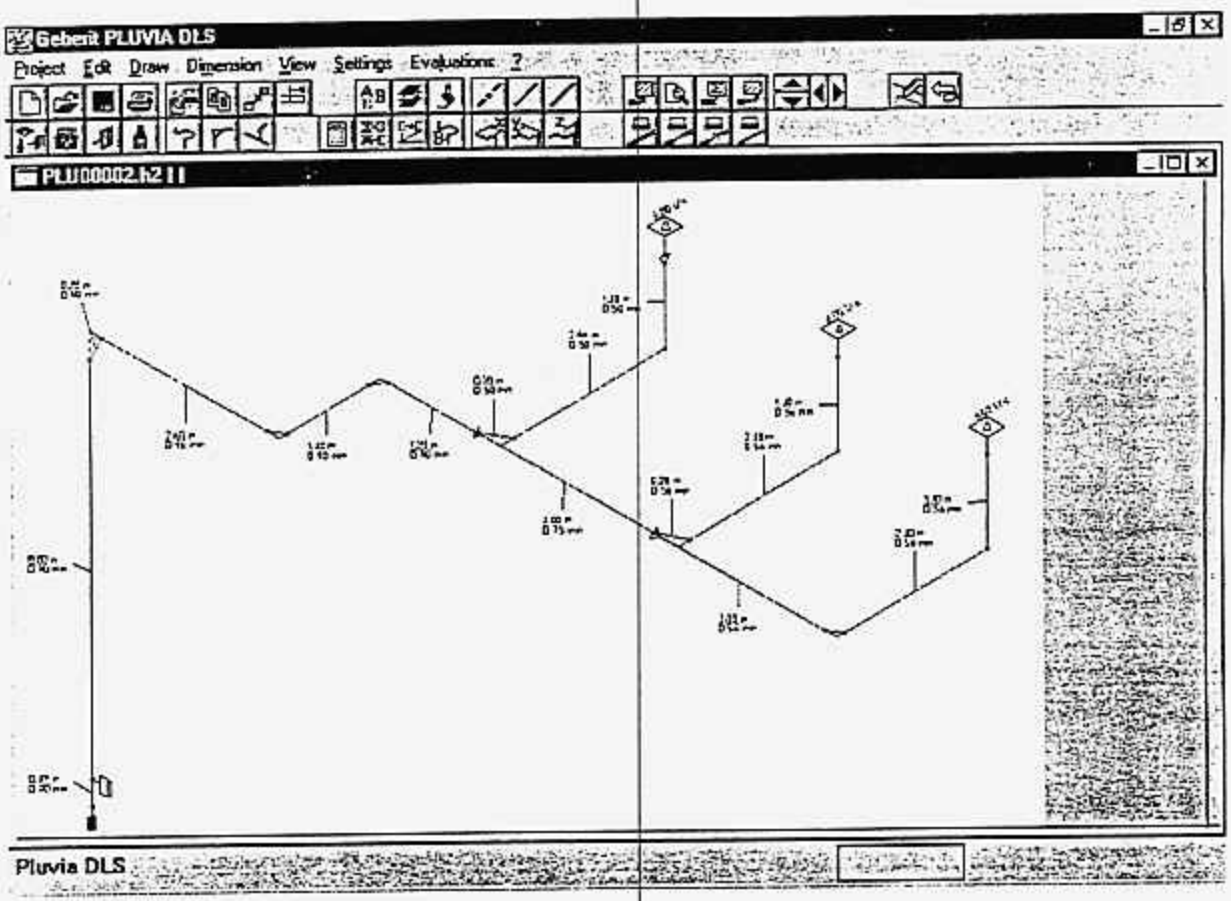
First of all, it is necessary to tell the system what is the project for the subsequent data. If the user wishes, it is possible to create links from the project being created to addresses of partners who are involved. These addresses may already exist or they can be created later. Subsequently, these addresses are printed on all documents. In addition, we have structured the application in such a way that it is possible to manage several partial projects within a project. We will be able to make excellent use of this capability later on when it comes to evaluating the materials required. This means material quantities from more than one partial project can be printed out in the same list.

Defining the project also allows the stored data to be processed at a later date. Once the project has been defined, the program displays an interface reminiscent of a CAD system. The system then waits for a three-dimensional drawing to be entered. A 30° drawing grid is specified for this purpose. The operator uses the mouse to draw in the pipes on the screen. Preassembled graphic elements such as pipe elbows, junctions and roof outlets are available for this purpose. Whenever a junction is used in a pipe, the system automatically divides the stretch of pipe into two sections, because adding a junction amounts to defining a point in space which is relevant for the calculation. After the pipe has been drawn on the screen, it is necessary to specify the amount of rain arriving at each roof outlet. The data worked out in the preparatory stage are used for this in the same way as they were for making the drawing.

Following this, it is possible to enter the actual pipe lengths of the individual pipe sections (in the case of vertical pipe sections, the pipe length corresponds to the geodetic height). Pipe sections which have already been updated are shown in a different colour.

After all the data have been entered, the program performs the calculation to determine the pipe diameters. The user is kept informed of the current status of the calculation since the stretch of pipe currently being calculated is displayed in another colour. The calculation algorithm used is designed to optimise the pipe diameters. The calculation initially checks the rules specified by the system manufacturer such as the minimum geodetic height or the minimum speed of flow in the pipes. The dimensions of the pipes are fixed provided these rules have been observed. The program informs the user if the rules have not been followed at any point in the piping system so the user can make the necessary corrections. Our statistics have shown that automatic calculation is possible for 80 % of all buildings planned in practice. When the calculation process is completed, the program automatically displays the dimension texts for the pipe sections drawn on the screen.

The system includes a preset layering technology in order to reduce the amount of information shown on the screen during working. This allows information to be displayed or suppressed selectively.




Screen view of Pluvia DLS

### 3.4 Results of the planning

It is only possible to print out documents for systems which have been calculated successfully. This is in order to guarantee that the rules of the system are complied with.

The following documents can be displayed on the screen or printed out as the results of a calculation which has been performed successfully:

- Plan drawing with variable lettering
- Table with the values calculated for the individual pipe sections
- List of materials
- Offer comprising materials and prices

The plan drawing can be imported into a CAD program using the DXF interface. The table, the list and the offer can be imported into normal Microsoft programs using the standard interfaces.

Example of hydraulic calculation list

GEBERIT

09.09.96
20:25:20
1

Project: CIB-W62 Seminar
Sub project: Lostorf
Contactr: Geberit Technik AG

The Geberit guarantee agreement is vaild for the function of the system, provided that only pipe and fittings of the Geberit Pluvia product range, bearing the Geberit trade mark are used and that installation is carried out by a Geberit Approved installer in accordance with Geberit Installation Technology.

All data necessary for this calculation are based on the spezification form the customer and/or his authorised representative.

WARNING : Values with "F" do not satisfy the Geberit design criteria.
These val MUST

| Position [No] | Dimension [mm] | Length [m] | Height [m] | Target [l/s] | Discharge [l/s] | Vacuum [mbar] | Velosity [m/s] | Water/ Air mixture [%] |
|---|---|---|---|---|---|---|---|---|
| 1 | 90 | 0,37 | 0,37 | | 17,95 | -19 | 3,6 | 91 |
| 2 | 90 | 8,00 | 8,00 | | 17,95 | -518 | 3,6 | 91 |
| 3 | 90 | 0,28 | 0,20 | | 17,95 | -514 | 3,6 | 91 |
| 4 | 90 | 2,60 | | | 17,95 | -448 | 3,6 | 91 |
| 5 | 90 | 0,14 | | | 17,95 | -431 | 3,6 | 91 |
| 6 | 90 | 1,30 | | | 17,95 | -390 | 3,6 | 91 |
| 7 | 90 | 0,14 | | | 17,95 | -373 | 3,6 | 91 |
| 8 | 90 | 1,20 | | | 17,95 | -319 | 3,6 | 91 |
| 9 | 75 | 3,00 | | | 12,00 | -218 | 3,7 | 88 |
| 10 | 56 | 3,00 | | | 6,00 | -116 | 3,2 | 97 |
| 11 | 56 | 0,14 | | | 6,00 | -100 | 3,2 | 97 |
| 12 | 56 | 2,30 | | | 6,00 | -19 | 3,2 | 97 |
| 13 | 56 | 1,30 | 1,30 | | 6,00 | -76 | 3,2 | 97 |
| 14 | 56 | 0,10 | 0,10 | 6,00 | 6,00 | 0 | 3,2 | 97 |
| 15 | 56 | 0,28 | | | 6,00 | -192 | 3,8 | 80 |
| 16 | 56 | 2,38 | | | 6,00 | -91 | 3,8 | 80 |
| 17 | 56 | 1,30 | 1,30 | | 6,00 | -96 | 3,8 | 80 |
| 18 | 56 | 0,10 | 0,10 | 6,00 | 6,00 | 0 | 3,8 | 80 |
| 19 | 50 | 0,28 | | | 5,95 | -284 | 3,9 | 100 |
| 20 | 50 | 2,44 | | | 5,95 | -128 | 3,9 | 100 |
| 21 | 50 | 1,30 | 1,30 | | 5,95 | -144 | 3,9 | 100 |
| 22 | 56 | 0,10 | 0,10 | 6,00 | 5,95 | 0 | 3,0 | 100 |

## 3.5 System requirements

The Windows program presented here will be available in several languages. It is currently available in German and English.

The program must be installed on a PC running the Windows 3.11 or Windows 95 operating systems. An A4 inkjet or laser printer makes a suitable output device.

## 4 Summary

The use of the PC program presented here provides a straightforward means of making up for the disadvantage of the calculations needed for siphonic roof drainage system. The interface and the fundamental aspects of using the program are in accordance with the standards specified by Microsoft Windows and are accepted by a very large number of users. The results of the planning process are adapted to the Geberit Pluvia system and correspond to the technical requirements recommended by the system manufacturer. Using the program gives the planner a comprehensive guarantee that the system thus designed will function perfectly in practice and comply with the safety requirements.

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World Plumbing Conference Hong Kong June 1993 WORKSHOP PAPERS G.J.W. Marsh, MBE, MGC IEng FIOP

# Topic B7

## Discharge Capacity of Rainwater Stacks: A Review of Belgian Research Results

K. De Cuyper, Belgium

# DISCHARGE CAPACITY OF RAINWATER STACKS: A REVIEW OF SOME BELGIAN RESEARCH RESULTS

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September 1996

**Abstract**

The correct drainage of rainwater is important for the conservation of a building. It seems however that rainwater discharge pipes are still designed relying upon not fully correct calculation rules. Research done on this topic at CSTC/WTCB in the early 70's, provided such correct calculation information, but this seems not to be known. Starting with a comparision of the rainwater stack capacity calculation in some European countries and in a document issued by the European Standardisation Commitee, the paper tries to explain the discrepancies between the different national approaches, relying upon the research results of CSTC/WTCB.

**Keywords:** rainwater, discharge stacks, weir flow, full bore flow, orifice flow.

## 1. Introduction.

Humidity is of a major concern in the context of healthy buildings, a topic which receives quite a lot of interest these last years. In avoiding the building to become wet, the installations for water supply and water drainage, between which the rainwater installation, play an important role: if they fail, the building will indeed be confronted with a humidity problem. In case of problems related to the water supply or waste water installation, the damage can in general be limited, because people control these installations. In case of rainwater drainage installations, this isn't the case: if they are leaky or under-dimensioned the problem is sometimes difficult to control and damage can be important. This is probably the main reason why much attention is in most countries being paid to the rainwater drainage: in Belgium for instance, there is no standard on waste water drainage of buildings, but there is since 1953 a standard on rainwater drainage of roofs. With great interest was than also looked to the standardisation work, set up by the Working Group 21 of the Technical Comity 165 of the European standardisation comity (CEN), on rainwater drainage.

One of the surprises we had in analysing one of the documents issued [1], was the high drainage capacity attributed to the rainwater stacks. This can be illustrated by figure 1, which represents the stack capacity as indicated in the regulatory documents of Germany (D : DIN)[2], France (F : DTU) [3], Switzerland (CH : SN)[4], Belgium (BBRI 1) [5], and as indicated the considered draft of CEN (prEN)[5]. From this figure it is clear that the CEN and Swiss proposals differ quite from the values used in other European countries. The question raised how to explain these important differences.

As CSTC/WTCB had done research on the capacity of rainwater stacks, in the late 60's-early 70's, we decided to pick-up again the issued results in order to find an explanation to the noted discrepancy. These research results were already presented at the first CIBW62 Seminars.This paper brings the results of this analysis. Hereto we first review the concerned research results §2. In §3 we then use these results for commenting the above indicated discrepancy. The §4 presents the conclusions.

## 2. A review of the CSTC/WTCB research results

### 2.1 General

The research aimed at establishing the water drainage capacity of stacks fed radially at their top under constant water head, as function of

- their configuration -some of the configurations tested are represented in figure 2-
- their diameter
- their length
- the water head (H on figure 2)above their top.

It was realised by the Belgian Building resaerch Institue (CSTC/WTCB) at the test facilities of the French Plumbers Organisation at Saint-Remy-les-Chevreuse in France.

### 2.2 Types of flow occuring

A first thing which was noted, is that three different kinds of flow conditions can occur in such stacks : weir flow, orifice flow and full bore flow.

The weir flow (fig3A), occurs for low values of the head (H) above the inlet of the stack. For this type of flow the research established the following relation between the flowrate and the head is the following:

$$Q = (\alpha+\beta H/D)\,\pi DH\,\sqrt{2gH} \quad (1)$$

where:

Q : is the flowrate in (l/s)
H : is the head above the inlet of the stack, in (dm)
D : is the internal diameter of the pipe, in (dm)
g : is the gravitational acceleration: 98,1 dm/s$^2$
$\alpha$ and $\beta$ : are coefficients characterising the stack entrance with respect to the flow;
- in case of sharp entrances : $\alpha$ = 0.453 and $\beta$=0.35
- in case of conic entrances : $\alpha$= 0,578 and $\beta$=0.35.

In these flow conditions, the flowrate is thus independent from the length and the configuration of the stack (presence of bends for instance).
In a graph with the flowrate on the horizontal axis and the head in vertical axis, this relation is represented by the 'a curve' : see figure 4. Increasing the diameter, without changing the configuration, results in a shifting of the curve to the right on the graph: from a till a'.

Rising the head will thus increase the flowrate according to relation (1). However from a certain flowrate on ($Q_E$ on figure 4), the weir flow ends and the full bore occurs (fig 3B); the transition from one flow to another is gradual. For this last flow type the relation between the flowrate and the head was established as being (curve c on fig.4):

$$Q = ((\pi D^2)/4)\ \sqrt{(2g(L+H+Y+a)/(1+\zeta+\zeta_e + \lambda L/D))} \quad (2)$$

where,

Q, L, H and D as above, formula (1);

Y : the length of the eventual conical part, in (dm)

$\zeta$ : headloss factor at the entrance of the stack(-)

$\zeta e$: headloss factor of the bend(s)(-)

$\lambda$ : friction factor in the pipe (-)

One can see that the flowrate depends als on the length of the stack and when the length is raised, the point where the transition from weir flow to full bore flow occurs, moves to the right on the graph(fig4).

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Starting from a weir flow, it is possible to have a third type of flow, i.e. the orifice flow, which only occurs in certain conditions. Conditions which can lead to orifice flow are:

- a rapid rise of the flowrate up to a value given by:

$$Q = 0.5\ \sqrt{(2g\ D^5)} \quad (3)$$

- straight stacks with conic entrance and lenghts < 1m;
- straight stacks with sharp entrance and L/D<40

The relation between the flowrate and the head is this time given by:

$$Q = \mu\ (\pi D^2/4)\ \sqrt{(2gH)} \quad (4)$$

where:

$\mu$ : is the contraction coefficient (-)

all other symbols are as above.

This relation is represented by curve b on figure 5. This type of flow is not stable and when the head is lowered, the flow follows curve b'on figure 5.

### 2.3 Practical results

Figure 6 show the type of results which obtained in the CSTC/WTCB research, for a straight stack configuration with conical entrance.

It will be clear that the use of such a diagram is not at all easy. Going out from the hypotheses that the flow condition should remain of the weir type, we were able to transform the information in diagrams like the ones represented in the figures 7 and 8.

The use of these diagrams is as follows:

- If you have to drain a flowrate 600l/min and the head allowed on top of the stack is 50mm, while the stack is according to the configuration of figure 7, you will have to use a stack with a diameter of about 100mm, whatever the length of the stack is.

- In case the allowed head is 60mm. and the length is 3m, you can use a 65mm stack. But in case the length is only 1.5 m, one will have to use a 70mm stack.

In fact the mixed lines connect all the points where for a given stack length, full bore occurs. This means that for a certain allowed head, the points under the curve which corresponds with the lenght of the considered stack, have full bore flow conditions and can't be used.

## 3. Application of the CSTC/WTCB results to the figure 1.

From the above review it is clear that the capacity of stacks which are fed at their top doesn't depend only on the diameter, but certainly also on the water head above the stack, as well as on their length and on the stack configuration.. The length of the stack being important for the maximum flowrate which can be discharged without having full bore flow. Giving stack capacities, without any reference to the water height above the top and thus on the roof in case of flat roofs is an uncomplete and even dangerous information.

The curve BBR1 on the figure 1, was calculated using equation (1) with a water head of 35mm and a sharp entrance. For little diameters all curves are situated under the so calculated curve. Above 75mm, the CEN curve as well as the Swiss one are however already situated above the BBR1 curve. This means that these stacks, in order to realised their calculated capacity, will have to be loaded at heights well above 35mm, value set forward as the maximum in the CEN proposal.
Anyhow also the German and French curves rise above the BBR1 curve for larger diameters, with again the risk to create serious overloads on flat roofs.

One must however notice that the CEN-proposal states that the capacity of the system is usually dependend upon the capacity of the outlets, the calculation of this capacityleading indeed to flowrates which are much lower than those proposed for stacks. But it is not clearly stated that it is not allowed to use stacks with a diameter which is less than the diameter of the outlet. If this would be the case the stack capacity table in the CEN proposal would be useless.

## 4. Conclusion.

It seems that the drainage of rainwater from roofs is still not correctly adressed inmost standards, although the availability of research results since nearly 30 years now.

The approach adopted in certain standards seems us to be dangerous; it must be hoped that in these countries buildings are provided with well calculated overflow possibilities.

The different flow phenomena described in our research results provide also the basis for the understanding of the siphonic rainwater drainage.

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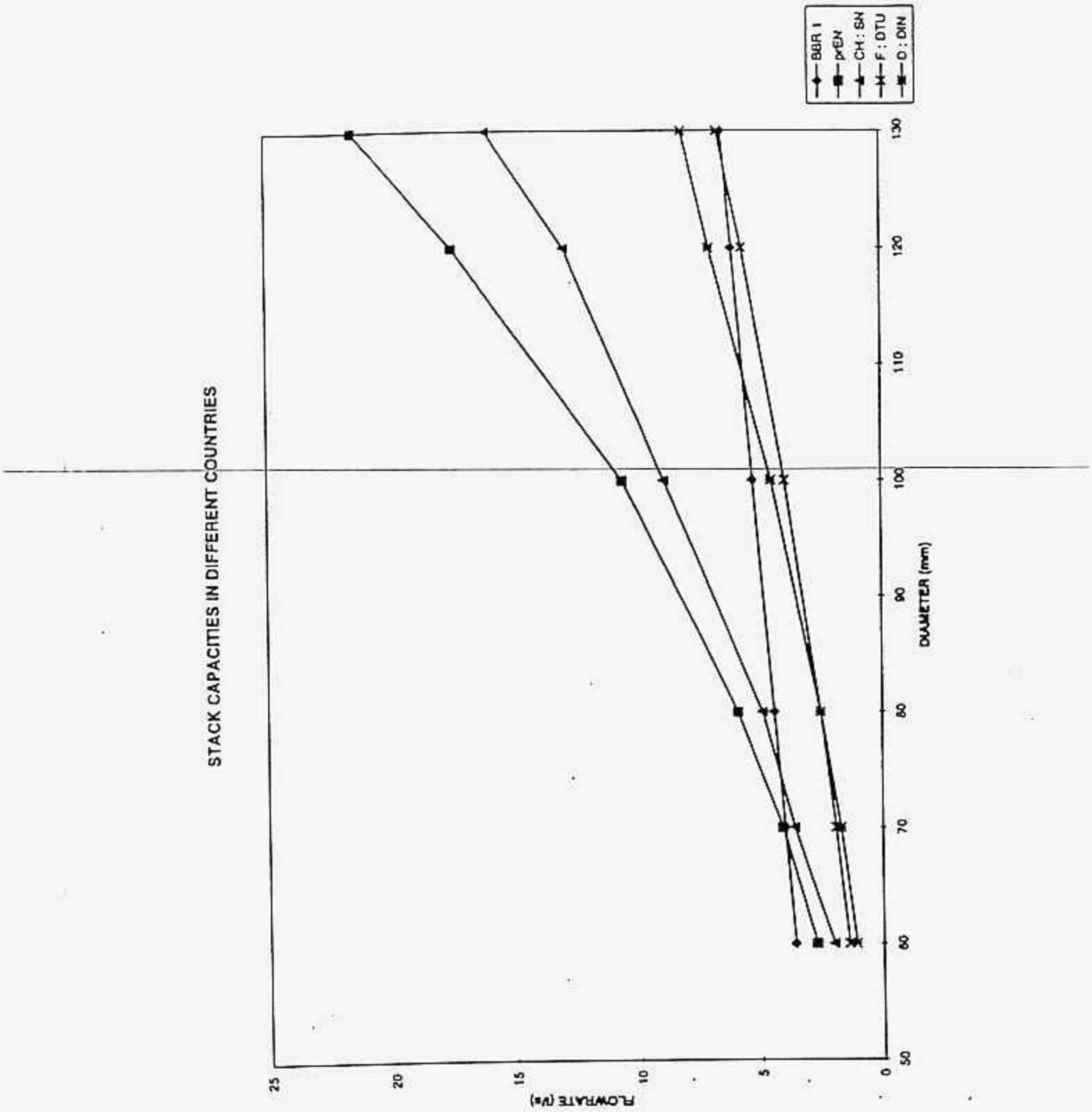



Figure 1. Stack capacities according to different national standards.

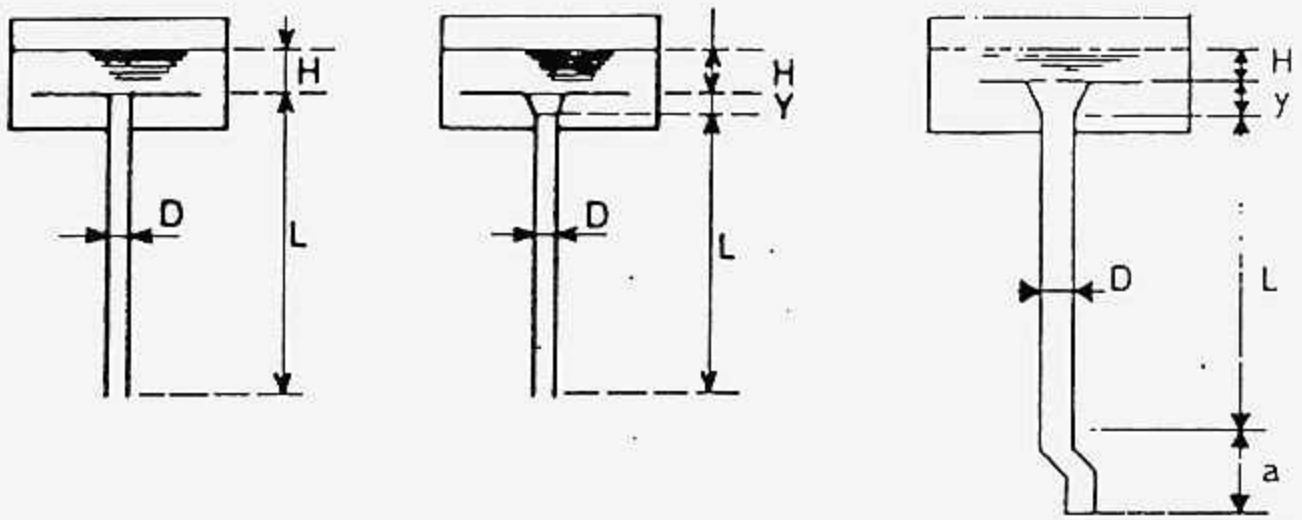



Figure 2. Examples of configurations considered in the CSTC/WTCB research

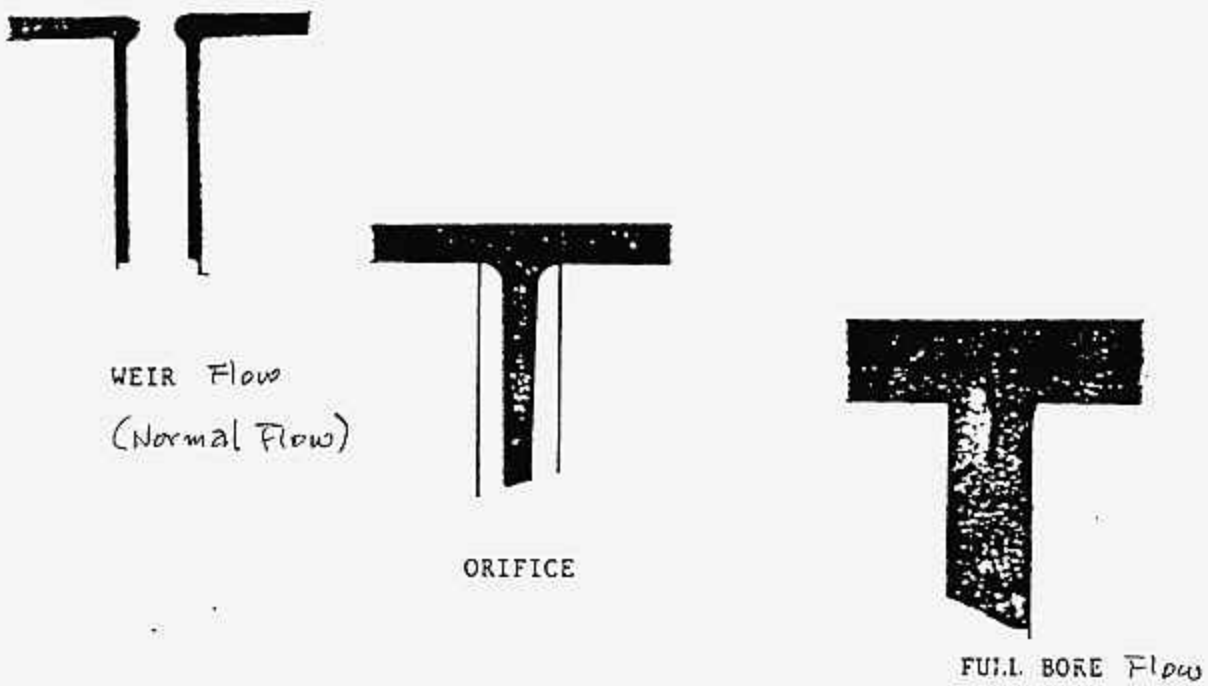



Figure 3. Types of flow occuring in rainwater pipes which are fed at their top

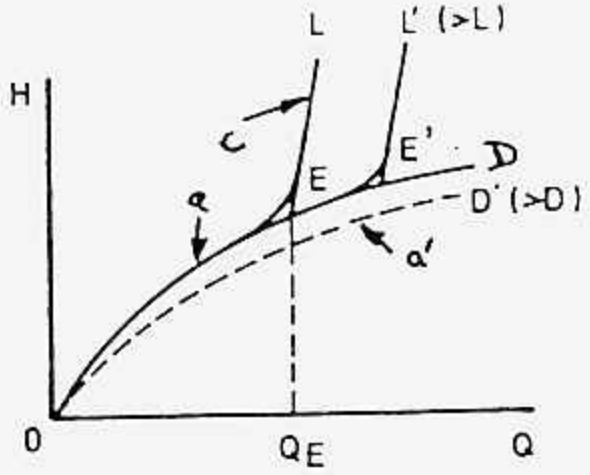



Figure 4 Relation between flowrate and head: weir flow and full bore

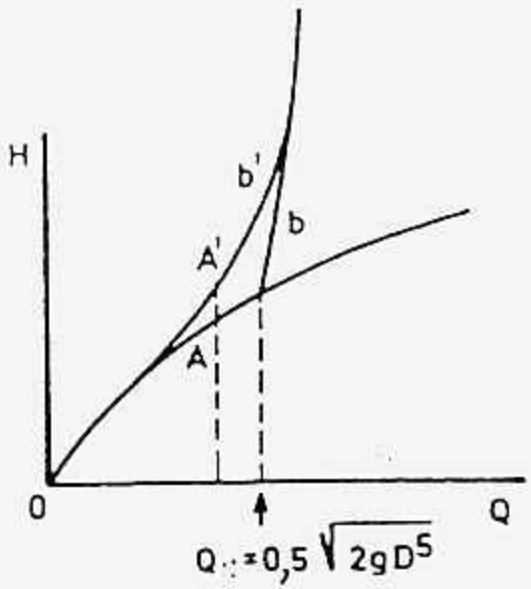



Figure 5 Relation between flowrate and head: weir flow and orifice flow.

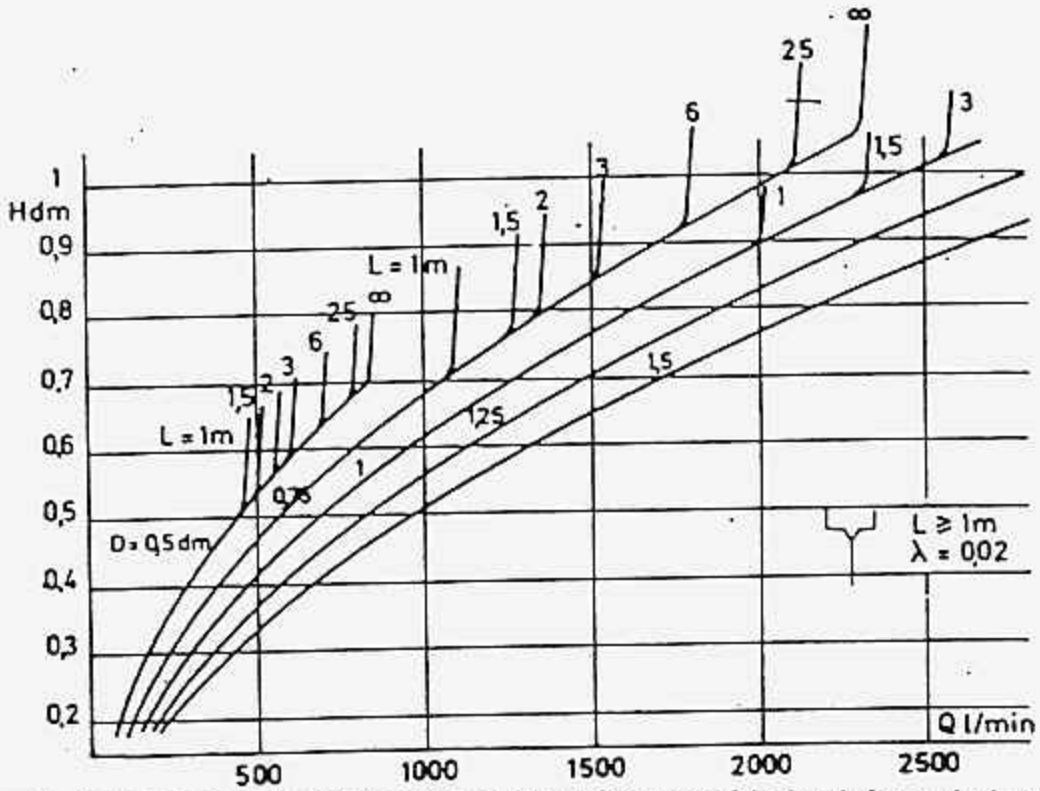



Figure 6. discharge capacity of rainwater stacks as function of the head, for conical entrance.

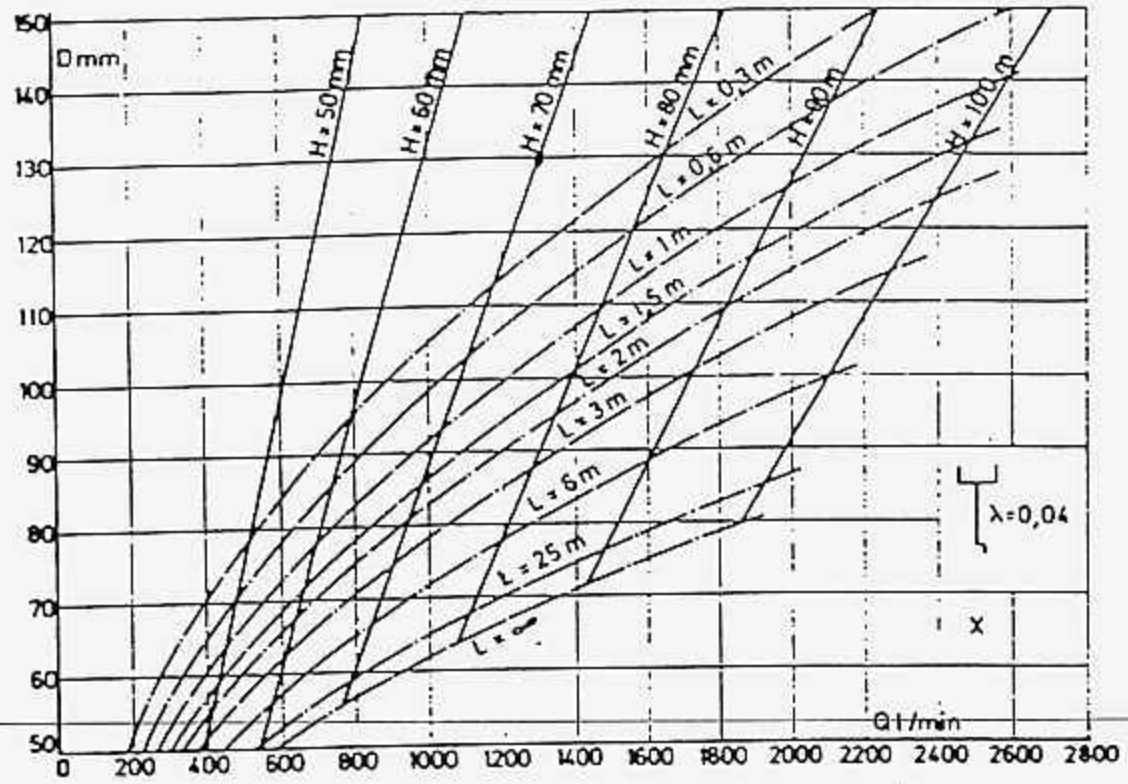



Figure 7. Diagram for calculating rainwater stacks with two bends and a sharp entrance.

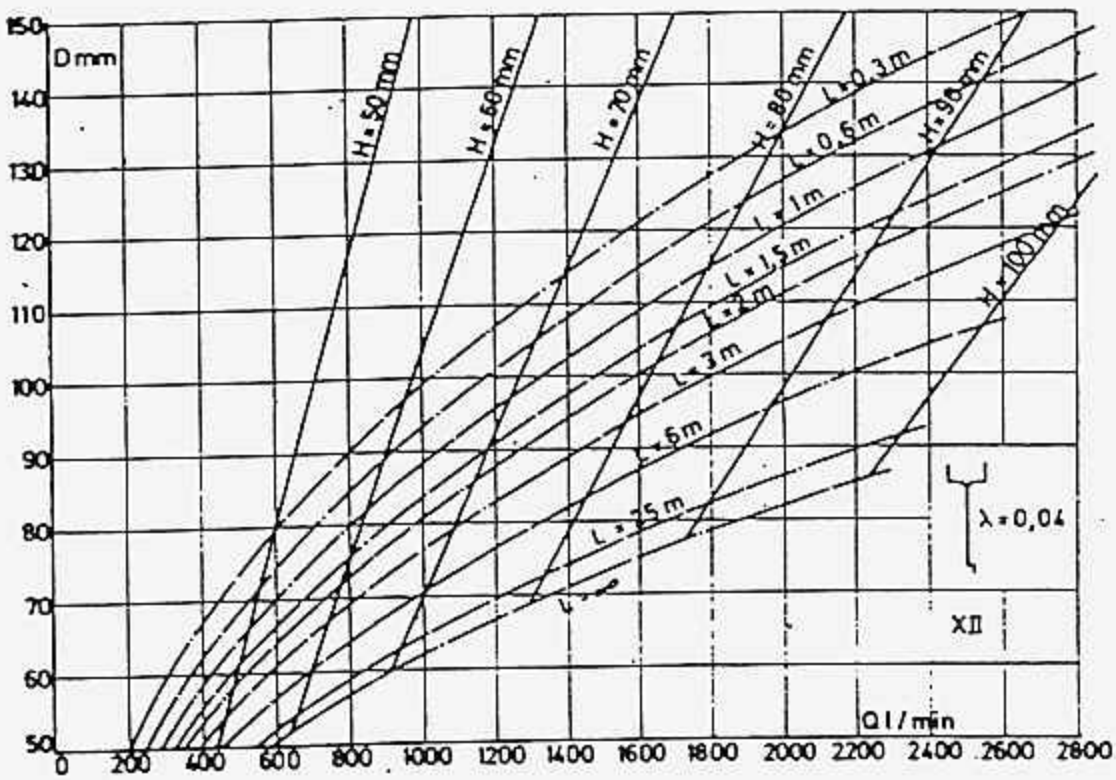



Figure 8. Diagram for calculating rainwater stacks with two bends and a conical entrance

# Topic B9

## Swiss Regulations for the Discharge of Rainwater: Rainwater seeping through the Ground

B. Stadelmann, Switzerland

# Swiss regulations for the discharge of rainwater: Rainwater seeping through the ground

B. Stadelmann, Switzerland

1. General
2. Fundamental principles / Official permission / Types of waste-water effluent drainage
3. Surface seep drainage systems
4. Underground seep drainage systems
5. Accumulation retention reservoirs

## 1. General

Much of our everyday life has to do with water. Even whilst still at school, we were instructed on the natural circulatory systems of water in general.

(Fig. 1)

In the extraction of drinking water, only that part of the circulation is of interest to ourselves as a rule, that occurs after the seepage of rain water into the ground substrate has taken place. And as drinking water is extracted as a rule from the layers where water previously seeped, we come upon a fundamental principle: ground water is not to be polluted by the seepage of rain water. This fundamental principle is therefore primarily to be complied with in the planning and construction of underground seep drains.
Our water conservation legislation places us under a duty for the overall conservation of the purity of areas of surface water and for the maintenance of the natural water circulatory systems. Areas of surface water are to be conserved against pollution. Legislation prescribes that we are *"to permit unpolluted waste-water effluent to seep in accordance with the ordinances of the cantonal authorities. Should local conditions not allow such seepage, then official permission will be granted by the cantonal authorities to conduit the seepage into an area of surface water. In this respect, accumulation retention measures are to be provided, so that large accumulated volumes of water at any one instance can be permitted to drain away continuously at a constant rate."*

Let us however pose ourselves the question: why then seep drainage at all ?
It was not very long ago when a philosophy of drainage was prevalent in our society, to collect all volumes of water as proficiently as possible and to drain it away. This philosophy however was accompanied by many negatives aspects, such as

- an overloading of the sewer infrastructure and waste water-effluent sewage purification plants;
- a decrease in the purification capacity in the waste-water effluent purification sewage plants on account of a too high degree of dilution of the dirty water by clean effluent;
- a reduction in the renewal of accumulations of ground water.

Our Country was very thinly populated before the times of intensive building construction. As a rule, and with few exceptions, rainwater seeped away in the location where it precipitated. Various types of ground substrate had the capacity of accommodating and compensating for high accumulation volumes in the precipitation of rainwater. Our new drainage philosophy is therefore directed to approach such original circumstances more closely. Efforts are to be made to pave as little of the ground surface as possible.
Continuously flowing, unpolluted drainage water is not to be mixed with dirty water, but introduced into the natural water circulatory systems. Unpolluted rainwater from roofs and paved surfaces is to be seep-drained away and thus introduced into the natural water circulatory system. Any instantaneous high level accumulations in volume in the sewers infrastructure is to be avoided by means of accumulation retention reservoirs.

## 2. Fundamental principles / Official permission / Types of waste-water effluent drainage

Various acts of national and regional legislation form the basis for the planning of, and official permission for seep drainage. The Swiss Standard No. SN 592000 provides exact details of how such installations are to be planned. Some of the basic requirements for compliance under the Standard are cited as follows:

- Ground water conservation has a clear priority in the planning of seep drain systems;
- The seepage of surface water into the ground substrate is generally to be preferred to seepage into a seep drain system;
- The structure of the ground substrate has to be ascertained at the intended location for the planning of a seep drain system. A hydro-geological expertise will provide such details. Such an expertise can be elaborated for single projects or for entire geographic zones. A geologist is of course to be retained for the elaboration of such an expertise.
- Official permission has to be applied for and granted for all seep drain projects.

Let us take a further look at the various types of waste-water effluent:

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A decision is to be taken in any event, as to whether seep drainage is viable, dependent on the origin and the consistency of the waste-water effluent involved.

The disposal of dirty water from households, trade and industrial operations is to be connected up to the sewers infrastructure, and is thus not to be taken into account in any discussion on seep drainage.

Seep drainage is to be preferred for the disposal of rainwater from roofs and paved surfaces. Attention should be given to the consistency of the surfaces from which the rainwater is to be drained. The daily use made of such surfaces can have a significant influence on the degree of pollution of the rainwater involved, and thus plays an important role in the decision whether to permit seep drainage, or on how such is to be effected. We shall be returning to these aspects when considering the various forms of seep drainage at a later stage.

Clean waste-water effluent, as well as water from fountains or cooling plant is to be seep drained. Such may only be disposed of in the sewer infrastructure and subsequent waste-water effluent sewage purification plant, in small amounts or with special official permission.

Reference has already been made previously to a variety of seep drain systems. As we have already heard, surface seep drainage is to be given priority over seepage into seep drain systems. In the case of both these types, the situation of the ground water table has to be taken into consideration. A natural vertical seepage route of at least 1.0 metre, measured from the lower edge of the filter layer should be in existence above the maximum ground water table. The two types will be explained during the following remarks.

## 3. Surface seep drainage systems

(Fig. 2)

Surface seep drainage is obtained when paved parking areas, driveways or access ways are constructed as permeable to water. Water can be made to seep directly into the ground at the point of accumulation by means of an appropriate ground surface construction. Such surfaces are laid out with grass-turf paving or concrete-grill blocks. The immediate substrate is constructed of seepage material such as hard-core and/or gravel respectively to act as a seep drainage pack. This form of paving is suitable for medium to good permeable subsoils. The disadvantages inherent in such systems are disregarded in practice, where the function of surface seepage can become temporarily impaired when the ground is frozen in winter.

A further possibility for surface seep drainage is to conduit the water into specially prepared depressions. These must of course be constructed permeable to water. In addition to the function of normal seep drainage, such depressions provide the possibility of accumulation retention capacity; but this speciality will be discussed at a later stage.

Only rainwater accumulating on driveways, access-ways and parking areas should be surface seep drained, wherever possible. Rainwater accumulating on roofs should be surface seep drained wherever possible; otherwise, such should be conduited into an underground seep drain system.
Should seep drainage not be possible, due to hydro-geological conditions, rainwater may be conduited via a rainwater drainage channel to a river or a lake. Any form of disposal into a dirty water conduit or channel is not permitted.

Surface seep drainage corresponds to the natural infiltration process of rainwater into the ground substrate. A good purification effect is thereby obtained. Apart from this, it ensures that a simple verification survey is possible by eye of the quality of the water being drained off and of the functionable capability of the seep drain system involved. For this reason, it is to be deemed the primary targeted form of any seep drain system.

**4. Underground seep drain systems**

Should any form of surface seep drainage not be possible, rainwater accumulating on roofs may be conduited into underground seep drain systems. Depending on local conditions, there are various possibilities available. The fundamental principle is again paramount, that the conservation of the ground water has always to be ensured.
Every underground seep drain system is to be equipped with advance sludge catchments. Such sludge catchments - as also, incidentally all services extending to the surface - may not serve as a flow inlet for accumulated surface waste-water, so that no water-hazarding fluids can obtain access to the seep drain system. For this purpose, screw-unioned and thick manhole covers are employed.

The first type of underground seep drain system is the

**seep drain shaft**

(Fig. 3)
In the case of a seep drain shaft, the seepage is effected at a relatively concentrated rate in one location point. This has the effect of only requiring minimum space. However, this form of seepage is fairly limited in its accommodation volume capacity, and therefore only suitable for smaller projects.

A seep drain shaft possess a minimum diameter of 1 metre. The wall of the shaft, underneath the flow inlet is perforated with apertures. The diameter and the height of the seepage shaft is determined on the one hand by the anticipated accumulation volume of water, and on the other by the seepage capacity of the ground substrate. The same basis is taken for the calculation of the water volume accumulation, that is also employed for the dimensioning of waste-water drainage pipes.
Water-impermeable material is used as extensively as possible above the seepage layer, for the surface covering around the seepage shaft.

Should the requisite seepage capacity not be obtained by means of a seep drain shaft, the effective seepage surface can be enlarged by the employment of a

**seepage trench.**
(Fig. 4)

As the term suggests, horizontally extended trenches can be excavated, that radiate out from a seep drain shaft, or from a control shaft, either in one direction, or in a star-shaped formation, until the requisite filter surface capacity is obtained. The width and the depth of the seepage layer are again dependent on the seepage capacity of the surrounding ground substrate. Two different variations of seepage trench are acceptable. Either a pipe is laid in the middle of the seepage layer, which has been perforated with apertures on its underside, or a trench is excavated and filled with a seepage layer, which is made up of rubble having a particle size of 30 to 80 mm. Extensively impermeable material is employed as a covering in such cases also, so that infiltration from above is largely prevented.

## 5. Accumulation retention reservoirs

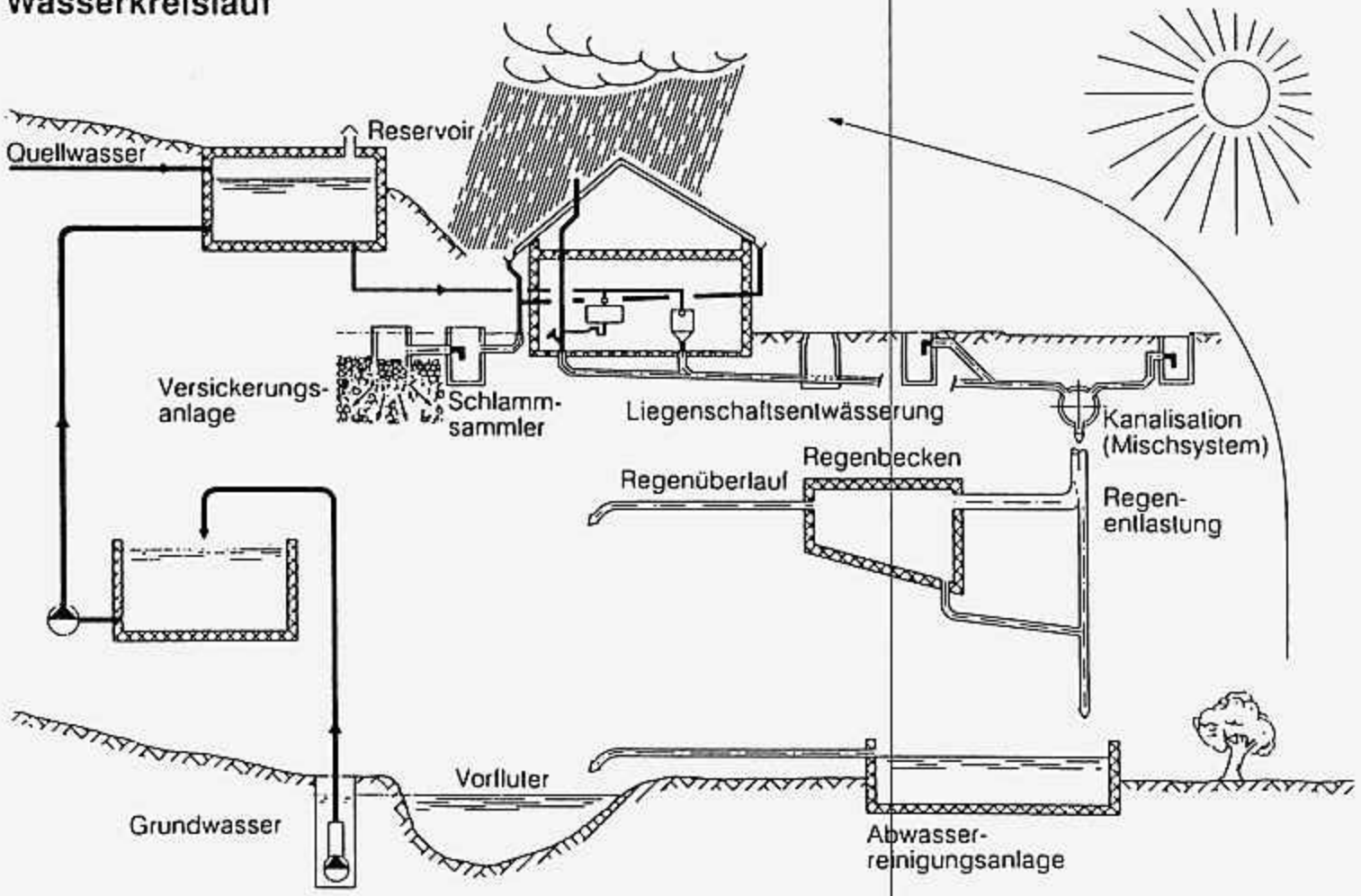
Rainwater accumulation retention reservoirs are employed to reduce high level flow rate impingements on the seep drain system, or to the sewer infrastructure. There are a variety of installations available for such purposes, ranging from garden biotopes to ponds, open-area space depressions, or even parking areas. In the construction of accumulation retention reservoirs, the drain outlet is intentionally dimensioned smaller than the flow inlet. The catchment container of a rainwater collection installation may also be employed as an accumulation retention reservoir.
The size, form and situation of retention reservoirs are dependent on local conditions. It is therefore meaningful to select as generous a capacity volume as possible. One aspect, that is not to be neglected, is that of the possible accident hazard. An open pond represents a special hazard for young children, and due care has to be paid to this aspect in the construction.

In the past few minutes, we have occupied ourselves with a brief overview discussion of our current seep drainage theory. By keeping an open eye on the geographic surroundings, it does however become apparent that there are often marginal differences between theory and effective practice. This should however not deter us from maintaining an ever daily awareness of the conservation of our ecological environment, and to give this aspect our greatest attention.

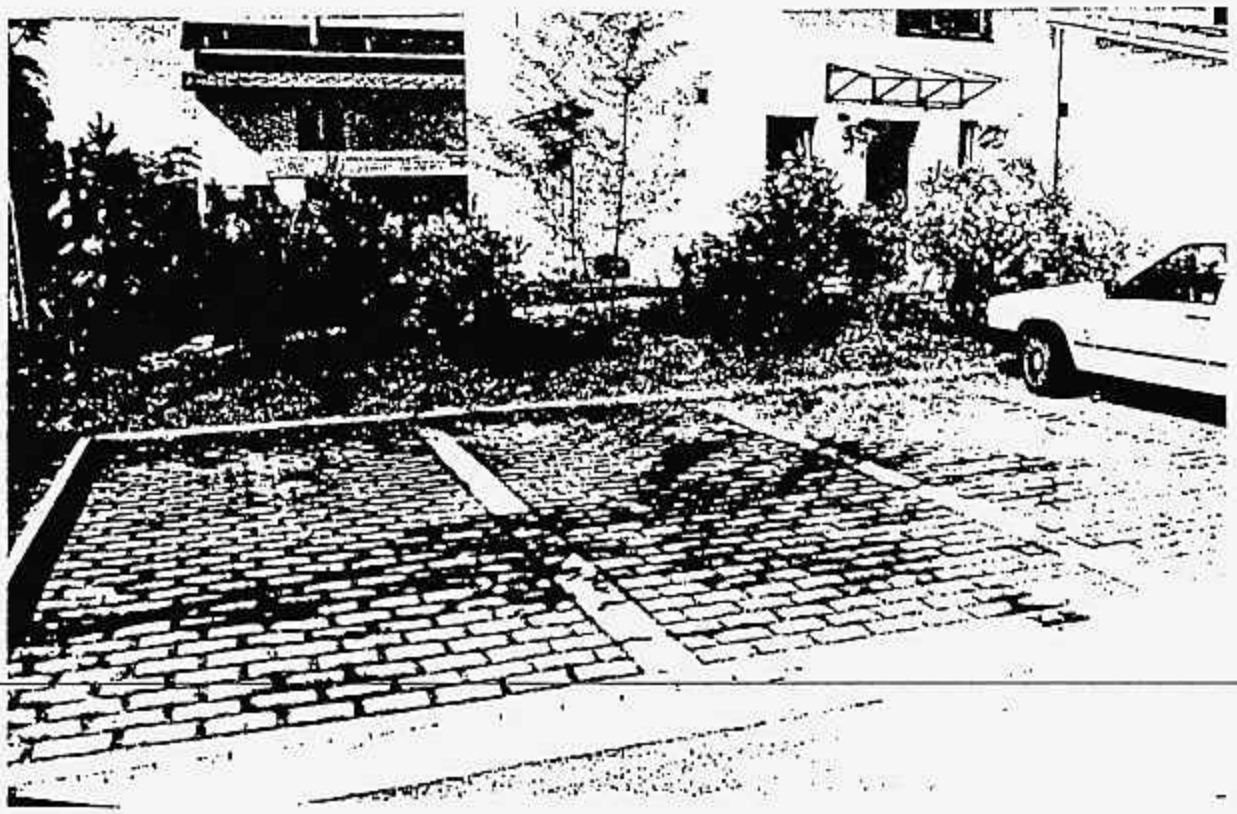
Bibliographical references:


- The Swiss Standard No. SN 592000
- Guidelines: seep drainage and water accumulation retention in the environs of real estate properties: issued by The Official Ecological Environment Agency of the Canton Lucerne, Switzerland.

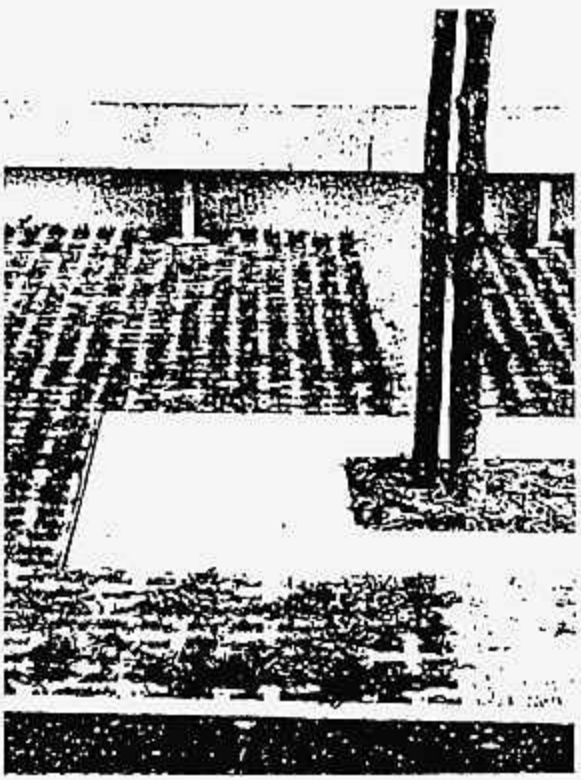
## 3.1.2 Wasserkreislauf



## Flächige Versickerung



Rasenfugensteine



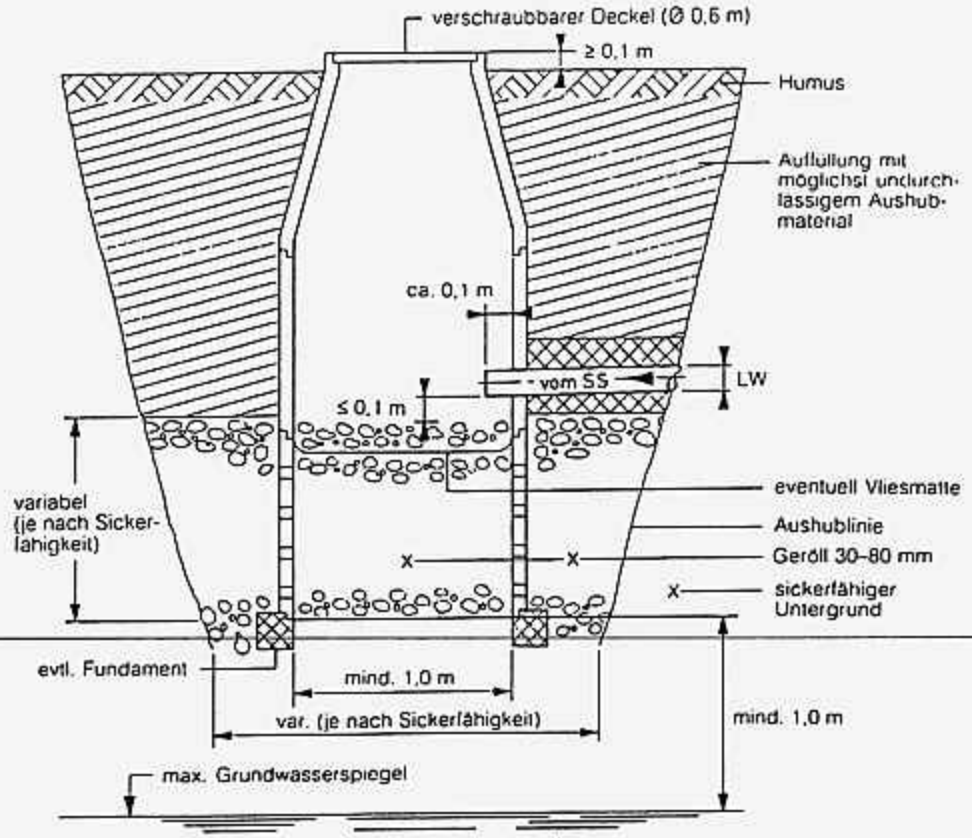
Rasengittersteine



Kieswege

Fig. 2

Beispiel eines Versickerungsschachtes:




Beispiel für grossen Wasserzufluss oder Zuleitung höher als 0.1 m über der Sickerpackung:

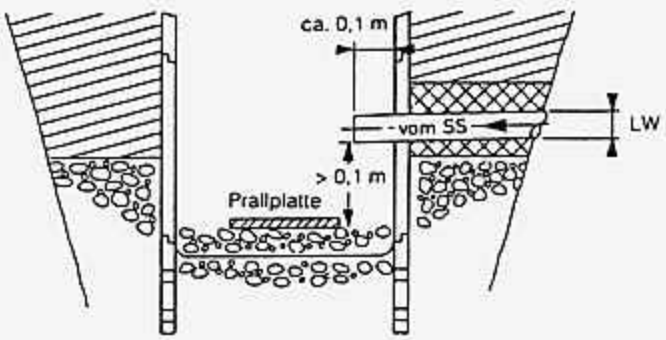
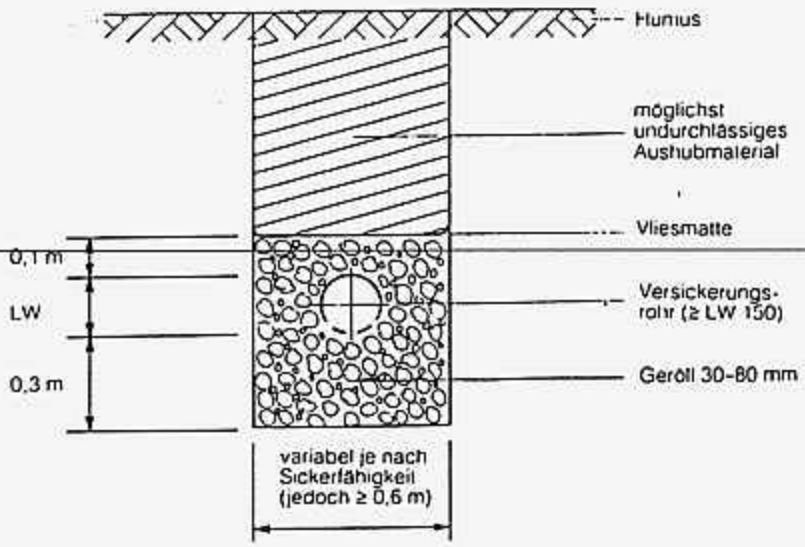



Fig. 3

## Versickerungsgraben mit Versickerungsrohr (Versickerungsgalerie)

Das Sohlengefälle des Grabens und der Leitung soll bei dieser Ausführung maximal 0,5% betragen. Als Versickerungsrohr wird ein mit den Löchern (Schlitzen) nach unten verlegtes Sickerrohr verwendet. Es soll mindestens von der Rohrweite LW 150 sein. Das Rohrmaterial muss den statischen Anforderungen dieser Verlegungsart entsprechen (unter Berücksichtigung auch von zukünftigen neuen Nutzungen, Überfahrten usw.). Am Ende des Versickerungsgrabens ist bei der Anwendung als Längsversickerung eine Kontroll- und Reinigungsmöglichkeit vorzusehen (Pulzstutzen, Schacht).




## Versickerungsgraben mit Sickerpackung (bis ca. 5 m Länge):

Das Sohlengefälle des Grabens muss bei dieser Ausführung mindestens 1% betragen. Der Graben kann je nach Sickerverhältnissen direkt an den Schlammsammler oder an einen Versickerungsschacht anschliessen.

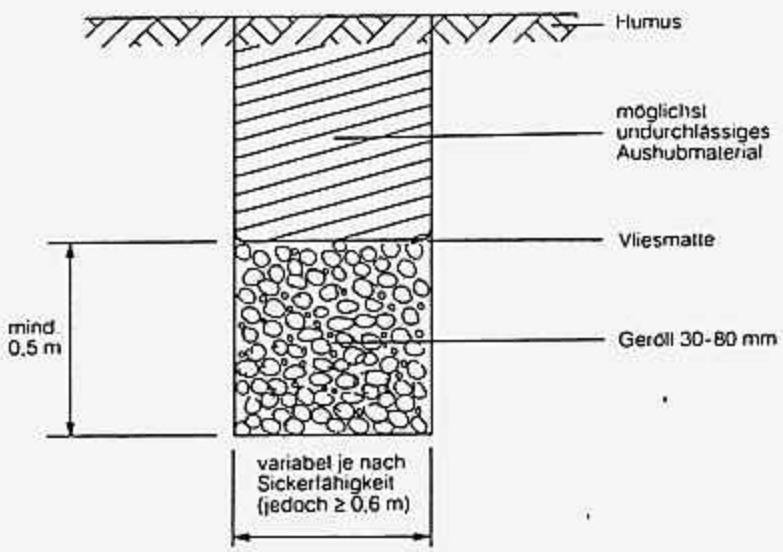



Fig. 4

# Topic C1

**Quality Control, ISO 9000**
**O. Gonçalves, Brazil**

# *THE PARTNERSHIP OF THE PRODUCTION CHAIN IN THE DEVELOPMENT OF QUALITY ASSURANCE PROGRAMS FOR PLASTIC PIPES*

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## 1. Introduction

The implantation of modern concepts of quality among the manufacturers of systems and components has meant a synonym of productivity and competitiveness, changing the scenery of the market and the way companies behave.

The increasing number of different techniques and methodologies to implant quality systems based on models of oriental origin or based on ISO 9000 standardized procedures caused difficulties to the companies when deciding procedures to be adopted. This occurred because in most cases there is a lack of system approach in quality. The quality matter can be analyzed according to the following aspects:

- **individual company** - the aspects of productivity, individual competitiveness and corporation and technical culture must be considered in the quality system to be adopted. There must also be a gradual and supervised implantation process aimed at achieving the established goals. The quality system can only be effective when it is completely incorporated to the company's culture and ISO 9000 certification is one of the steps of the process. Quality system that is implanted only with the purpose of obtaining ISO 9000 certification might not last long.
- **industrial sector - production chain companies** - The establishment of a partnership process must consider the perennial aspects, the sector competitiveness, the institutional culture related to quality and technological development. This partnership occurs with the related associations aiming at the development of Quality Assurance Programs with both an evolutionary and audited implantation process. The implementation of this process depends on the company capability of absorption of the new technologies, on the demands of the user/clients related to performance and costs, and on the institutional and ecological factors.

This paper focuses on quality in the industrial sector

Towards the beginning of the 90's the Brazilian Government made significant changes in its economic policy. The economy was opened. There was adopted a model of international competitiveness. The Federal Government then launched the PBQP - Brazilian Quality and Productivity Program in partnership with private institutions aiming at quality awareness, improvement of research and laboratories bases, development of models of quality management, encouragement of dialogue between government and private entities and finally wield the purchase power of the State to foment quality.

The Civil Construction Sector - including building construction and sanitation - considered during the elaboration of its PBQP Reference Document that institutional actions should involve all those constituting the production chain within the Quality Cycle of Civil Construction as shown in Figure 1.

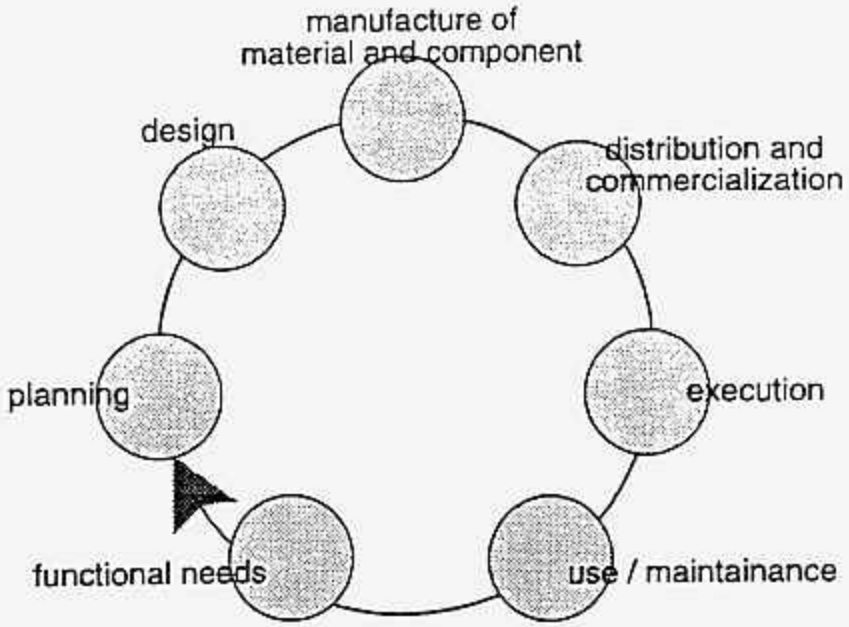



**Figure 1 - Quality Cycle of Civil Construction - Production Chain**

In the PBQP Reference Document one of the Civil Construction strategies and actions involving the industrial sectors was:

"To support and encourage quality assurance programs, promoted by private initiative and involving companies, in partnership and cooperation, in a production chain including from raw material to the final product".

In accordance to this PBQP strategy and related to water supply and drainage systems for buildings PVC resin and pipe manufacturers have decided to develop the Quality Assurance Program for PVC Pipes and Fittings presented below.

## 2 . Quality Assurance Program for PVC Pipes and Fittings within Building

The utilization of PVC pipes and fittings for cold water and drainage within buildings began in the early 60's, increased its application during the 70's and represents nowadays the components largely used in plumbing systems. In the early 70's there was created ASFAMAS (Association of the Manufacturers of Sanitation Equipment and Material). It involved in its PVC Chapter the PVC components manufacturers for water supply and drainage systems. At that time ASFAMAS concern was to create the first national standards together with ABNT - Brazilian Technical Standards Association.

The increase of the use of PVC piping systems caused in the 70's and 80's a considerable growth in the number of manufacturers. It's important to notice that a great part of these manufacturers were producing PVC pipes in **non conformity** with the national standards. From 1983 on, the ASFAMAS in conjunction with ABIVINILA - Brazilian PVC Resin Producers Association established a partnership of the production chain to do away with **non conformity producers** and in 1989 launched the Quality Assurance Program for PVC Pipes and Fittings

within Buildings called PGQ/PVC. The picture of quality of PVC pipes sector in the year of 1989 was the following:

- manufacturers of PVC pipes for plumbing systems - approximately 80
- manufacturers associated to ASFAMAS-PVC 07
- national production of PVC pipes in non conformity 35% to 40% of the total production

The adopted model for the PGQ/PVC is based on the concepts and on the procedures established in ISO 9000 standards series, in particular ISO 9002 and on the models of third party certification which was also praised by ISO. To manage the PGQ/PVC they hired an independent company of great technical capability, and proven credibility and acting in the civil construction field - buildings and sanitation.

## 2.1 PGQ/PVC goals

The main goal of the program - to formulate a technical and management basis - enables the manufacture of components (PVC pipes to water supply, drainage and venting for buildings) and installation of said components with controlled characteristics in order to fulfill the users/clients requirements aiming at:

- reach and maintain the quality, according to products technical specifications, in conformity to the users' needs;
- provide confidence to those engaged in the program that the aimed quality is being achieved and maintained;
- provide confidence among consumers of these products that the aimed quality is being obtained.

## 2.2 PGQ/PVC flow chart and attributions

Figure 2 presents a flow chart of the PGQ/PVC containing the entities involved:

- production chain
  - Sector Associations - ASFAMAS-PVC and ABIVINILA
  - Resin / Compound Producers;
  - Components manufacturers (PVC pipes);
  - dealers and final user.
- quality management
  - Independent company (TESIS)
  - Institutional Laboratory
  - data base and resources

and the attributions and established flow including:

- general directives - technical and administrative;
- audits sampling management, tests and results;
- sector data - qualification and issue of report;
- orientation and recommendation to the final users / clients

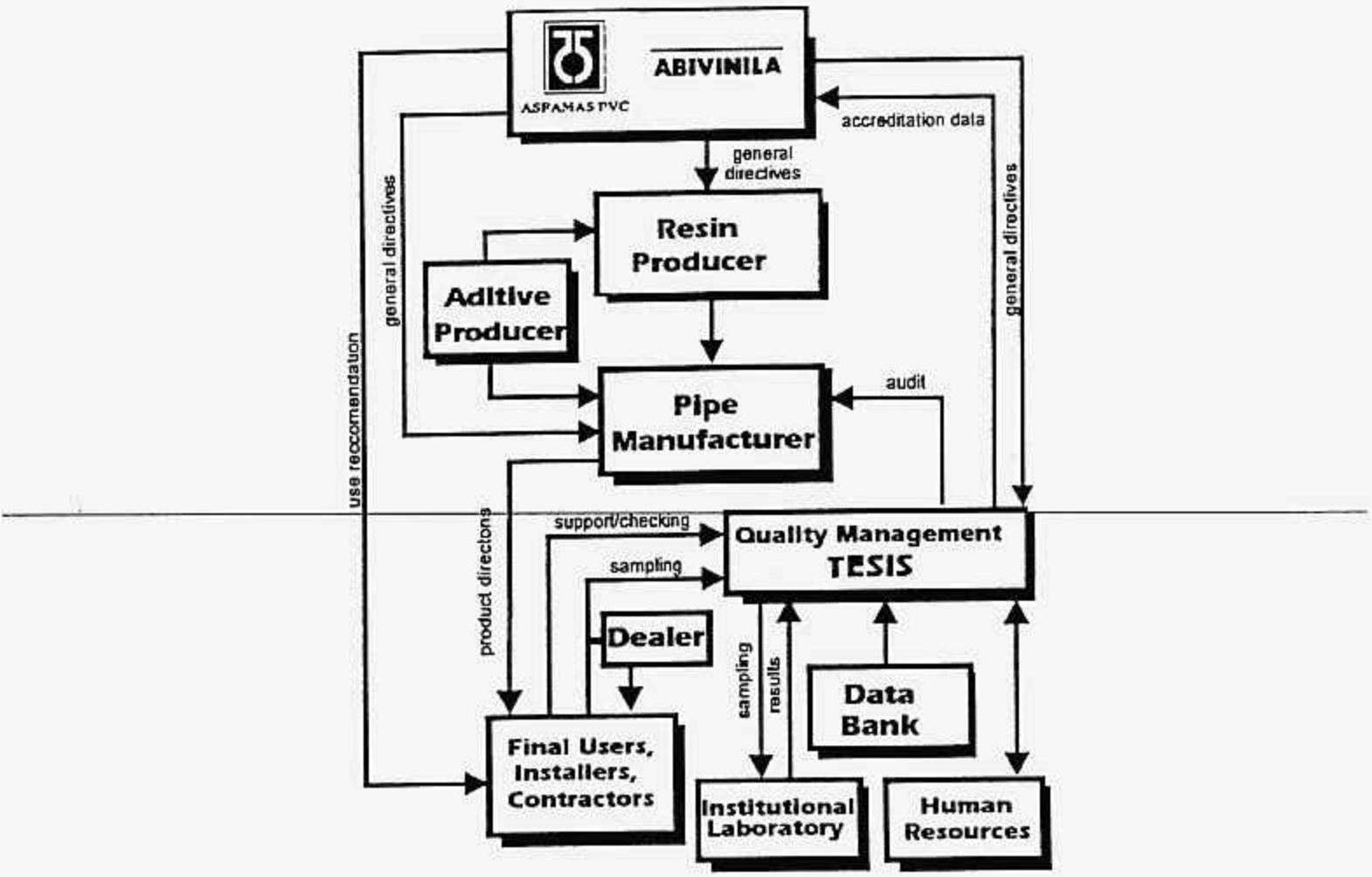



Figure 2 - Flow Chart of the Program

## 2.3 Activities developed in PGQ/PVC

The main activities developed in the PGQ/PVC are presented below:

- Elaboration of Technical Standards

  Technical standards have been developed with the cooperation of the companies involved in the program. The scope of these standards aimed at national and international market (including MERCOSUL). They were developed according to ABNT patterns and included:

  - technical specifications of products;
  - procedures of design, handling, transportation, storage and installation;
  - test methods checking the properties present in the specifications.

- Elaboration of Technical and Functional Documentation of the Quality Audit Program

  Directives and standards (codes) have been developed in order to run the program and the audit activities, including the documents below:

  - documents of the responsibilities and the duties of the companies involved in the Quality Audit Program - raw material producer, pipe manufacturer and audit company;
  - documents to audit the quality;
  - documents to engage companies that are willing to participate in the program.

- Institutional Laboratory of the Program

  It is a laboratory structure that gives support to the activities proposed in the documentation of the program.

  Basic Conception:

  It is an independent structure with low and rationalized costs using the existing laboratory resources of the companies and expanding them with the acquisition of new equipment. The Institutional Laboratory shall be constituted by:

  - laboratory equipment of the companies involved in the program that would be used, by the independent company, in order to maintain its neutrality;
  - laboratory equipment of the official accredited laboratory network;
  - laboratory equipment acquired cooperatively, and installed in a neutral location and managed by the audit company.

- Implementation of the Quality Audit

  Elaboration of the plan (annual / semestral) to implement the quality audit involving:

  - quality audit in the manufacturers of PVC pipes for water supply and drainage for buildings;
  - quality audit in the retailer / client

  The results of the audit of the sector are handed to the associations (ASFAMAS-PVC and ABIVINILA) keeping the information secret preserving thus the individuality of the companies.

- Institutional Activities Program

  The Institutional activities are those which present the program itself to the official organizations and to the technical institutions including:

  - create a data base of technical information, human resources and sector data information;
  - divulge the quality program in the Government Entities (Ministries and Secretaries);

- take part in the Brazilian Productivity and Quality Program - PBQP in the field of Civil Construction Industry;
- take part in the SGT-3 - MERCOSUL Technical Standardization - CSM-9 Plastic Components for Civil Construction;
- develop the program with ABNT - Brazilian Technical Standards Association under the CB-02 - Brazilian Committee of Civil Construction;
- take part in the activities of interest in the area which are promoted by entities linked to Civil Construction such as Contractors Unions, and Engineering Institutes;
- further the program and the product through Workshops and Seminars.

## 2.4 PGQ/PVC Documentation

The basic documentation of the program is constituted by the following texts:

- Technical Standards - ABNT and MERCOSUL
  - product specifications - 4 texts;
  - test methods - 22 texts;
  - design and installation procedures - 2 texts.
- Functional Documentation
  - Program Basis - Technical conditions and responsibilities of the entities;
  - Basic conditions to accredit manufacturers in the Program;
  - Quarterly reports of the Sector Quality - 30 texts
- Technical documentation
  - condition for storage and transportation of PVC pipes;
  - procedures to purchase and receive of PVC pipes for water supply and drainage systems;
  - technical guide to quality control;
  - technical instructions to PVC pipes sampling purchase;
  - procedures to quality audit visits;
  - lot inspection criteria - Sampling plans.

## 2.5 Results of the implantation of the PGQ/PVC

The main result observed was a complete change in the picture of the PVC pipes quality. The situation nowadays (April 96) can be expressed by the following data:

| | |
|---|---|
| • manufacturers of PVC pipes for plumbing systems | approximately 70 |
| • manufacturers associated to ASFAMAS which are involved in the Program | 16 |
| • national production of PVC pipes in non conformity | 6% to 8% of the total production |

A great improvement can be observed in the quality of PVC pipes with the increased number of involved manufacturers in PGQ/PVC (from 7 in 1989 to 16 in 1996) and a large reduction in the percentage of the non-conformity manufacturers (from 35% to 40% in 1989 to 6% to 8% in 1996).

Another important result to be mentioned is that the company focus on quality enabled patterns of performance established in the technical standardization to be improved. Said patterns existed at the beginning of the PGQ/PVC in 1989. From 1995 onwards the standard tests were revised and what was observed is that the technical parameters required for PVC pipes and fittings improved significantly.

This specific type of institutional work uniting all the segments of the PVC production chain, by the implantation of Quality Assurance Programs (PGQs) is being applied to other plastics components for Civil Construction. When aiming at the institutionalization of the mechanisms defined in the PGQ the CEDIPLAC - Center of Development and Documentation of Plastic Industry to Civil Construction - was created and is herewith presented.

## 3. Center of Development and Documentation of the Plastics Industry to Civil Construction - CEDIPLAC

The CEDIPLAC, created in 1994, is a center providing documentation and developing plastic technologies in Civil Construction - Buildings, Sanitation and Infrastructure. It is a private non profit organization acting through its Quality Assurance Programs (PGQ) that carry all the production chain included in the plastic sector such as the manufacturers of components and systems and the producers of resins and compounds in the civil construction sector, the design and consulting companies and the contractors as well as in the institutional sector the governmental corporations and the entities linked to the final users. CEDIPLAC's mission is to foment the development of the plastic industry towards civil construction and this through:

- development of plastic systems and components;
- quality of the sector and productivity improvement;
- implementation of technical standardization;
- improvement and integration of human resources;
- creation and diffusion of data bank.

## 3.1 CEDIPLAC and the Quality Assurance Programs

As mentioned, the CEDIPLAC bases itself on the Quality Assurance Programs (PGQ) in the same mold and with the same development of PGQ/PVC presented in Chapter 2.

Presently the CEDIPLAC maintain Quality Assurance Programs for different products and systems:

PGQ-1 - Quality Program for **PVC Pipes and Fittings** - initiated in 1989 focusing:

- water supply and drainage within buildings (PGQ/PVC)
- water distribution systems
- sewage systems

PGQ-2 - Quality Program for **Building Construction Components with PVC Profiles** - initiated in 1990 focusing:

- doors and windows;
- ceiling panels;
- sidings, etc..

PGQ-3 - Quality Program for **PE Pipes and Fittings for Gaseous Fuels** -initiated in 1992 and focusing:

- public systems (nets) for distribution of natural gas;
- private systems for LPG distribution.

PGQ-4 - Quality Program for **Plastics Systems for Control of Losses and Water and Energy Conservation** - initiated in 1994 focusing:

- water service pipe and water metering;
- valves and sanitary appliances for water conservation.

PGQ-5 - Quality Program for **Hot Water Plastic Systems** - initiated in 1996 focusing:

- CPVC (PVC-C) piping systems;
- gas instantaneous water heaters of high performance(safety x efficiency).

PGQ-7 - Quality Program for **PE Pipes and Components for Civil Construction** - initiated in 1995 focusing:

- water distribution systems - electrofusion and butt fusion.

Notice that **PGQ-6** - Quality Program for Electricity and Telecommunication Duct Systems is under preliminary study and shall be implanted from 1997 onwards.

Therefore CEDIPLAC's main purposes , through its Quality Assurance Programs (PGQs) are:

- increase the participation of plastic systems and components in the civil construction market as well as research and development activities of the sector;

- coordinate the development of standards to plastics systems and components for civil construction;
- aim at the quality of the civil construction plastics products coordinating the quality audit, developing mutual trust among manufacturers and the respect to the consumer;
- support the manufacturers during the implantation of the quality management systems according to ISO 9000 series;
- act as technical information center as well as a sector center of plastic for civil construction answering the clients' interests regarding quality assurance, requirements and use of products;
- arrange agreements with universities aiming at the improvement of human resources and training as well as better partnership in the production chain where clients are involved in the development of products and services.
- support the efforts towards harmonization of MERCOSUL.

### 3.2 CEDIPLAC and technical standardization

The development of standards and patterns is one of the purposes of this Center. As a consequence, CEDIPLAC is responsible for the Sub-Committee 111 - Plastic for Civil Construction of the Civil Construction Brazilian committee (CB-2) from the ABNT - Brazilian Technical Standards Association. Therefore, for a four years period, CEDIPLAC is in charge of the Sector Standardization Plan (PNS) concerning Plastic in Civil Construction. This task includes the establishment of study commissions, the elaboration and revision of texts and the standardization process planning activities.

CEDIPLAC has developed, so far, through its PGQs, **22 specification of product lines** and components as well as **90 test methods** and **17 procedures of design and installation** of system's. Those standards were conceived in accordance to the principle of integrated groups of texts (procedures, specification and test methods) rendering the investigation task easier and showing that the system and its respective product line were standardized systemically.

CEDIPLAC also takes part in the Mercosul standardization process associating since 1990 Argentina, Brazil, Paraguay and Uruguay and more recently Chile. The MERCOSUL Standardization Committee (CMN) was created in 1992 constituted by the National Standardization Entities - (ABNT for Brazil), developing its role through the Mercosul Sector Committees (CSM). The CSM represents the industrial segments of the society and aim at the establishment of standardization programs and the management of the harmonization and elaboration processes of technical standards.

CEDIPLAC is in charge of CSM - 9 Mercosul Sector Committee - 9 - Plastics for Civil Construction since 1996 as well as the Brazilian standardization committee. The CSM-9 initial scope is the elaboration and harmonization of 9 procedures (design and execution of systems), 8 specifications of product line and 45 test methods, involving mainly PVC pipes and fitting; PE pipes and fittings and PVC-C pipes and fittings.

So far CMN have approved 4 test methods which are now validated as Mercosul Technical Standards.

### 3.3 CEDIPLAC research and development

CEDIPLAC's way of acting - through its PGQs - involving plastic production chain for Civil construction - helped to create a favorable environment for institutional actions, for cooperative research and development of system projects aiming at the broadening of the market.

Taking this into account, CEDIPLAC, in association of 3 companies participants of the PGQ/PVC and the Escola Politécnica of the University of São Paulo (EPUSP) agreed (late in 1995) to create and implant a "Center of Research and Development of 100% Plastic Sewerage System". This center is constituted of a building in an area of approximately 600m2 and a laboratory with an area of approximately 1300m$^2$, both linked to the Building Systems Laboratory at EPUSP. The activities to be developed in this Center include:

- establishment of design models and dimensioning of the sewerage system 100% plastic - experimental survey of technical parameters;
- technical development of the sewerage system components - substitution of manholes by simpler plastic devices;
- development of cleaning technique and maintenance by means of hidrojet equipment;
- training program for engineers and technicians;
- elaboration of technical documentation, base of design and execution of 100% plastic sewerage system.

This center is being build and plans foresees that it will operate by the first semester of 1997.

### 4 Final Comments

The involvement in partnership and cooperation of this production chain in the development of Sectors Quality Programs resulted in rise in quality of the products and in the increase of productivity in the production and installation processes. The results obtained through the implantation of the PGQs and the institutionalization of CEDIPLAC in the 90's can be resumed as follows:

- evolution of the plastic components for civil construction with the reduction of products manufactured outside of the standard patterns and the improvement of production processes - **vertical quality**;
- coordination of the plastic sector defining the actual needs in relation to components and process development produced by other industrial sectors but interacting with the plastics systems, for instance hidrojet equipment, hydraulic valves, water heaters, etc. - **horizontal quality**;
- creation of an institutional environment in order to develop cooperative and integrated works aiming at the increase of the plastic market share for civil construction - **sector competitivity**.

Thus, it can be observed that the tendency of the Brazilian model is the consolidation of this model of work with the strengthening of the production chain acting in partnership aiming at vertical quality as well as the evolution of the coordinated horizontal quality.

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# Topic C3

## Introduction of ISO 9000 Systems in Plumbing and Heating Contractors Companies

J. Tester, Switzerland

# The Introduction of ISO-9000 Quality Assurance Systems for Plumbing and Heating Contractors or: „Coaching is the Magic Word!"

**A review of the Swiss building market, with special consideration given to the heating and plumbing trades, and their quality control problems .**

*A paper by Jay Tester, technical adviser with the Swiss Plumbing Contractors Association (SSIV), Zurich, Switzerland.*
*Not all figures are included in this paper due to copyright problems.*

The ability to play a piano concerto from Tschaikowsky, Rachmaninow or Ravel from memory, has some parallels to a system, whose aim is to ensure the quality of customer services. However, instead of ascending to the delights of classical music, let us first descend into the depths of the Swiss building market, which is currently at an all time low.

## Poor Switzerland

In a referendum held in 1992, Swiss voters rejected the entry of Switzerland into the internal European Market, and thus, to all intent and purpose, into the European Union. Practically speaking, Switzerland is an isolated island in the heart of Europe, just as we were during the Second World War. As opposed to those days, when our nation was entitled the „Land of the Blessed", we are today rather more amusingly seen as „The Country which is continually misses the Boat". Swiss industry is currently shutting up shop at home and reopening again in surrounding countries, or even overseas including Asia. Hundreds of thousands of Swiss jobs were outsourced to new production facilities and reports of redundancies and works-closures beginning to be just as much a part of the news as the daily weather forecasts. The exit of industry from the country has lead to the situation of no new building construction being required for trade and industry, and there are regular headlines of the type „Number of Building Permits is continues to decline" in the Swiss press. As if this were not enough, the house building market has recently threatened to collapse, because demand has already been satisfied.
The Swiss building industry now finds itself at the beginning of a fundamental crisis and it is agreed that a considerable number of firms will be bidding farewell to business life. The only organization to survive, will be those that are successful in maintaining the long term quality of their services at a high level. In the face of increasingly hostile competition, only the most effective and customer-oriented organizations are going to survive (slide).

## Continuous Improvement

The successful organization of the future will be one that is fully aware of its strengths and weaknesses and reacts to these with a clearly defined corporate strategy. On the basis of a realistic self-analyses the requisite corrective measures will be introduced in good time and far-reaching goals and sights are defined. An organization without any form of business strategy will stagger from experience to experience, like a punch-drunk boxer shortly before the final knockout blow.

One-dimensional technically oriented organizations are going to find it difficult in the future, because, as a result of their unilateral focusing, they will with certainty fail to notice relevant social changes.

Autocratically managed organizations, whose chief executive is of the opinion that he knows better than his workforce, are increasingly exposed to recruitment problems, because the young people of today no longer appreciate this style of management. Required is a workforce oriented management style, where highly motivated teams of colleagues can be built up. The entire workforce should consist of self-directed work-teams that are fully responsible for the results of their work. The successful organization will have a process of ongoing development within a culture of continuos improvement. Creativity is systematic and the method for survival; the sole constant is unremitting innovation and adjustment.

The successful organization will possesses an advanced system of quality assurance, to assist in meeting increased customer requirements.

## Advanced Quality Assurance Systems

Advanced quality assurance systems do not just emerge from the „straight-jackets" introduced by some written standards; they are developed and adopted by the workforce as a whole and are build up by innovative, flexible, open, performance-oriented and committed workforce-teams. The chief executive of a company with an advanced quality assurance systems restrict himself to management tasks and only provide assistance when a member of the workforce has difficulty in fulfilling his assignments. **Coaching is the magic Word!** The modern entrepreneur directs his organization in the same way as a coach runs his team of football players. The chief executive delegates authority to his workforce, but he expects commitment and personal responsibility from every individual on the other hand..

## Marketing

Professional marketing concepts are new for organizations within the building industry, and rather unusual. In the face of less binding customer loyalty, active sales will become more and more important. Professional marketing concepts are therefore part of advanced QM-Systems. A company news paper and a brochure for new services are some parts out of a professional marketing concept (samples available).

### Customers / Workforce

It is important to be aware of the requirements and opinions of both customers and the workforce. Organizations with advanced quality assurance systems are in possession of a tool, which will enable the requisite information to be collected. In order to illustrate this more clearly, an example is shown of a typical **workforce questionnaire** and its graphic evaluation (slides).

### Advanced Training

The advanced training of the workforce in the building industry is should include not only exhaustive training in technical skills, but also in management and interpersonal skills as team-building, group behavior and psychology, etc. For example, several organizations consider it useful to give their fitters a course in public speaking (communication skills), as they know that benefits can be obtained in practice from their workforce demonstrating self confidence with customers, site managers and architects.
A training program checklist of a small firm with a workforce of seventeen, where consideration was given to making the **training measurable** is shown as an example of new ideas (slide).

### Descriptions of working procedures

Technical instructions and the painstaking descriptions of working practices, as well as their complete documentation, and therefore retro-traceability continue to remain an important mainstay in quality assurance (slides).

### New Trends / New Services

A new aspect is an intensive pre-occupation with the social and technical environment. Only those, who are capable of recognizing trends at an early stage, will be able to protect themselves from wrong decisions. As an example, the following thoughts: In the face of the increasing number of „zero energy" houses, which require no conventional heating system, contractors should consider, whether it might not be sensible to build up a second business-area dealing with building cladding or alternative energy equipment. Additional and profitable fields of activity are also opening up in the booming infrastructure technologies of control and safety facilities.

## Environment

A new aspect is the continual preoccupation with the effects of the organization activities upon the environment. Society is already moving towards demanding that manufacturing industries should be made responsible for the damage they inflict upon the environment. In the building industry, institutional employers, insurance companies, banks are the organizations beginning to make such requirements too and demanding tenderers to show evidence of operating an environmental management system. As an example, a graph is shown of Switzerland's first ISO 14000 certified plumbing contractor (25 employees), which has set itself the target, of making savings of 1,000 litres of fuel in 1997. The dark gray areas indicate the saving which will be achieved, whilst the light areas show the burden remaining on the environment.

## Is ISO-9000 sufficient?

The aspects discussed previously go far beyond the basic requirements of ISO-9000. Cynics have even suggested, that ISO-9000 is so rudimentary in its layout, that it is possible to produce „certified rubbish" without the intervention of anybody, as long as the business records can be traced back over a number of years. The formal quality management assurance requirements of the type laid down in ISO-9000 therefore fail to satisfy future needs. The future belongs only to quality assurance systems applied with total commitment.

## SSIV-Activities

In collaboration with external consultants, SSIV has developed an advanced quality assurance system in which all the requirements described above are covered.
The system is termed Integrated Quality Management System or IQM-System. The patented Logo (slide) is intended to show the human being (red stripe), technology ( blue stripe), environment (green stripe). The symbol of a smiling face expresses the idea that high quality can rather be achieved by happy people.
Although IQM is constructed quite differently to ISO-9000 and ISO-14000, but it complies with their requirements in every aspect.

## Introduction of IQM-Systems

A certain number of Swiss heating and plumbing contractors already operate a quality assurance system. Nevertheless, they represent a minority of the total number of heating and plumbing contractors. The word „minority" tends to have a somewhat „negative" aspect, and reference should perhaps be made, to a small but fine „elite".
In the case of those organizations that have introduced a comprehensive, integrated an IQM-System, it has been possible to determine the following considerable changes.

**Workforce Climate**

All organizations report evidence of a far better attitude in the workforce; and that the relationship between management and workforce is better balanced than previously. In addition, the relationships between the organization, its suppliers, customers and architects - i.e. all outside contacts - are considerably improved, and friction and frustration in the daily course of business, have reduced.

**Damages Statistics**

All firms are of the opinion, that there is enormous potential for avoiding or reducing defects and damage. For this reason claim statistics have been established. In this regard, it is assumed that damages have arisen, when the claim exceeds 100 Dollars. This would be the case for example, when two workmen have to wait half an hour for a supplier. Total annual figures of 150'000 and 200'000 Dollars of damages have been recorded and savings of half of these sums have been achieved.

**Capital Investment**

When quality assurance were first introduced into the heating and plumbing trades in Switzerland (1993), it was assumed that the costs would not be less then 80'000 Dollars. The standardization and optimization of the procedure have today brought down the costs to 20'000 Dollars. However, these figures do not include the internal costs due to time the workforce put into the build up of a quality assurance system. A rule of thumb is, that internal costs run at about double that of external costs. On this basis, we are talking today of an overall capital investment figure of between 60'000 and 80'000 Dollars.

**Pay-back**

All organizations questioned, including all those possessing extremely expensive assurance systems, report that they had assumed that the capital investment could be paid back within time periods ranging from one to three years trading.

**Owners / Managers**

When chief executive or managing directors are questioned as to whether the efforts have paid-off, they usually produce a saintly look, and the effects of the enormous work and emotional stress, to which they were exposed during the introduction of the quality assurance system, can be read off their faces. As in the case on an alpine climber, who has to pause for breath once he has reached the summit, satisfaction is only experienced after the passage of time. However, after that, there is just no holding these people, and sometimes the impression is given of a missionary preacher, intent of spreading some new religion.

## Is an Advanced or Integrated Quality Assurance System needed?

This question now brings us round full circle. We have arrived back at the point where an explanation should be given of the connection between the ability to play a piano concerto faultlessly and a quality assurance system.

There are three parallels.

1. The listener to a piano concerto demands a quality performance; in just the same way as any consumer of any type of service. The pianist is in a position to satisfy this demand or not; in exactly the same way as the management of a heating and plumbing contractor and its workforce are able, to provide a high degree of quality, or not.
2. The pianist began his profession quite small, and in his initial years clung desperately to the C-major key on the white keys, without having the slightest idea of the millions of possibilities opened up by using the whole tonal system with its multitude of triads and scales. Organizations having an quality assurance system focused to the pure ISO-9000 only, represent pupil pianists, ranging up and down the C-major scale, using only the white notes, without benefiting from the additional possibilities, that an advanced or integrated quality assurance system is able to provide.
3. The pianist needs to keep a piece of sheet music in front of his eyes for several years, before he is capable reproducing the most complicated of pieces in his mind, and to be able to play them by heart, free from errors. This is also typical of an organization where the instructions, check lists, process descriptions etc., need to be used many times, before being able knowing all these things by heart, and to be able to recite them whilst sleeping.

Coming back to the initial question:

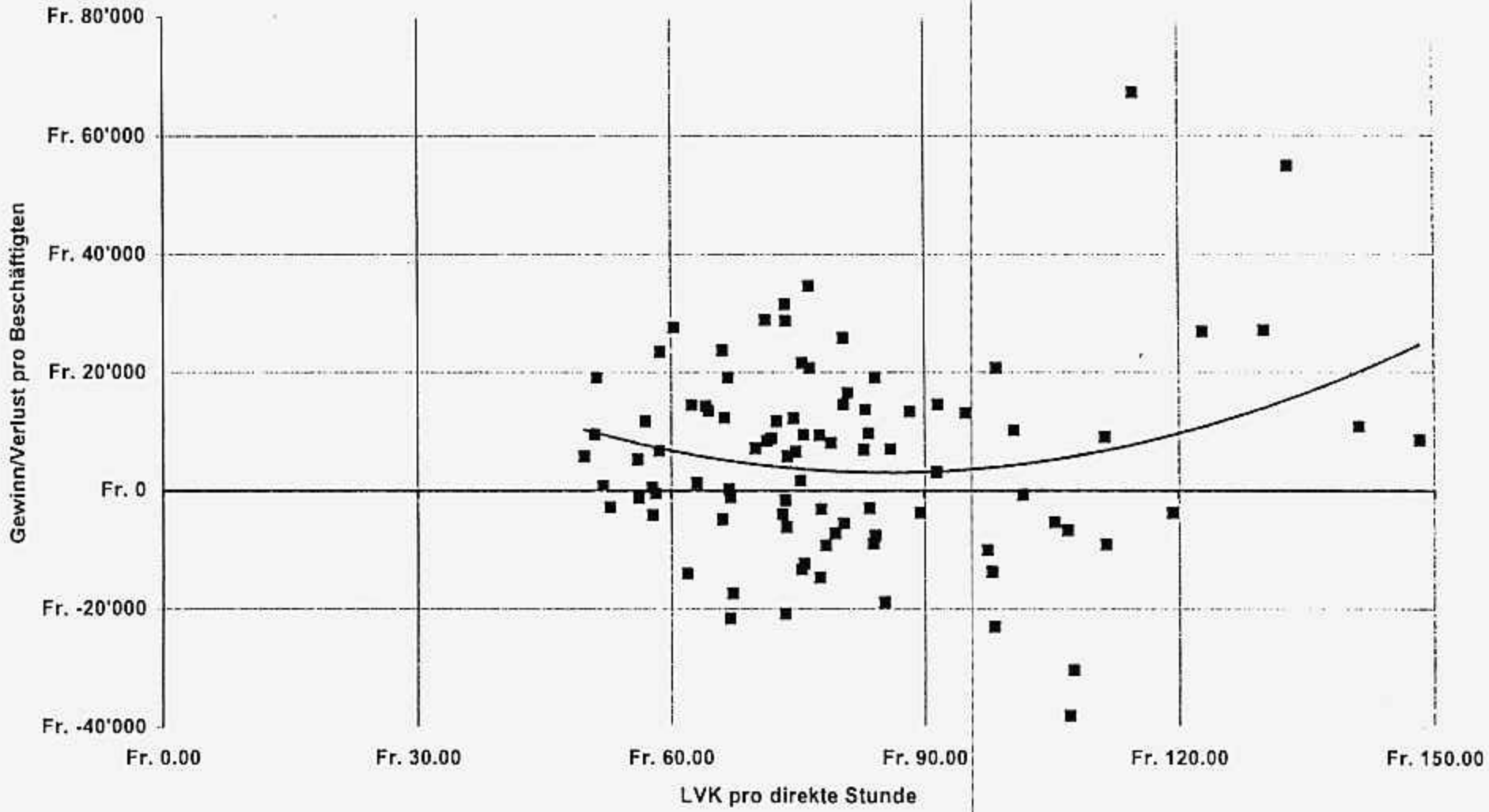
Do companies in the building industry need a quality assurance system?

The answer is: **Yes!**

Do such organizations need an **advanced or integrated** quality assurance system?

The answer is: **Who wants to play in C-major key only?**

## 9.4 Streuung nach Lohnverkaufskosten pro direkte Stunde und Betriebsgewinn pro Beschäftigten



**Ihre Arbeitszufriedenheit**

Geben Sie bitte an, wie zufrieden Sie mit Ihrer Arbeit sind, und wie wichtig die einzelnen Bereiche für Ihre Arbeitszufriedenheit sind.

| | **Zufriedenheit** | **Wichtigkeit** |
|---|---|---|
| | 1 2 3 4 | a b c d |
| 1. Arbeitsbedingungen (Umfeld, Ausstattung) | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 2. Arbeitsorganisation | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 3. Arbeitsplatzsicherheit | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 4. Arbeitszeitregelung | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 5. Betriebsklima | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 6. Entscheidungs- und Handlungsspielraum | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 7. Ansehen des Verbandes | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 8. Fort- und Weiterbildungsmöglichkeiten | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 9. Lohn/Einkommen | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 10. Information | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 11. Aufstiegsmöglichkeiten | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 12. Kollegen | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 13. Leistungsbeurteilung | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 14. Möglichkeit, meine Fähigkeiten einzubringen | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 15. Qualität der Arbeit | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| 16. Vorgesetzte | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |
| | 1= sehr unzufrieden<br>2= unzufrieden<br>3= zufrieden<br>4= sehr zufrieden | a= unwichtig<br>b= wenig wichtig<br>c= wichtig<br>d= sehr wichtig |

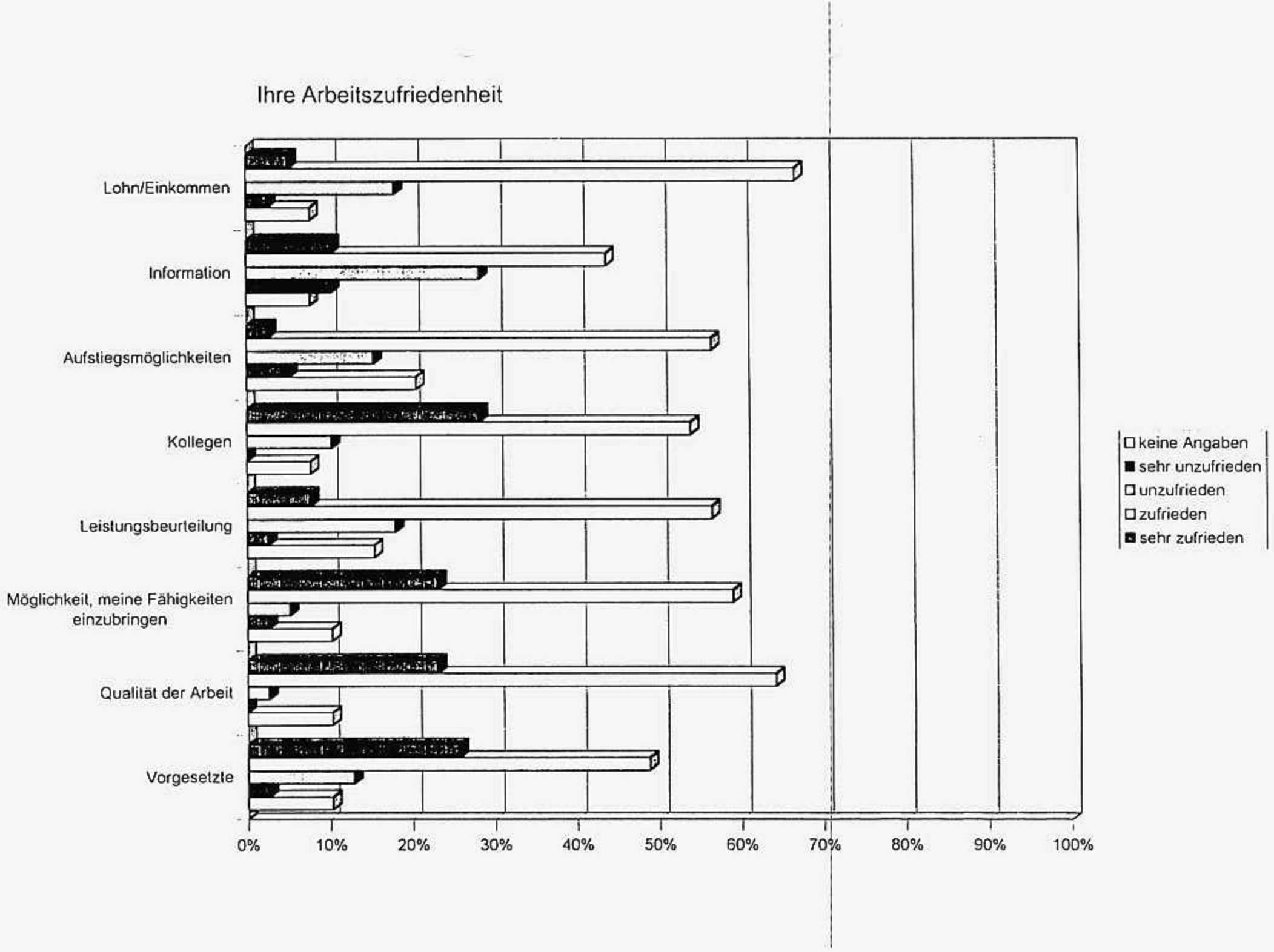
Wie beurteilen Sie Ihre Arbeitszufriedenheit insgesamt:

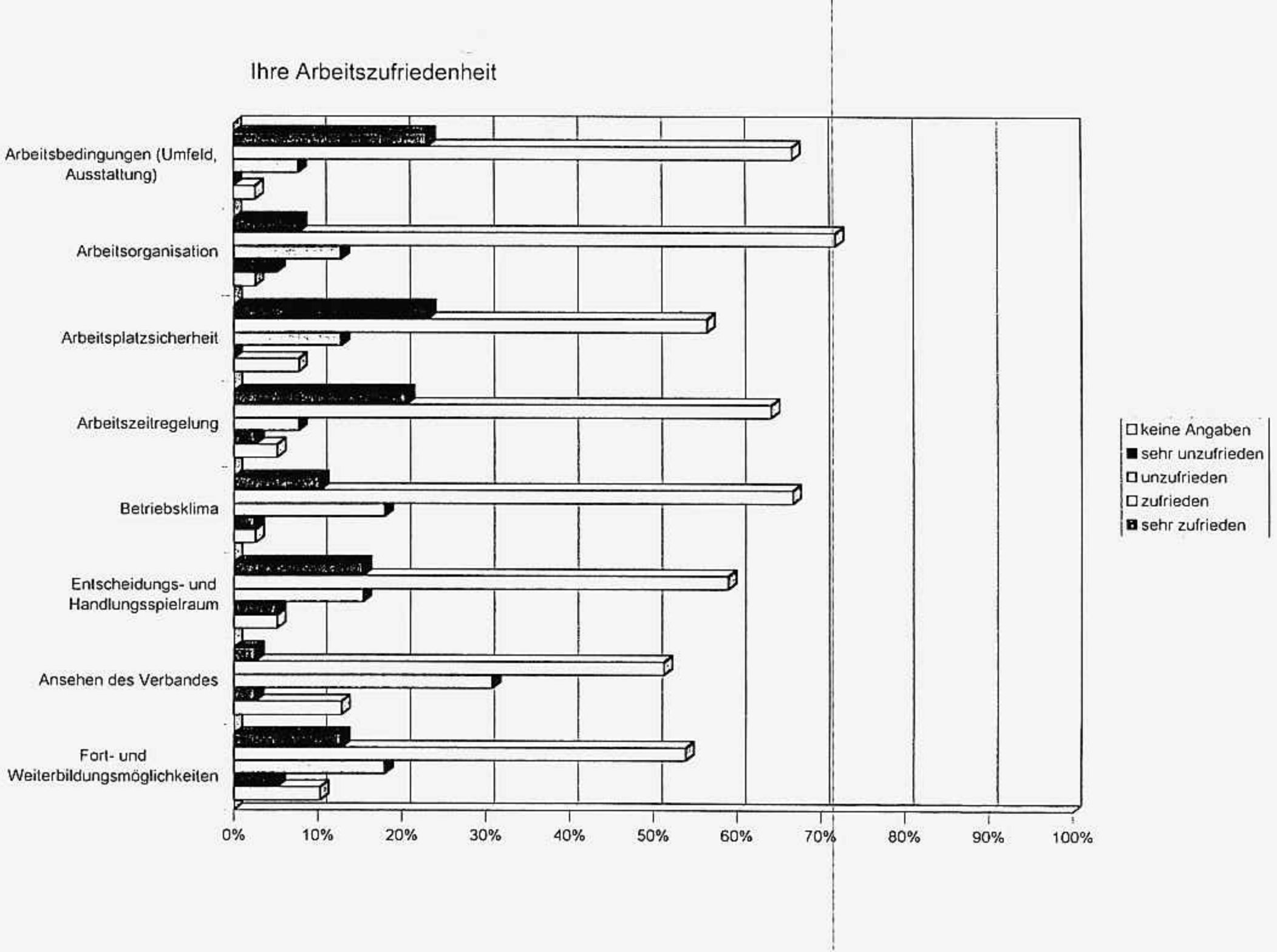
☐ sehr unzufrieden
☐ unzufrieden
☐ zufrieden
☐ sehr zufrieden

**Ihre Meinung interessiert uns!**
Deshalb nochmals vielen Dank, dass Sie bis zum Schluss durchgehalten haben.



SSIV Auf der Mauer 11 Postfach 6340 8023 Zürich Telefon 01 251 74 00 Telefax 01 251 32 28


Ihre Arbeitszufriedenheit
Lohn/Einkommen
Information
Aufstiegsmöglichkeiten
Kollegen
Leistungsbeurteilung
Möglichkeit, meine Fähigkeiten einzubringen
Qualität der Arbeit
Vorgesetzte
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
keine Angaben
sehr unzufrieden
unzufrieden
zufrieden
sehr zufrieden

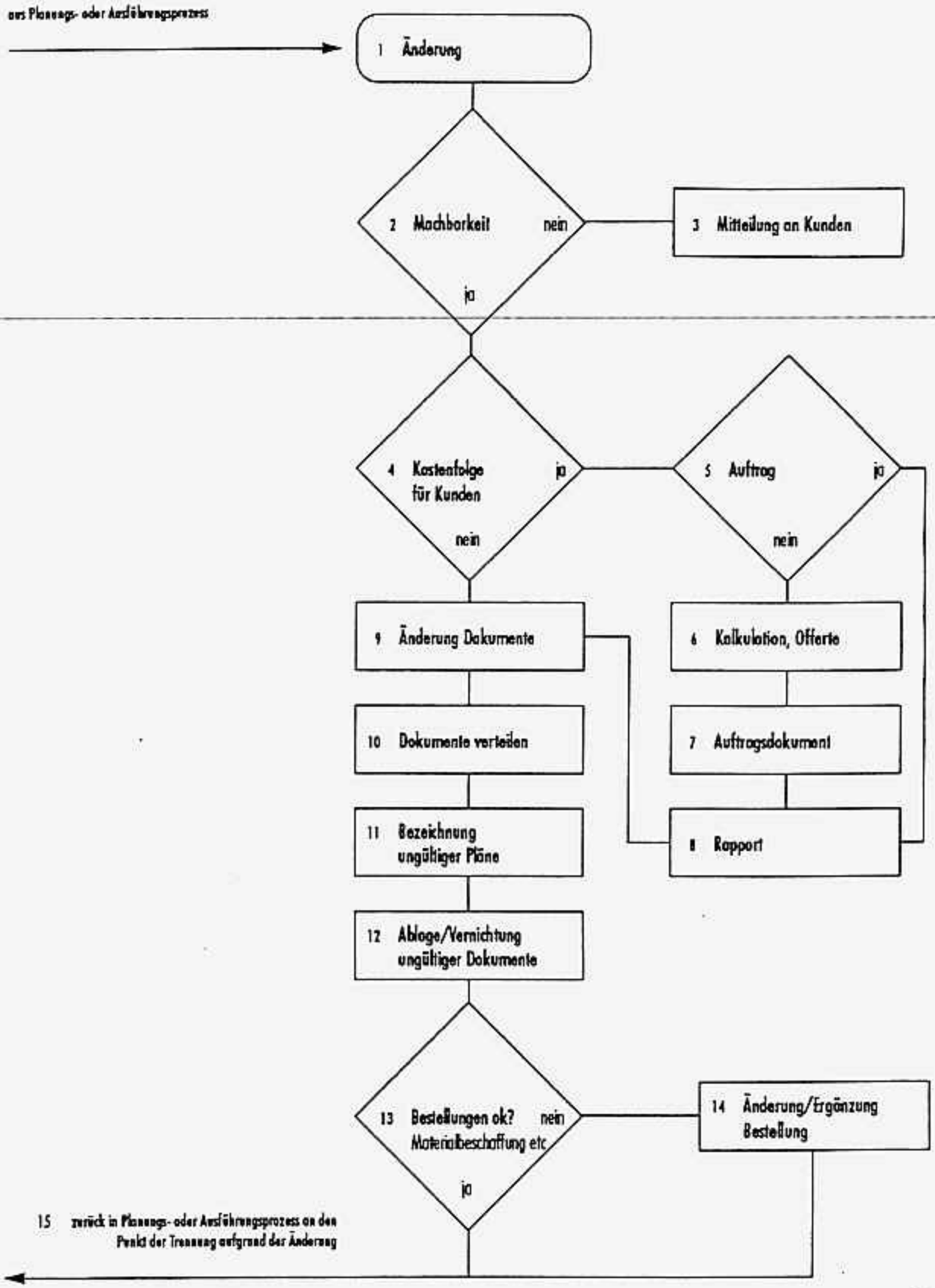

Ihre Arbeitszufriedenheit
Arbeitsbedingungen (Umfeld, Ausstattung)
Arbeitsorganisation
Arbeitsplatzsicherheit
Arbeitszeitregelung
Betriebsklima
Entscheidungs- und Handlungsspielraum
Ansehen des Verbandes
Fort- und Weiterbildungsmöglichkeiten
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
keine Angaben
sehr unzufrieden
unzufrieden
zufrieden
sehr zufrieden

| | GIS-Verantwortung | Verantwortung Logistig/AVOR | Kundendienst | Pikettdienst | Projektierung | Leitung Vorfabrikation/Lager | Sanitärinstallateur | Apparatemontage allgemein | Montage Whirlpool | Montage Clos o mat | Montage Trennwände | Montage Blewannen | Montage BZ-Möbel | Montage Vorwand-System GIS | Montage Vorwand-System Mepla | GF-Z-Mass System | GF und Kupfer löten | Optipress Stahl | Optipress Kupfer | Mannesmann-Press | GF-PVC kleben | Polybuten GF | Mepla-System | Optiflex | Sanipex | Instaflex | Unisan | Straub-Verbindungen | PE-Geberit-Ablauf | PE-Geberit (Pluvia) | PE-Geberit Silent | PE-Wavin Ablauf | Astolan-Wavin Ablauf | Guss Ablaufinstallation | ET-Ablaufinstallation | Begleitheizung Tobler | Begleitheizung Raychem | Regulierung WW-Zirkulation | Isolation Armaflex roh | Isolation Geberitisol | Isolation Schalen roh | Isolation komplett sichtbar | Vorfabrikation Abläufe | Entsorgung Materialien | Autogen-Schweissen | Elektro-Schweissen | Schutzgass-Schweissen | Kenne spez. Befestigungst. | Hochdruck Guss für Bodenleitung | Hochdruck PE Bodenleitung | Hochdruck ET Bodenleitung | Reservoir- und Pumpenwerkst. | Niederdruck PE Bodenleitung Gas | Gasinstallation System Briegaflex | Abluft- und Frischluft Fe verzinkt | Enthärtungs- und Osmoseanlagen | Abwasserpumpenanlagen | Schutzrauminstallation | Total |
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| Beat Burren | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Marcel Christinger | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Peter Hafner | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Eduardo Lucas | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ricardo Lucas | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Patrik Lüthard | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Bruno Marra | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Beat Plüss | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Jean-Pierre Porchet | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ueli Schaad | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Philipp Schibli | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| John Weber | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Heinz Wernli | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ernst Wüst | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| Christian Frei | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Andreas Sommer | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| Total | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

4 Kann ausbilden
3 Selbständige Anwendung
2 Unselbständige Anwendung (mit Lehrabschluss)
1 Kann nicht anwenden
0 Spezialist

grün wird ausgebildet (Jahr)
gelb Ausbildung ist vorgesehen (Jahr)

## 4.3.6 Änderung




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Erklärungen zur Subroutine **Änderung**

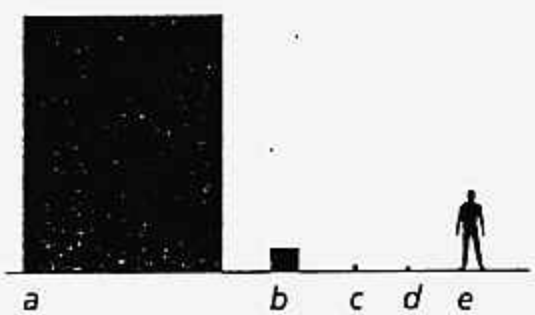
| Nr. | Bezeichnung | Anweisung | Dokumente | Verantw. |
|---|---|---|---|---|
| 1 | Änderung | Ist in jeder Phase des Planungs- oder Ausführungsprozesses möglich | Pläne, Auftrag<br>AEN | PL<br>SM<br>HM |
| 2 | Machbarkeit | Subroutine, Seite 430 | | |
| 3 | Mitteilung an Kunden | Falls der Auftrag nicht ausgeführt werden kann, wird der Kunde schriftlich (ausnahmsweise mündlich) informiert | Brief<br>AEN | SB<br>PL |
| 4 | Kostenfolge für Kunden | Feststellung | AEN | SB<br>PL |
| 5 | Auftrag ja/nein | Feststellung | AEN | |
| 6 | Kalkulation, Offerte | Subroutine 'Offerte', Seite 432 | | |
| 7 | Auftragsdokument | Sobald uns der Kunde die Änderung in Auftrag gibt, werden sämtliche Auftragsdokumente (Nachtrag zum Werkvertrag, Auftragsbestätigung) durch uns oder den Besteller erstellt | AEN | PL<br>SB |
| 8 | Rapport | Rapport wird erstellt | Rapport | HM<br>SM<br>PL |
| 9 | Änderung Dokumente | Änderungen werden (wenn zeichnerisch möglich) in den Dokumenten nachgetragen.<br>Speziell: Bei auszugsweisen Änderungen von Plänen oder Dokumenten sind diese mit dem Kleber KOR/FRG zu kennzeichnen. | Pläne<br>Werkverträge/Nachträge, Auftragsbestätigung (unterschrieben)<br>KOR/FRG<br>AEN | HM<br>SM<br>PL |
| 10 | Dokumente verteilen | Die korrigierten Dokumente werden im Bauordner abgelegt. Im Büro sind immer ein Satz gültige/korrigierte Dokumente zur Objektablage vorhanden | gültige Dokumente | HM<br>SM<br>PL |
| 11 | Bezeichnung ungültiger Dokumente | Die ungültigen Dokumente werden mit dem Kleber «ungültig» versehen. Ebenso müssen folgende Angaben ersichtlich sein:<br>– Ersetzt durch: ...<br>– Datum, Visum | ungültige Dokumente<br>UNG | HM<br>SM<br>PL |

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## *Budgetierte Umweltleistung in Kilo*

*Basis: Einsparung von 1'000 l Benzin im Jahr (= 10% des Verbrauchs)*




*a 2'300 kg $CO_2$ (Kohlendioxyd)*

*b 20 kg CO (Kohlenmonoxyd) mit Katalisator-Fahrzeugen*

*c 2 kg HC (Kohlenwasserstoff)*

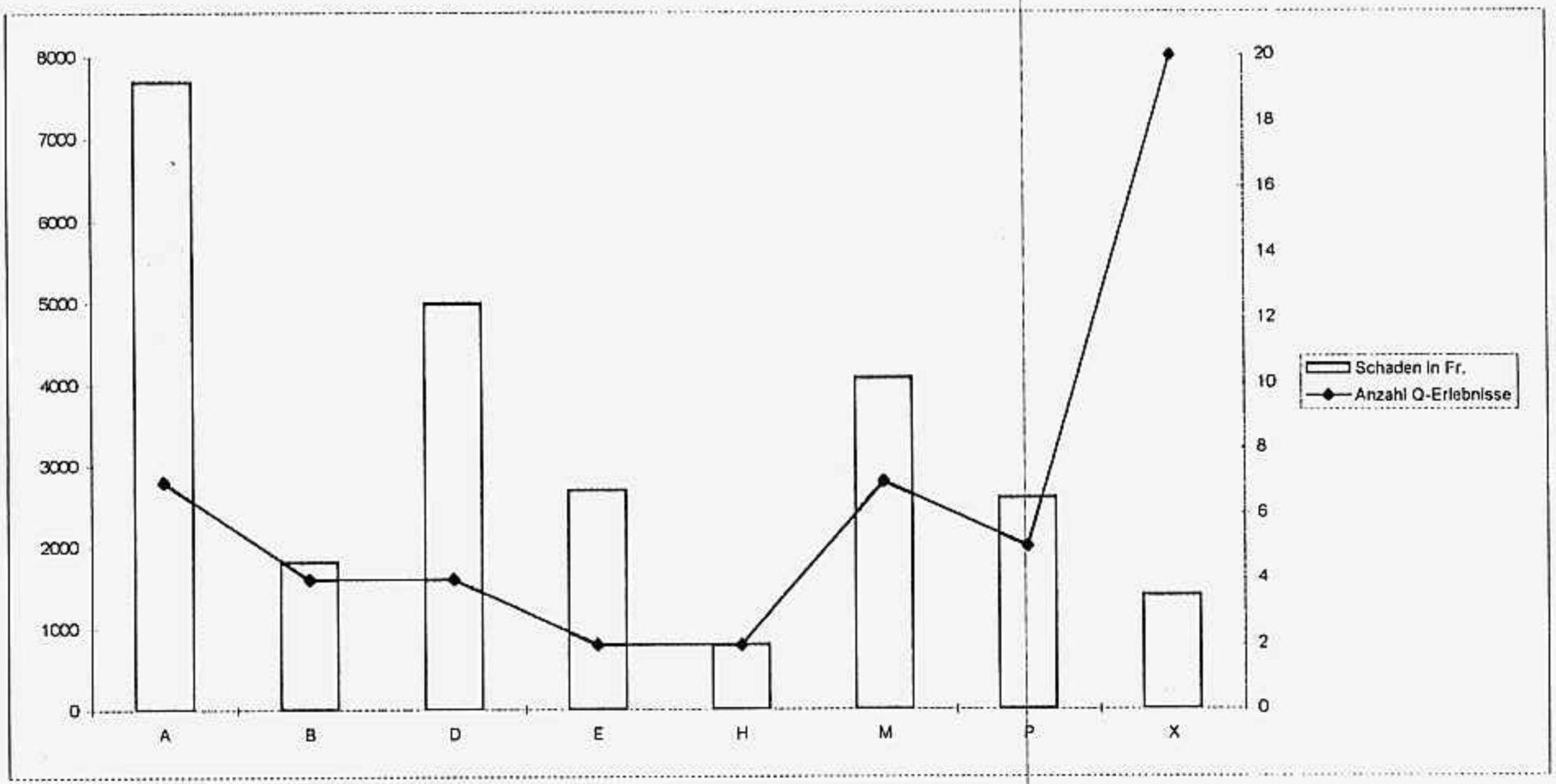
*d 1,5 kg $NO_x$ (Stickoxyde)*

***Zum Vergleich***

*e 65 kg Mensch*

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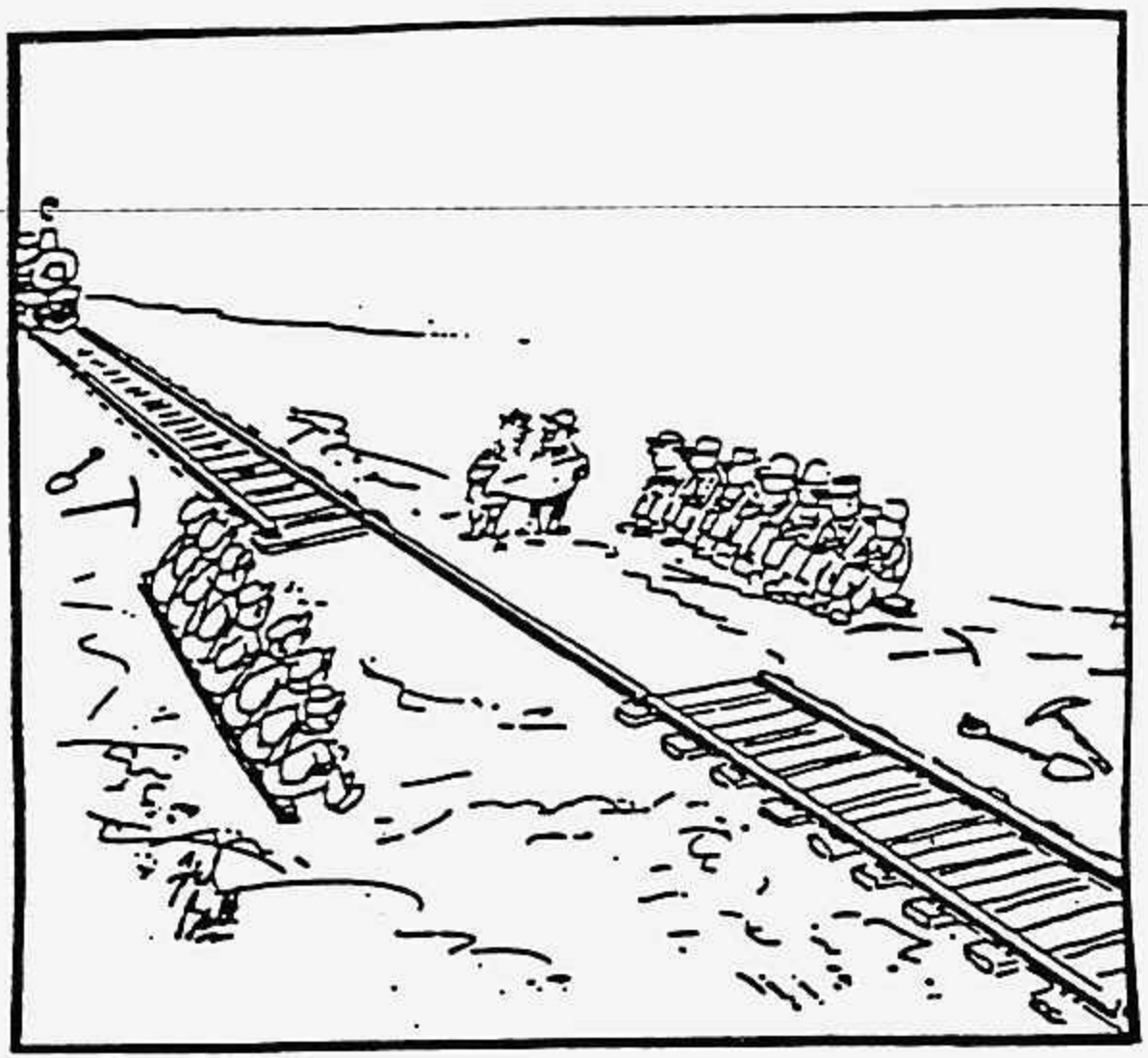
Auswertung nach Schadenarten 1995




**Legende Schadenarten**

| | | | |
|---|---|---|---|
| HQM | A | Hilfsmittel | H |
| Jungmonteure | B | Montagemethodik | M |
| Diverses | D | Planung | P |
| Einlagen | E | Externes Verschulden | X |

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**Mach's gleich richtig**

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