A survey of the sanitation load for domestic high-rise building estates in Hong Kong

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Abstract
A reasonably accurate estimation on the sanitation load is necessary for designing an effective and healthy drainage system. This is particularly important for developed cities, such as Hong Kong, having many high-rise residential buildings. Load estimation method based on the ‘fixture unit’ approach has been established and used for the load estimations. However, design data in practice have not been examined for various architectural designs and user behavioral patterns in high-rise residential buildings nowadays. In this study, the probable drainage loads in 14 high-rise buildings of five low-cost residential estates are investigated. A face-to-face interview has been conducted in 2003-2004 and the discharge flow rates of the installed sanitary appliances were measured in 597 apartments. The probable number of sanitary appliances discharging simultaneously is determined with the ‘fixture unit’ approach and compared with the design values used for the buildings. This study proposed the probable drainage demands for some high-rise residential buildings in Hong Kong. The database is useful for evaluating various drainage system designs in high-rise residential buildings for cities having a high population density.

Keywords
Sanitation load, high-rise residential buildings, survey

1 Introduction
Hong Kong is a developed city having a high population of 6.7 million and limited area of 1067 km² (Hong Kong Census and Statistics Department 2001). The tiny portion (20%) of flat land for construction has led to a concentrated high-rise environment with a very high population density. The tallest residential buildings in Hong Kong are Sorrento (tower 1: 75 floors, 256 m high; tower 2: 66 floors, 236 m high, both are
completed in 2003), The Harbourside (75 floors, 255 m high, completed in 2003), The Harbourfront Landmark (70 floors, 233 m high, completed in 2001) and The Belcher’s towers 1-6 (61-63 floors, 221-227 m high, completed in 2001) (Skywscrapers.com 2004). Apart from the residential buildings in private sector, many government funded residential buildings are constructed with heights over 140 m. In order to design an effective building drainage system, a reasonably accurate estimation for the drainage loads is necessary (Swaffield and Galowin 1992; Wise and Swaffield 2002).

Over the past 40 years, load estimation for drainage pipe sizing based on the probability of using outlet simultaneously \( P_d \) and the design discharge flow rate of the outlet \( q_d \) (L/s) at a limiting failure rate \( \lambda \) (e.g., 0.5-1%) has been adopted in many drainage designs (Laws of Hong Kong 1997; Plumbing services design guide 2002; Swaffield and Galowin 1992; Wise 1973; Wise and Swaffield 2002). Various investigations were conducted to determine these two design parameters (\( P_d \) and \( q_d \)) and a ‘fixture unit’ approach was adopted for drainage pipe sizing (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002). The design data from the investigations on low-cost housing were used to determine the pipe sizes of plumbing and drainage systems (Hunter 1940). The Building Research Establishment conducted an investigation into the use of sanitary appliance and the flow rate distribution of water supply in local authority flats of five floors in an 18-storey block in North London (Webster 1972). These works provided the statistical basis for design data formulation of building drainage system designs, and later works in the USA and in the UK have attempted to improve the available database (Butler 1991; Hunter 1940; Konen 1985; Swaffield and Galowin 1992; Webster 1972). However, these data might not be suitable for some high-rise residential buildings in Hong Kong nowadays due to the various architectural designs and user behavioral differences. Pertinent modifications on the design values for local buildings must be determined carefully and supported with systematic research studies on the drainage system demands of the buildings.

Following the massive outbreak of the Severe Acute Respiratory Syndrome (SARS) in early 2003, the drainage system in high-rise residential buildings has become a major concern. The suspected contaminated single stack system was accused of transporting the virus into living units through the same stack. The additional wastewater from washing, cleaning and sterilization has increased the drainage loads. Therefore, review the system design to cater for the actual building demands is urgently required. For the initial step, the development of a database for estimating the probable drainage loads in buildings has been proposed (Wong and Mui 2004). This study investigates the probable loads of the drainage systems in 14 high-rise buildings of five typical residential estates in Hong Kong. The usage patterns and discharge flow rates of the installed domestic sanitary appliances in 597 apartments were measured. The time of probable discharge, mean time between usages, probability of simultaneous discharge and the probable discharge flow rate of the appliances were determined. With the survey results, the probable flow rate in a typical drainage stack and the corresponding size of the stack are determined by the ‘fixture unit’ approach and compared with the design values commonly used for local buildings (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002).
2 Design approach

The probabilistic approach was used to study the simultaneous discharge from a group of sanitary appliance outlets for a common drainage stack (e.g., CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002; Webster 1972). If an outlet has repeated cycles of discharge with an average discharge time $t_d$ (s) and the average time interval between discharges $T_d$ (min), the probability of the outlet discharging $p_d$ at any instant is,

$$p_d = \frac{t_d}{60T_d} \quad \ldots (1)$$

Assume the discharge action is binomially distributed; the probability of $N$ outlets discharging out of $M$ identical outlets is given by,

$$M P_{d:N} = C_N^{M-N} p_d^{M-N} p_o^{N} ; \quad M \geq N \quad \ldots (2)$$

where,

$$C_N^M = \frac{M!}{N!(M-N)!} \quad \ldots (3)$$

The probability of the outlet not discharging $p_o$ at that instant is,

$$p_o = 1 - p_d \quad \ldots (4)$$

A system would be designed for $N$ (out of $M$ installed) appliance outlets discharging simultaneously. This system is considered as ‘engineering unsatisfactory’ (i.e., ‘failure’) if more than $N$ appliances are discharging at any instant. The failure rate $\lambda$ is determined by the sum of the probability that more than $N$ appliances discharging simultaneously,

$$\lambda = P(N+1)+P(N+2)+...+P(n-1)+P(n) = \sum_{i=N+1}^{n} P_i ; \quad N < M \quad \ldots (5)$$

An independent use of the appliance at random times is assumed and the failure rate could be interpreted as the proportion of the time that $(N + 1)$ or more outlets discharge simultaneously. The number of the simultaneously discharging appliances $N$ can be determined for the probability of discharging $P_d$ at an allowable failure rate $\lambda$ with equation (5).

Newton’s interpolatory divided-difference formula for equally-spaced nodes (known as Stirling’s formula) would be applied to solve the binominal distribution (Bull 1956, CIBSE 1988) and yield the result with an error function (Zwillinger 1996),

$$\sum_{M_{p1}+z}^{M_{p1}-z} P = \text{erf} \left[ \frac{z}{\sqrt{2Mp(1-P_d)}} \right] \quad \ldots (6)$$
where, $z$ is the number of standard deviations $\sigma$ away from the mean that will result in the least value of $N$ is not exceeded more than the limiting failure rate $\lambda$ set. For the limiting failure rate set at $\lambda = 0.01$,

$$N = M_p + 1.8\sqrt{2M_p(1 - p_d)} \quad \ldots (7)$$

where, $p_d$ is the probability of simultaneous operation for the appliance.

Alternatively, the result would be approximated by the normal distribution (Breese 2001) for $\lambda = 0.01$,

$$N = M_p + z\sigma \quad \ldots (8)$$

For the limiting failure rate $\lambda = 0.01$, the corresponding value of $z$ is 2.33. It is suggested $z = 2.5$ is a ‘safer’ choice in practice because the normal approximation would underestimate the probable number of appliances simultaneous in operation $N$ in small systems, e.g., $M < 30$ (Breese 2001; Zwilinger 1996),

$$N = M_p + 2.5\sigma \quad \ldots (9)$$

The standard deviation of appliances in operating $\sigma$ is,

$$\sigma = \sqrt{M_p(1 - p_d)} \quad \ldots (10)$$

This is very close to those approximated by the error function that,

$$N = M_p + 2.55\sigma \quad \ldots (11)$$

Some appliances, e.g., washbasins, sinks or bathtubs might be filled up (using a plug) before discharging the water (known as a ‘plugged flow’). The discharge time $t_d$ (s) of the appliance $i$ would be determined by the probability of filled-up discharge $P_f$ and the operating time of the water tap $t_a$ (s),

$$t_{d,i} = (P_f t_d + P_u t_a) \quad \ldots (12)$$

where, $P_u$ is the probability of appliance discharge without using a plug,

$$P_f + P_u = 1 \quad \ldots (13)$$

The discharge time for a filled-up appliance $t_d$ (s) for the appliance $i$ that is filled with water at a fraction $\phi_a$ of its capacity $V_a$ (m$^3$) is determined by,

$$t_{d,i} = \left( \frac{1000 V_a \phi_a}{q_d} \right)_i \quad \ldots (14)$$

where, $q_d$ (L/s) is the discharge flow rate for the appliance filled with water and can be measured experimentally (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002; Wise 1973).
A typical drainage system involves more than one appliance type and each appliance type would associate with different usage patterns and the discharge probabilities. A system of Discharge Unit (DU) was used to take into account the differing probabilities (Breese 2001; BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002). The same design flow rate \( q_d \) (e.g., 10 L/s) would be produced from a group of a number appliance \( M_i \) installed or from a group of an equivalent number of hypothetical appliances \( M_h \), which has a discharge unit of 1.

\[
q_D = (Nq_d)_h = (Nq_d)_h
\]

The discharge unit of the appliance \( DU_i \) is,

\[
DU_i = \frac{M_i}{M_h}
\]

where,

\[
M_i = \left( \frac{N - z \sigma}{p} \right)_i
\]

The total load of a drainage stack is the sum of the discharge units for all the connected appliances. Relationship between discharge units and actual flow rates was established by utilizing the steady free surface flow equations and the depths of flow were calculated for various pipe gradients and diameters (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002; Swaffield and Galowin 1992; Wise and Swaffield 2002). Graphical presentation or mathematical expressions in determining the total discharge flow rate for the stack \( \Sigma q_{d,i} \) (L/s) with the total discharge units \( \Sigma DU_i \) were provided in design guides (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988) to determine the drainage stack size. The discharge flow rate \( \Sigma q_{d,i} \) (L/s) can be related by,

\[
\sum q_{d,i} = C_1 + C_2 \left( \sum DU_i \right)^{C_3}
\]

where, \( C_1, C_2 \) and \( C_3 \) are constants as shown in Table 1 (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988).

### Table 1: Constants for determining the probable discharge flow rate

<table>
<thead>
<tr>
<th>Design guide</th>
<th>Application range</th>
<th>( C_1 )</th>
<th>( C_2 )</th>
<th>( C_3 )</th>
<th>Correlation coefficient ( R )</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOP (1977)</td>
<td>70 ( \leq ) DU ( &lt; 158 )</td>
<td>0.9</td>
<td>0.0061</td>
<td>1</td>
<td>0.9941</td>
</tr>
<tr>
<td></td>
<td>158 ( \leq ) DU ( \leq 6500 )</td>
<td>0</td>
<td>0.073</td>
<td>0.64</td>
<td>NA</td>
</tr>
<tr>
<td>IOP (1987)</td>
<td>All DU</td>
<td>0</td>
<td>0.0458</td>
<td>0.666</td>
<td>NA</td>
</tr>
<tr>
<td>IOP (2002)</td>
<td>All DU</td>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
<td>NA</td>
</tr>
<tr>
<td>BS5572 (1994)</td>
<td>100 ( \leq ) DU ( \leq 20000 )</td>
<td>2.3895</td>
<td>0.0622</td>
<td>0.6659</td>
<td>0.9999</td>
</tr>
<tr>
<td>BSEN 12506 (2000)</td>
<td>All DU</td>
<td>0</td>
<td>0.5</td>
<td>0.5</td>
<td>NA</td>
</tr>
<tr>
<td>Wong and Mui (2004)</td>
<td>70 ( \leq ) DU ( &lt; 158 )</td>
<td>0.9</td>
<td>0.0061</td>
<td>1</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>158 ( \leq ) DU ( \leq 6500 )</td>
<td>0</td>
<td>0.073</td>
<td>0.64</td>
<td>NA</td>
</tr>
</tbody>
</table>

\( NA = \) Not applicable
The appliance with a relatively long discharge time (e.g., 10 minutes) would be considered as a continuous flow $q_c$ (L/s) in determining the stack size (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988),

$$\sum q_{d,i} = q_c + C_1 + C_2 \left( \sum DU \right)^{C_3} \quad \cdots (19)$$

The flow capacity of stack $q_s$ (L/s) with the stack diameter $D_s$ (mm) is given by (Wyly and Eaton 1961),

$$q_s = 31.9\phi_s^{5/3}D_s^{8/3} \quad \cdots (20)$$

where $\phi_s$ is the fraction of the cross-sectional area of the stack occupied by the water. The capacity of a stack flowing at quarter full (i.e., $\phi_s = 1/4$) is shown in Table 2 (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988). In this study, a probable growth of water consumption (10%) in future 10 years is assumed in determining the maximum discharge units allowed in a drainage pipe in Table 2 (Hall et al. 1988). Additional discharge to stack may be due to 2 components: extended duration of discharge at the design flow rate; or increased quantity of discharge with the same probability of use. For simplicity, the increment of the design flow rate in a stack is taken to be the same proportion of the water consumption increment.

### Table 2: Design capacities of a main vertical drainage pipe

<table>
<thead>
<tr>
<th>Stack diameter $D_s$ (mm)</th>
<th>Maximum allowable discharge unit</th>
<th>Maximum allowable flow rate (L/s)</th>
<th>Maximum allowable discharge unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>950</td>
<td>1200</td>
<td>750</td>
</tr>
<tr>
<td>125</td>
<td>2200</td>
<td>2800</td>
<td>2500</td>
</tr>
<tr>
<td>150</td>
<td>4900</td>
<td>6000</td>
<td>5500</td>
</tr>
<tr>
<td>175</td>
<td>9700</td>
<td>Not specified</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>16700</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3 Survey

Five typical high-rise residential building estates in Hong Kong are selected at various geometrical locations, the building age and architectural designs in order to study the usage patterns and the details of the building drainage appliances. The five estates provide 26,500 apartments and the population is 113,000 persons (Hong Kong Census and Statistics Department 2001; Wong and Mui 2004). A total of 1,300 households were randomly invited for this study. Their apartments were using common stacks in 14 high-rise buildings of 38-42 floors with the height up to 150 m. Invitation letters
were sent to introduce the objectives of this study, survey period and the survey details. Representatives in 597 households were participated in a face-to-face interview survey conducted in 2003-2004.

A total of 1,300 apartments were visited and the 597 occupants were interviewed. The details of the interview were summarized in Appendix. The occupant load variations during a day throughout a week were surveyed. Most of the interviewees were the major users of the sanitary appliances in the apartment as they stayed in home of longest resident time. During the interview, they were asked to provide information for the usage patterns of the day prior to the interview, and the hourly usage patterns on weekdays, weekend, Sunday and holiday with the corresponding activities. The average time between appliance demands was surveyed. The frequency of using a plug of the appliance and the fill-up level were recorded. The appliance type, physical size and the brand name were recorded. The average flow rates of the water taps installed at sink, washbasin, shower and bath were measured with sample operations by the occupants, and the discharge time and the refilling time of a WC cistern were measured.

![Figure 1: Age group of the respondents](image1.png)  
![Figure 2: Occupant load](image2.png)

## 4 Results and discussion

Figure 1 shows the age distribution of the 597 interviewees. Not much surveyed samples fell within the younger age groups as compared to the distributions of the all 5 estates and population of Hong Kong. It is reported that the average number of occupant per household is 4.2 with the distribution shown in Figure 2. In contrast, the average family size of Hong Kong was 3.1 with the distribution shown in the figure, as recorded in 2001. The surveyed maximum occupant load factor (OLF) is very close to the design limits of 4.5-9 m²/person as shown in Figure 3 (Buildings Department 1996; Wong 2003). The survey sample is considered to be representative to the population for age group ≥ 30. The occupant load variations in weekdays and holiday of the sample apartments are shown in Figure 4. A higher occupant load for weekdays but similar variations for holidays were found for this study, as compared to the previous study for residential buildings (Wong 2003).
The hourly demands for the sanitary appliances are shown in Figure 5. It is reported that the maximum hourly demands per person for WC, washbasin, shower and bath are 0.88, 1.14, 0.29 and 0.28, respectively. The average demands of WC and washbasin were compared with the expected average demand reported by the interviewees as an indicator to confirm the validity of the responses. The expected average demands of WC and washbasin are 3.00 and 3.01 hours, respectively, with the frequency
The corresponding expected hourly demands are 0.33 per person for both WC and washbasin and consistent with the average demands calculated from the surveyed usage patterns, which are 0.28 and 0.32 per person for WC and washbasin, respectively. The demands for washing machines and sinks would be on unit basis, and only one washing machine and one sink were found in each apartment. The maximum hourly demands of the washing machines and sinks are 0.25 and 0.41 per appliance, respectively.

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**Figure 5: Hourly demands of some domestic appliances**

(a) WC, washbasin, shower and bath

(b) Washing machine and sink
Interestingly, user may flush more than once after the use of a WC as shown in Table 3. The discharge time per flushing is shown in Figure 7. It is reported that 9 L flushing cistern was installed in all the surveyed apartments. The frequency distribution of the average discharge flow rate in Figure 8 shows that the maximum average discharge flow rate is 2.1 L/s, which is consistent with the design values (1.2 to 2.27 L/s) used in current practice (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Plumbing services design guide 2002). The surveyed average discharge flow rate is 0.85 L/s.

### Table 3: Number of flushing operations per demand of a WC

<table>
<thead>
<tr>
<th>No of flushing</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>82.2</td>
</tr>
<tr>
<td>2</td>
<td>16.4</td>
</tr>
<tr>
<td>3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

**Figure 6: Expected time between demands for WC and washbasin**

**Figure 7: Discharge time for a WC flushing**

**Figure 8: Average discharge flow rate of a WC flushing**
Table 4: Probability of fill-up an appliance before discharging

<table>
<thead>
<tr>
<th>Probability</th>
<th>Washbasin</th>
<th>Sink</th>
<th>Bath tub</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.25</td>
<td>73.7 %</td>
<td>51.7 %</td>
<td>94.5 %</td>
</tr>
<tr>
<td>0.25 – 0.49</td>
<td>15.7 %</td>
<td>26.7 %</td>
<td>2.5 %</td>
</tr>
<tr>
<td>0.5 – 0.74</td>
<td>4.5 %</td>
<td>0.3 %</td>
<td>1.2 %</td>
</tr>
<tr>
<td>≥ 0.75</td>
<td>6.1 %</td>
<td>21.3 %</td>
<td>1.6 %</td>
</tr>
</tbody>
</table>

Table 5: Fill-up level of an appliance before discharging

<table>
<thead>
<tr>
<th>Fill-up level</th>
<th>Washbasin</th>
<th>Sink</th>
<th>Bath tub</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.25 full</td>
<td>16.6 %</td>
<td>4.1 %</td>
<td>9.5 %</td>
</tr>
<tr>
<td>0.25 – 0.49</td>
<td>64.5 %</td>
<td>56.4 %</td>
<td>38.1 %</td>
</tr>
<tr>
<td>0.5 – 0.74</td>
<td>16.6 %</td>
<td>33.7 %</td>
<td>40.5 %</td>
</tr>
<tr>
<td>≥ 0.75</td>
<td>2.3 %</td>
<td>5.8 %</td>
<td>11.9 %</td>
</tr>
</tbody>
</table>

A washbasin, sink or bath would be filled up before the water is discharged. The fill-up probabilities of the appliances are shown in Table 4 and the probable fill-up levels are shown in Table 5. The results show that the appliances would not be filled up frequently. Many users reported that the bathtub would be used as a shower. They also expressed that more than one baths/showers would be taken a day and the frequency distribution is shown in Figure 9. This is very different from the survey results for other regions that the demand ranged from 0.07 to 0.7 baths per day with an average of 0.4 baths per day (Ligman et al. 1974; Webster 1972).

Figure 9: Number of baths or showers taken per day for a person
Table 6: Preparation of meal

<table>
<thead>
<tr>
<th>Normally prepare a meal?</th>
<th>Breakfast</th>
<th>Lunch</th>
<th>Tea</th>
<th>Dinner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>34.8 %</td>
<td>56 %</td>
<td>0 %</td>
<td>94.5 %</td>
</tr>
<tr>
<td>No</td>
<td>65.2 %</td>
<td>44 %</td>
<td>100 %</td>
<td>5.5 %</td>
</tr>
</tbody>
</table>

The water tap operation time for a washbasin, shower and sink is shown in Figure 10. The operating time of a shower water tap is between 4 to 40 minutes, with the average of 12 minutes. The tap operating time of a washbasin varying from few seconds (e.g., for hand washing) to over 2.5 minutes were recorded with an average operating time of 12.3 s. The operating time of a sink water tap would be closely related to the meal preparation, cooking and related activities. It is noted that people in Hong Kong would boil tap water for drinking purposes. The survey showed that about 1/3 households would normally prepare breakfast, 1/2 would prepare lunch and almost all would prepare dinner as shown in Table 6. The tap operating time was classified for breakfast, lunch and dinner preparation and is shown in Figure 10. The tap operating time of the sink $t_a(s)$ would be correlated with the meal preparation time $T_a(s)$.

Figure 11 shows the distribution of the fractional tap operating time (normalized by the preparation time $T_a$). A correlation for the tap operating time $t_a(s)$ with correlation coefficient of 0.904 is obtained,

$$ t_a = 0.315T_a $$

… (21)
The water tap discharge flow rates for showers, sinks and washbasin are shown in Figure 12. The corresponding average flow rates are 0.3, 0.17 and 0.16 L/s and match with the design values (0.1-0.3 L/s for shower head and bath, 0.15 L/s for taps at sink and washbasin) in design guides (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Laws of Hong Kong 1997; Plumbing service design guide 2002). A relatively congested usage pattern (e.g., for WC and washbasin) was indicated from this survey as the intervals is slightly shorter than the 1200 s adopted in design guides (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Laws of Hong Kong 1997; Plumbing service design guide 2002). It is reported that longer operations of water taps at shower and sink were found. In fact, people in Hong Kong would take a longer shower. The survey also showed that much water would be consumed at the sinks.

The survey results were then used to derive the probabilities of discharge and the discharge flow rates of the domestic appliances as summarized in Table 7. The design values used in practice for local residential buildings are listed in the table for comparison. The probable discharge flow rates due to a number of appliances are shown in Figure 13 and compared with those determined with the design practice (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Laws of Hong Kong 1997; Plumbing service design guide 2002). The predicted discharge flow rates of this study for WCs and washbasins are at the low side among the predictions while the predictions for sink, shower, bath and washing machine show reasonable consistencies.

Figure 14 shows a typical arrangement of the domestic appliance in local residential high-rise buildings that a drainage stack and a ventilating pipe are provided. It is a common design for small apartments with one washroom and one kitchen. The stack collects wastewater from the two adjacent apartments of each floor. Cross ventilating pipes would be installed between the drainage stack and the ventilating pipe at every three floors.
Table 7: Design drainage loads for typical domestic sanitary appliances

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Probability P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WC</td>
<td>0.0084</td>
<td>0.004</td>
<td></td>
<td></td>
<td>0.0059 - 0.03</td>
<td></td>
</tr>
<tr>
<td>Washbasin</td>
<td>0.0128</td>
<td>0.01</td>
<td></td>
<td></td>
<td>0.0083</td>
<td></td>
</tr>
<tr>
<td>Sink</td>
<td>0.167</td>
<td>0.015</td>
<td></td>
<td></td>
<td>Not specified</td>
<td></td>
</tr>
<tr>
<td>Shower</td>
<td>0.555</td>
<td>0.2</td>
<td>Not specified</td>
<td>Not specified</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Bath</td>
<td>0.0112</td>
<td>0.015</td>
<td></td>
<td></td>
<td>0.167-0.0417</td>
<td>Not specified</td>
</tr>
<tr>
<td>Washing machine</td>
<td>0.065</td>
<td>N/S</td>
<td></td>
<td></td>
<td>0.02-0.125</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discharge flow rate (L/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WC</td>
<td>0.85</td>
<td>2.27</td>
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<td>0.23</td>
<td>0.34</td>
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<td>0.6</td>
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<tr>
<td>Shower</td>
<td>0.32</td>
<td>0.08</td>
<td>0.1-0.45</td>
<td>0.4-1.3</td>
<td>0.07-0.15</td>
<td>0.4-0.5*</td>
</tr>
<tr>
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<td>1.06</td>
<td>1.3</td>
<td>1.1</td>
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<tr>
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<td>0.6</td>
<td>0.6</td>
<td></td>
</tr>
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<td>Discharge Unit</td>
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</tr>
<tr>
<td>WC</td>
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<td>6</td>
<td>1.2-2</td>
<td>4-7</td>
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<td>1</td>
<td>0.3</td>
<td>1</td>
<td>0.3</td>
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<tr>
<td>Sink</td>
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<td>3</td>
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<td>1.3</td>
<td>7</td>
<td>0.6</td>
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<tr>
<td>Shower</td>
<td>13</td>
<td>1</td>
<td>Not specified</td>
<td>0.4-1.3*</td>
<td>&lt;1**</td>
<td>0.4-0.5*</td>
</tr>
<tr>
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<td>5-12#</td>
<td>6</td>
<td>7</td>
<td>1.3</td>
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<tr>
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<td>4</td>
<td>0.6</td>
<td>3-18</td>
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</table>

* With plug; ** Use flow rate for design; # Use as a shower is allowed;

The design discharge flow rates of the buildings are shown in Figure 15. It is noted that the no discharge flow rate was recommended for washing machine in the design guide (Plumbing service design guide 2002) (1977 edition). Good agreements were found among predictions with the current design guides for a building up to 20 floors. This study proposed higher probable discharge flow rates of drainage stack for high-rise residential buildings in Hong Kong because a higher probability of simultaneous discharge would be encountered.

The corresponding stack size for the discharge flow rate is determined and shown in Figure 16. The sizes determined by the design guides are shown for comparisons (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Laws of Hong Kong 1997; Plumbing service design guide 2002). It is observed that a larger stack size would be determined with the new editions of design guides. In general, the required stack size would be one grade larger than those predicted by the previous guides. For a building with the typical arrangement up to 60 floors, the required stack size lays between the recommended sizes of the current design guides. A larger drainage stack would be required for the building over 60 floors.
Figure 13: Comparison of the probable discharge flow rate at a group of appliances
5 Conclusion

The drainage load must be accurately estimated in order to design a good drainage system for high-rise residential buildings. Design values used in current practice might not account for different architectural designs and user behavioral patterns for a city having a dense living environment, such as Hong Kong. With the survey results from the five typical high-rise residential building estates in Hong Kong, building drainage loads are derived with the fixture unit approach. The probable discharge flow rates for the appliances typically arranged in the low-cost residential high-rise buildings are examined. The implications on the required drainage stack size are discussed and compared with those calculated with the design data currently used for local buildings. It was found that good predictions were made with the current design values for typical residential buildings up to 60 floors. A larger drainage stack would be required for typical high-rise residential buildings in Hong Kong. This study provides a database of
drainage loads in high-rise residential buildings in Hong Kong and enables further studies on the drainage system designs for cities having a high population density.

6 References

Buildings Department, Code of practice for the provision of means of escape in case of fire, Hong Kong Building Authority (1996).
Bull, L. C., Simultaneous demand from a number of draw-off points, IHVE Feb (1956).
Laws of Hong Kong, Chapter 123I Building (standards of sanitary fitments, plumbing, drainage works and latrines) regulations (1997).

7 Appendix Interview survey
1. Survey date and time
2. Apartment details: Location of flat, building height, number of storey, apartment floor area, number and location of escape staircases
3. User details: Age group, gender, occupant load, occupation, occupant load variations in last week,
4. Sanitary provisions: Number of toilets, water closets, washbasins, bathtubs, showers, sinks, washing machines, model of the appliances, appliance capacity, and duration of discharge for WC cistern
5. Usage pattern records for toilets, water closets, washbasins, bathtubs, showers, sinks, washing machines yesterday, in hourly basis
6. Average usage rate and occupant time of toilets, water closets, washbasins, bathtubs, showers, sinks, washing machines
7. Frequency in filling up the appliance before discharging, for bathtub, sink, washbasin and the level of filling
8. Number of flushes after the use of WC
9. Operating time of water tap at sink, shower, bathtub and washbasin for certain activities specified
10. Cooking activities: Number breakfast, lunch, tea, dinner, etc. prepared a day, preparation time and tap operation time

8 Presentation of Authors

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