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Water Use Patterns in Vietnamese Hotels: Modeling Toilet and Shower Usage

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Abstract: Water saving is a key issue in rapidly developing countries, such as Vietnam, that face various water resource management challenges. This study investigated water-use patterns in a hotel in Ho Chi Minh City in Vietnam. It aimed to quantify the efficiency of water-saving devices through modeling toilet and shower usage patterns, including water consumption. The shift in hourly consumption of cold and hot water was also identified. Analysis revealed that, on average, a full toilet flush occurs 3.3 times/day, a half flush 3.0 times/day, water consumption due to shower usage is 48.1 L/day, showering time is 7.3 min/day and the shower water temperature is 37.7 °C. Shifting levels of hot and cold water use revealed high activity in the morning time and that there are two peaks, occurring in the morning and at night.

Keywords: water-saving equipment; water usage; vietnamese hotel

1. Introduction

A great deal of attention has been paid to the co-benefits of saving water. An important effect is that it directly reduces CO_2 emissions by lowering the energy needs for operating and maintaining water and wastewater management facilities. The Japanese government has proposed the "Joint Crediting Mechanism" (JCM) for international use, and this scheme requires the modeling of equipment use in order to quantify the effects of cold and hot water saving devices on CO_2 emission reduction.

Regarding investigations related to the water consumption and usage of toilets and showers, there are numerous studies of households in Spain [1,2], the United Kingdom [3], Australia [4], Kenya [5] and Portugal [6], in addition to the work done by the authors in Japan. However, there are fewer studies that examine usage in hotels, although hot and cold water usage in a Japanese city center hotel [7] and in a business hotel [8] have been analyzed. Past studies conducted by the authors have produced models of toilet and shower usage in Vietnamese households [9]. Still, it is crucial to construct a model of toilet and shower usage in a Vietnamese hotel based on real measurements and on-the-ground investigation, because many Vietnamese hotels are considering the introduction of hot and cold water-saving equipment.

Therefore, this report investigates the pattern of water use in guest rooms in a Vietnamese hotel and suggests a model of toilet and shower usage by quantifying and assessing the efficiency of water-saving devices.

2. Investigation Overview

2.1. Overview of Building and Facilities

The hotel is outlined in Table 1, and the facilities for supplying hot and cold water are outlined in Figure 1.

Table 1. Description of the hotel.

Hotel Name	Renaissance Riverside Hotel Saigon
Location	Ho Chi Minh City
Hotel class	5 star
Total guest rooms	336 rooms
Building structure	21 floor 2 underground floor
Established	1998
Facilities	Guest rooms restaurants coffee lounge bar lounge fitness center business center spa

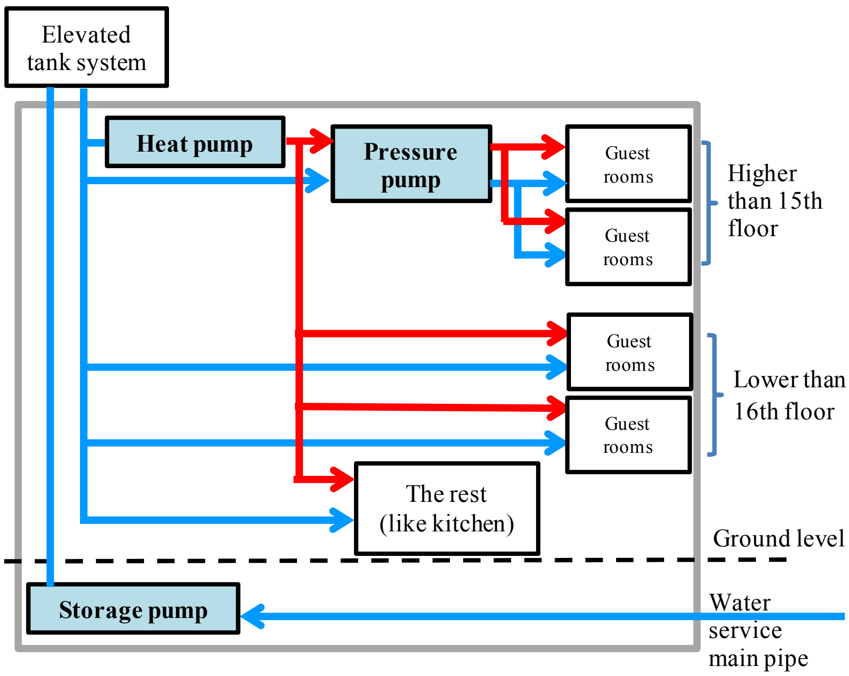

Figure 1. The facilities for supplying hot and cold water.

The site of the study was the Renaissance Riverside Hotel Saigon, which is an affiliate of the Marriott Group. It is located in the center of Ho Chi Minh City, near the business and the entertainment areas, so the guests' reasons for staying include both business and sightseeing. Three heat pumps are used for supplying the hot water system, and the water supply system is a general elevated tank system. In addition a pressure pump is used for the floors above the 15th floor, in order to ensure a stable water supply pressure.

2.2. Bathroom Overview

The bathrooms in the hotel study were typical hotel bathrooms, including a shower, hot water tap for the bathtub, a tap for the sink and a toilet. It was not possible for both the shower and the tap of the bathtub to emit water at the same time as they were part of a switching system controlled by pop-up metal fittings. Water temperature was controlled by combining hot and cold water with a single lever. Additionally, the shower was a water-saving model, which included a 9.5 L/min flow valve, so the flow-rate could not exceed this limit. The toilet was also a water-saving type that used 4.8 L per full flush and 3.0 L per half-flush.

2.3. Measurement Overview

This investigation selected six guest rooms, and measured the water use for six months from 1 October 2013 until 31 March 2014. To measure the water use of a bathroom, a measurement system was utilized with a flow-rate sensor, a temperature sensor and a programmable logic controller (PLC). The bathroom plan, the hot and cold water supply pipe layout and the measuring points are shown in Figure 2.

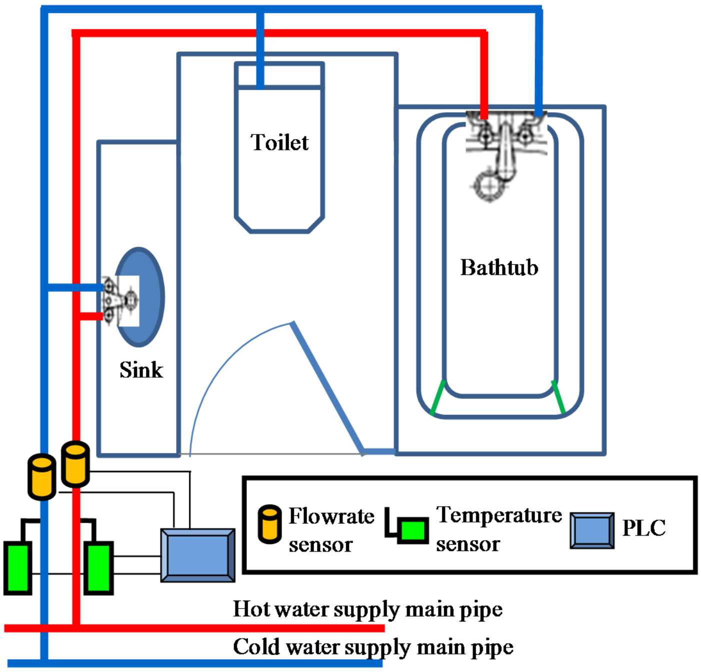

Figure 2. The bathroom plan and the measurement points.

Usually flow-rate sensors are set separately on the shower, the tap of the sink and the toilet and then the flowrates of each equipment are analyzed. However, the hotel did not allow the researchers to cut pipes close to the equipment in order to install sensors, so the data was recorded to the PLC from the flow-rate sensor and the pipe surface temperature sensor. These were set on the bifurcation of the hot and cold water supply main pipes. This recording was done every 2 s and the flow data (0.0124 L/Pulse) as well as both the hot and cold water pipe's surface temperature were stored.

2.4. Activity Separation Algorithm

As shown in Figure 2, the flow-rate sensors were set at each bifurcation of the hot and cold water supply main pipes. The flow data, which was recorded when the toilet, sink or bath was used, identified specific activities based on a gap of more than 30 s between individual pulse signals. A database containing data separated according to activity type was then constructed. The database stored information on each action such as the date, the time, the amount of hot water and cold water, the temperature and the flow rate. For the convenience of measuring points, it was necessary to separate the activities stored in the database into the following actions: face washing, toilet, showering and filling the bath. The flowchart used for separating the types of activities is shown in Figure 3.

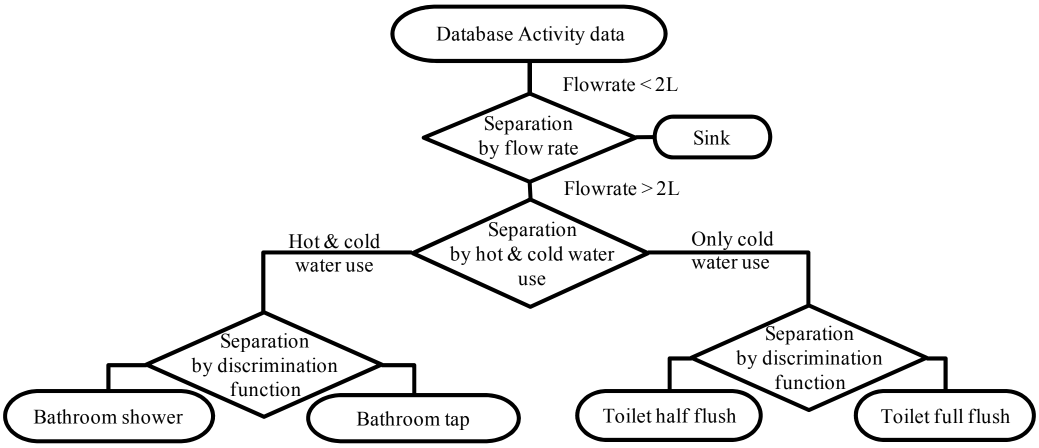

Figure 3. The flowchart used to separate activities.

First, in order to identify water-use patterns associated with face washing, recorded activities were separated by hot and cold-water use. This separation threshold was set based on the statistical data acquired from a preliminary monitoring assessment of the face washing occurring in each room. In the next step the remaining activities were separated by the amount of hot and cold water used, defining them as a toilet action in the case that only cold water was used and as a bath activity in the case that both hot and cold water were used. In the case of a "toilet" action, the full flush and the half flush were separated by discriminant analysis through binary function which used the amount of water and time as variables. This drew on prior data collected on the water-usage characteristics of a full flush and half flush of the toilet type under investigation. Likewise, for the bathing action, the showering and filling the bath activities were separated by discriminant analysis through the linear discriminant unary function using the flowrate as the variable. Each linear discriminant function was determined by assuming the actual measurement value, which was estimated by carrying out the particular action in advance, in function of the population. Moreover, the linear discriminant function was determined per room, due to the different dispersion of plumbing equipment in each room.

It is unlikely that simultaneous use of the toilet, bath and sink occurred because all three installations are set in the same space, as shown in Figure 2, and they are considered to be used by one person in a normal room usage situation. However, it is likely that the toilet use action will lead to a hand washing action at the sink, so separation of toilet use and hand washing actions is considered in Section 3.2 below.

3. Result and Discussion

3.1. Operation Rate and the Number of Occupants Per Room

The aggregated operation rate derived from the hotel's management data and the statistical amount of occupants per room is shown in Table 2 and the monthly transition is shown in Figure 4.

Table 2. The operation rate and occupants per room.

Total	Operation Rate (%)	Number of Occupants (Person/Room)
Average	68.7	1.43
Standard deviation	9.1	0.08
Maximum	85.2	1.59
Minimum	58.6	1.31

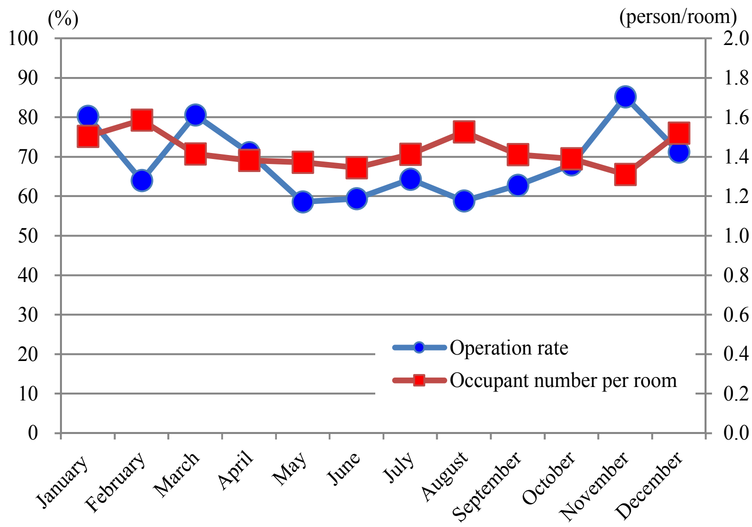

Figure 4. The operation rate and the transition of occupant number per room.

One reason for the tendency of decreasing operation rates in the period from May to October is because Vietnam has a monsoon season in that period, so fewer guests stay for sightseeing during that time.

3.2. Outcome of the Hand Wash Action Separation Analysis

The threshold flow rate values were set so that a 99.5% confidence interval could be obtained from the toilet usage data in all of the measured rooms. The aforementioned statistical values for full and half toilet flushes are shown in Table 3 (The upper limit is the average value minus the value of 3σ, the lower limit is the average value minus the value of σ. The toilets used in this investigation were tank-type toilets, so the tank filling time per flush statistic in Table 3 shows the amount of time it takes for new water to be supplied to the tank reservoir after each type of flush.).

Table 3. The statistical values for full and half toilet flushes.

Item	Room	A	B	C	D	E	F	Total Average
The flow volume of a full toilet flush (L/flush)	Average	4.51	5.22	4.70	4.75	4.74	5.61	4.92
	Standard deviation	0.04	0.03	0.06	0.05	0.08	0.06	
	3σ	4.62	5.33	4.88	4.91	4.97	5.79	-
	−3σ	4.40	5.12	4.52	4.59	4.51	5.43	
The tank filling time of a full toilet flush (ss/flush)	Average	31	32	26	27	26	32	29
	Standard deviation	1	1	2	1	1	2	
	3σ	34	35	32	30	29	38	-
	−3σ	28	29	20	24	23	26	
The flow volume of a half toilet flush (L/flush)	Average	2.77	3.22	3.44	3.32	3.06	3.27	3.18
	Standard deviation	0.11	0.12	0.29	0.24	0.08	0.11	
	3σ	3.09	3.57	4.30	4.04	3.30	3.62	-
	−3σ	2.45	2.87	2.58	2.60	2.83	2.93	
The tank filling time of a half toilet flush (ss/flush)	Average	20	20	23	22	17	19	20
	Standard deviation	1	1	1	3	1	1	
	3σ	23	23	26	31	20	22	-
	−3σ	17	17	20	13	14	16	

However, in most cases the toilet use action is expected to also include a hand washing action. Although the values in Table 3 only reflect the flow volume and time of toilet flushes in particular, in practice the flow volume and time of hand washes also count towards the actual water usage.

Therefore an attempt was made to obtain measurements of both flow and time values in regards to the washing of hands after a toilet usage action. In regards to hand washes (n = 60), 15.03 +/− 7.99 s was determined to be the average necessary time for the completion of the action. Moreover, the time required to start the hand wash after finishing the actual toilet usage action is 3.5 +/− 0.99 s. It is important to consider both this time gap as well as the duration of the actual action for determining the upper value of the toilet water supply if the values for hand washes are to be added to the total. Hence, the upper value is set at 46 s, as calculated by taking the sum of the 3σ values for both full and half flushes in order to reach a 95% confidence interval (15.03 + 7.99 × 3 + 3.50 + 3 × 0.99 = 45.47). This value is bigger than the water flow time threshold value as seen in Table 3, thus if hand washing is taken into consideration the upper limit of water flow time can be set at 46 s regardless of the type of flush. As for the lower flow time limit, this was set as the average of each measured room's −3σ, assuming no hand washing action takes place.

Furthermore, the average cold water amount consumed for the washing of hands was determined to be 0.8 +/− 0.62 (L), whereas the average hot water consumption was 0.8 +/− 0.61 (L) according to the results of the investigation. Thus, the model of water flow volume and flow time as measured for a toilet use action is presented in Table 4.

Table 4. The model of water flow volume and flow time.

Item	Room	A	B	C	D	E	F
Flow volume threshold for a full flush (L/flush)	Upper limit	7.32	8.03	7.58	7.62	7.67	8.49
	Lower limit	4.40	5.12	4.52	4.59	4.51	5.43
Flow time threshold for a full flush (s/flush)	Upper limit	46	46	46	46	46	46
	Lower limit	28	29	20	24	23	26
Flow volume threshold for a half flush (L/flush)	Upper limit	5.80	6.28	7.00	6.74	6.00	6.32
	Lower limit	2.45	2.87	2.58	2.60	2.83	2.93
Flow time threshold for a half flush (s/flush)	Upper limit	46	46	46	46	46	46
	Lower limit	17	17	20	13	14	16

3.3. An Example of Setting Linear Discriminant Function

As mentioned in Section 2.4, a linear discriminant function was used for each of the six investigated guest rooms in order to separate full and half flushes during the toilet activities and the showering and filling of the bathtub during the bathing activities. An example of the linear discriminant function as used for the toilet activities is shown below.

For the toilet usage total water volume and total time, both of which have very similar values during both full and half flushes (as can be seen in Table 4), are taken into account. The discriminant analysis is conducted in order to properly identify each type of flush, thus in other words to avoid erroneously determining what kind of flush was used.

In case the variable for the water volume is set as "x_1" and the one for time as "x_2", and given the probability distribution of $x = [x_1, x_2]'$ in the population [1], then the following Equation (1) can be assumed to represent the normal distribution N ($\mu^{[1]}$, Σ):

$$\mu^{[\mathbf{1}]} = \begin{bmatrix} \mu_{\mathbf{1}}^{[\mathbf{1}]} \\ \mu_{\mathbf{2}}^{[\mathbf{1}]} \end{bmatrix}, \sum = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{bmatrix} \tag{1}$$

On the other hand, the following Equation (2) is assumed to represent the normal distribution N ($\mu^{[2]}$, Σ) given probability distribution of $x = [x_1, x_2]'$ in the population [2] and whereby Σ is considered to be the same as above:

$$\mu^{[\mathbf{2}]} = \begin{bmatrix} \mu_{\mathbf{1}}^{[\mathbf{2}]} \\ \mu_{\mathbf{2}}^{[\mathbf{2}]} \end{bmatrix}, \sum = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{bmatrix} \tag{2}$$

If there would be a sample that belongs to either population [1] or [2], but for which it the designation is not known, then the correct population can be determined if the values of x_1 and x_2 are given. For this purpose the squared Mahalanobis distance is defined as follows:

$$\begin{aligned} D^{[k]2} &= (x-\mu^{[k]})'\textstyle\sum^{-1}(x-\mu^{[k]}) \\ &= [x_1-\mu_1^{[k]},\ x_2-\mu_2^{[k]}]\begin{bmatrix}\sigma^{11} & \sigma^{12}\\ \sigma^{12} & \sigma^{22}\end{bmatrix}\begin{bmatrix}x_1-\mu_1^{[k]}\\ x_2-\mu_2^{[k]}\end{bmatrix} \\ &= (x_1-\mu_i^{[k]})^2\sigma^{11}+(x_2-\mu_2^{[k]})^2\sigma^{22}+2(x_1-\mu_1^{[k]})(x_2-\mu_2^{[k]})\sigma^{12} \\ &= \sum_{i=1}^{2}\sum_{j=1}^{2}(x_i-\mu_i^{[k]})(x_j-\mu_j^{[k]})\sigma^{ij} \quad (k=1,2) \end{aligned} \tag{3}$$

whereby the Σ^{-1} (with the superscript indicating the inverse matrix) is defined as:

$$\sum^{-1} = \begin{bmatrix}\sigma_{11} & \sigma_{12}\\ \sigma_{12} & \sigma_{22}\end{bmatrix}^{-1} = \begin{bmatrix}\sigma^{11} & \sigma^{12}\\ \sigma^{12} & \sigma^{22}\end{bmatrix} \tag{4}$$

Equation (3) represents the extension of the one dimensional Mahalanobis *1 equation to two dimensions.

Note *1 The square of the Mahalanobis distance is the distance from the sample's x1 to each population, and can be defined as follows: $D^{[1]2} = \frac{(x_1-\mu_1^1)^2}{\sigma^2}, D^{[2]2} = \frac{(x_1-\mu_1^2)^2}{\sigma^2}$.

$D^{[k]2}$ is a quantitative measure of the statistical distance from x to the population mean vector $\mu^{[k]}$ of the population [k]. If $\Sigma = I_2$, representing a unit matrix, then $D^{[k]}$ would be an Euclidean distance. However generally $\Sigma \neq I_2$, so in that case $D^{[k]}$ represents a value obtained by the adjustment of the Euclidean distance by variance and covariance. In case the two-dimensional normal distribution N (μ, Σ) is given by the probability density function *2, which when transformed becomes like Equation (5), then the corresponding relationship between the probability density function and the squared Mahalanobis distance is $D^2 = (x-\mu)'\Sigma^{-1}(x-\mu)$.

Note *2 The joint-probability density function of the two-dimensional normal distribution is generally given as: $f(x,y) = \frac{1}{2\pi\sqrt{1-\rho_{xy}^2\sigma_x\sigma_y}}\exp\left(-\frac{1}{2}D^2\right)$

$$f(x) = \frac{1}{2\pi\sqrt{|\Sigma|}}\left(-\frac{D^2}{2}\right) \tag{5}$$

The discriminant is set using the Mahalanobis distance as follows:

$$\begin{aligned} D^{[1]2} \leqslant D^{[2]2} &\Longleftrightarrow \text{in the population } [1] \\ D^{[1]2} > D^{[2]2} &\Longleftrightarrow \text{in the population } [2] \end{aligned} \tag{6}$$

Here, we can use Equation (7), which is based on Equation (3).

$$D^{[2]2} - D^{[1]2} = 2\left[\mu_1^{[1]}-\mu_1^{[2]}, \mu_2^{[1]}-\mu_2^{[2]}\right]\begin{bmatrix}\sigma^{11} & \sigma^{12}\\ \sigma^{12} & \sigma^{22}\end{bmatrix}\begin{bmatrix}x_1-\overline{\mu}_1\\ x_2-\overline{\mu}_2\end{bmatrix} \tag{7}$$

However, one should consider that $\overline{\mu}_1 = \frac{\left(\mu_1^{[1]}+\mu_1^{[2]}\right)}{2}, \overline{\mu}_2 = \frac{\left(\mu_2^{[1]}+\mu_2^{[2]}\right)}{2}$. Equation (8) divided by 2 is called linear discriminant function, whose discriminant is determined as in Equation (9).

$$z = \left[\mu_1^{[1]}-\mu_1^{[2]}, \mu_2^{[1]}-\mu_2^{[2]}\right]\begin{bmatrix}\sigma^{11} & \sigma^{12}\\ \sigma^{12} & \sigma^{22}\end{bmatrix}\begin{bmatrix}x_1-\overline{\mu}_1\\ x_2-\overline{\mu}_2\end{bmatrix} \tag{8}$$

$$z \geqslant 0 \iff D^{[1]2} \leqslant D^{[2]2} \iff \text{in the population [1]}$$
$$z \geqslant 0 \iff D^{[1]2} > D^{[2]2} \iff \text{in the population [2]} \tag{9}$$

With full and half flushes designated as populations [1] and [2] respectively, the discriminants for each measured target room were calculated. Table 5 provides an example of results obtained in the examination of toilet activities in room A.

Table 5. Actual measured data (room A).

No.	Active Pattern	Total Flow Volume (L/min)	Time (s)	No.	Active Pattern	Total Flow Volume (L/min)	Time (s)	No.	Active Pattern	Total Flow Volume (L/min)	Time (s)
1	Full flush	4.53	32	13	Full flush	4.66	30	5	Half flush	2.80	20
2	Full flush	4.56	32	14	Full flush	4.53	30	6	Half flush	2.78	20
3	Full flush	4.51	30	15	Full flush	4.54	30	7	Half flush	2.80	20
4	Full flush	4.46	30	16	Full flush	4.59	30	8	Half flush	2.77	22
5	Full flush	4.54	32	17	Full flush	4.56	30	9	Half flush	2.78	20
6	Full flush	4.45	30	18	Full flush	4.55	32	10	Half flush	3.01	22
7	Full flush	4.53	32	19	Full flush	4.63	30	11	Half flush	3.03	20
8	Full flush	4.49	32	20	Full flush	4.55	30	12	Half flush	4.13	20
9	Full flush	4.50	32	1	Half flush	2.49	20	13	Half flush	3.01	22
10	Full flush	4.55	32	2	Half flush	2.84	22	14	Half flush	3.01	20
11	Full flush	4.65	28	3	Half flush	2.83	20	15	Half flush	3.05	20
12	Full flush	4.56	30	4	Half flush	2.84	20				

Given the full toilet flush data (based on the population [1], as defined in Equation (9)) we can calculate the following:

$$n[1] = 20$$

$$\hat{\mu}_1^{[1]} = \overline{x}_1^{[1]} = \frac{\Sigma_{i1}^{[1]}}{n^{[1]}} = \frac{90.94}{20} = 4.547$$

$$\hat{\mu}_2^{[1]} = \overline{x}_2^{[1]} = \frac{\Sigma_{i2}^{[1]}}{n^{[1]}} = \frac{614}{20} = 30.7$$

$$S_{11}^{[1]} = \sum \left(x_{i1}^{[1]} - \overline{x}_1^{[1]}\right)^2 = \sum x_{i1}^{[1]2} - \frac{\left(\Sigma x_{i1}^{[1]}\right)^2}{n^{[1]}} = 413.55 - \frac{90.94^2}{20} = 0.0574$$

$$S_{22}^{[1]} = \sum \left(x_{i2}^{[1]} - \overline{x}_2^{[1]}\right)^2 = \sum x_{i2}^{[1]2} - \frac{\left(\Sigma x_{i2}^{[1]}\right)^2}{n^{[1]}} = 18876 - \frac{614^2}{20} = 26.2$$

$$S_{12}^{[1]} = \sum \left(x_{i1}^{[1]} - \overline{x}_1^{[1]}\right)\left(x_{i2}^{[1]} - \overline{x}_2^{[1]}\right) = \sum x_{i1}^{[1]} x_{i2}^{[1]} - \frac{\left(\Sigma x_{i2}^{[1]}\right)\left(\Sigma x_{i2}^{[1]}\right)}{n^{[1]}} = 2791 - \frac{90.94 \times 614}{20} = -0.454$$

On the other hand, from the half toilet flush data (based on population [2], as defined in Equation (9)) we get the following:

$$n[2] = 15$$

$$\hat{\mu}_1^{[2]} = \overline{x}_1^{[12]} = \frac{\Sigma_{i1}^{[2]}}{n^{[2]}} = \frac{44.17}{15} = 2.945$$

$$\hat{\mu}_2^{[2]} = \overline{x}_2^{[2]} = \frac{\Sigma_{i2}^{[2]}}{n^{[2]}} = \frac{308}{15} = 20.53$$

$$S_{11}^{[2]} = \sum \left(x_{i1}^{[2]} - \overline{x}_1^{[2]}\right)^2 = \sum x_{i1}^{[2]2} - \frac{\left(\Sigma x_{i1}^{[2]}\right)^2}{n^{[2]}} = 131.9 - \frac{44.17^2}{15} = 1.803$$

$$S_{22}^{[2]} = \sum \left(x_{i2}^{[2]} - \overline{x}_2^{[2]}\right)^2 = \sum x_{i2}^{[2]2} - \frac{\left(\Sigma x_{i2}^{[1]}\right)^2}{n^{[2]}} = 6336 - \frac{308^2}{15} = 11.733$$

$$S_{12}^{[2]} = \sum \left(x_{i1}^{[2]} - \overline{x}_1^{[2]}\right)\left(x_{i2}^{[2]} - \overline{x}_2^{[2]}\right) = \sum x_{i1}^{[1]} x_{i2}^{[1]} - \frac{\left(\Sigma x_{i2}^{[2]}\right)\left(\Sigma x_{i2}^{[2]}\right)}{n^{[2]}} = 906.8 - \frac{44.17 \times 308}{15} = -0.2871$$

As a result we get the following equation:

$$\hat{\hat{\mu}}_1 = \frac{\hat{\mu}_1^{[1]} + \hat{\mu}_1^{[2]}}{2} = \frac{4.547 + 2.945}{2} = 3.746$$

$$\hat{\hat{\mu}}_2 = \frac{\hat{\mu}_2^{[1]} + \hat{\mu}_1^{[2]}}{2} = \frac{30.7 + 20.53}{2} = 25.62$$

$$\hat{\sigma}_{11} = \frac{S_{11}^{[1]} + S_{11}^{[2]}}{\left(n^{[1]} - 1\right) + \left(n^{[2]} - 1\right)} = \frac{0.0574 + 1.803}{(20 - 1) + (15 - 1)} = 0.0564$$

$$\hat{\sigma}_{22} = \frac{S_{22}^{[1]} + S_{22}^{[2]}}{\left(n^{[1]} - 1\right) + \left(n^{[2]} - 1\right)} = \frac{26.2 + 11.733}{(20 - 1) + (15 - 1)} = 1.149$$

$$\hat{\sigma}_{12} = \frac{S_{12}^{[1]} + S_{12}^{[2]}}{\left(n^{[1]} - 1\right) + \left(n^{[2]} - 1\right)} = \frac{-0.454 + -0.2871}{(20 - 1) + (15 - 1)} = -0.0225$$

$$\hat{\Sigma} = \begin{bmatrix} \hat{\sigma}_{11} & \hat{\sigma}_{12} \\ \hat{\sigma}_{12} & \hat{\sigma}_{22} \end{bmatrix} = \begin{bmatrix} 0.0564 & 1.149 \\ 1.149 & -0.0225 \end{bmatrix}$$

$$\hat{\Sigma}^{-1} = \begin{bmatrix} \hat{\sigma}_{11} & \hat{\sigma}_{12} \\ \hat{\sigma}_{12} & \hat{\sigma}_{22} \end{bmatrix} = \begin{bmatrix} 0.02 & 0.87 \\ 0.87 & -0.04 \end{bmatrix}$$

Thus, as explained earlier, the equation for the estimation of the linear discriminant function according to Equation (8) is the following:

$$z = \left[\hat{\mu}_1^{[1]} - \hat{\mu}_1^{[2]}, \hat{\mu}_2^{[1]} - \hat{\mu}_2^{[2]}\right] \begin{bmatrix} \sigma^{11} & \sigma^{12} \\ \sigma^{12} & \sigma^{22} \end{bmatrix} \begin{bmatrix} x_1 - \overline{\mu}_1 \\ x_2 - \overline{\mu}_2 \end{bmatrix}$$

$$= [4.547 - 3.746, 30.7 - 20.53] \begin{bmatrix} 0.02 & 0.87 \\ 0.87 & -0.04 \end{bmatrix} \begin{bmatrix} x_1 - 3.746 \\ x_2 - 25.62 \end{bmatrix}$$

$$= 32.184\ x_1 - 818{,}467\ x_2 - 363.23$$

The following is the discriminant equation for the values of the water flow (x_1) and the time (x_2) as shown in Table 5:

$$\hat{z} \geqslant 0 \iff \hat{D}^{[1]2} \leqslant \hat{D}^{[2]2} \iff \text{in population [1] (toilet full flush)}$$

$$\hat{z} < 0 \iff \hat{D}^{[1]2} > \hat{D}^{[2]2} \iff \text{in population [2] (toilet half flush)}$$

Note that with the same calculation the coefficients for each of the investigated guest rooms can be set as shown in Table 6.

Table 6. List of the coefficients.

Room	Coefficient of X_1	Coefficient of X_2	Complement
A	32.184	818,467	−363.23
B	−7.393	561,514	−139.844
C	3.0	345,600	−125
D	2.543	49,248	−25.92
E	1.00	172,800	−50.0
F	1.00	172,800	−45.0

If the above equation are used in order to calculate the discriminant values of the different toilet activities, then the identification rate is 100%.

3.4. Model of Toilet and Shower Actions

The toilet usage frequency (both full and half flushes), as well as the consumption, time and hot water temperature data, as measured in the six guest rooms, are shown per person and per room in Table 7.

Table 7. The statistical values of toilet and shower use.

Characteristic Value	Toilet Use Action per Person		Shower Use Action Per Person		
	Full Flush (Time/Day)	Half Flush (Time/Day)	Water Volume (L/Time)	Time (Min/Use)	Temperature of Hot Water (°C)
Average	3.3	3.0	48.1	7.3	37.7
Standard deviation	2.3	2.2	34.7	5.2	2.9

The output values gained from the activity separation algorithm show the toilet and shower uses per room. The toilet use and shower use per person were then calculated by dividing the output value by the average number of occupants.

Data from toilet use revealed that full flushes occur more than half flushes in the hotel environment compared to the mean Vietnamese household, although the total flush time is similar when compared to the results from the earlier study (Table 8)

Table 8. Toilet usage in Vietnamese households [9].

Item	Toilet Use per Person	
	Full Flush (Time/Day)	Half Flush (Time/Day)
Vietnam household model	2.1	4.8

This may be due to the difference in users' economic rationality. The toilet usage model in the previous study was targeted towards general households, so the burden of expenses was lowered by saving water. However, at places such as hotels, users have to pay a fixed amount of money, irrespective of the actual amount of water used. Therefore, their water-saving awareness level is considered low in the context of this study.

The showering data was compared with the results of an earlier study, in which the showering habits in Japan were measured and explored by means of a questionnaire. The previous study's results [10] are shown in Table 9.

Table 9. Showering habits in Japan.

The Investigation Object	Shower Use Action per Person			
	Water Volume (L/Time)	Instantaneous Flow (L/Min)	Time (Min/Use)	Temperature of Hot Water (°C)
A model of a Japanese household [10]	84.6	10	Summer: 7.6 Winter: 9.4	Summer: 39 Winter: 40

The research data from the Vietnamese hotel indicated a decrease in water usage, showering time and temperature of hot water when compared to the average Japanese household. Comparison of the instantaneous flow, the flow amount divided by the flow time, shows 6.6 L/min in the Vietnamese hotel to 10 L/min in the Japanese model. The variation in values between Vietnamese and Japanese data is caused by the different characteristics of the shower models used, not because of differences between the countries themselves. The average shower time in Vietnam is 7.3 min/use, which is close to the values seen in the Japanese summer data. This study shows that results obtained in Ho Chi Minh City, which has a consistent climate all year round, strongly resemble the data obtained in Japan during the summer. Moreover, it is believed that the difference seen in hot water temperatures is caused by the difference in climate zones of the investigative sites; namely the Torrid Zone in Ho Chi Minh and the Temperate Zone in Japan.

3.5. The Breakdown of Hourly Water Use in the Hotel in Vietnam

The breakdown of hourly hot and cold water use in a full and half toilet flush, in the shower and in the bath-tap at the hotel room is shown in Figure 5.

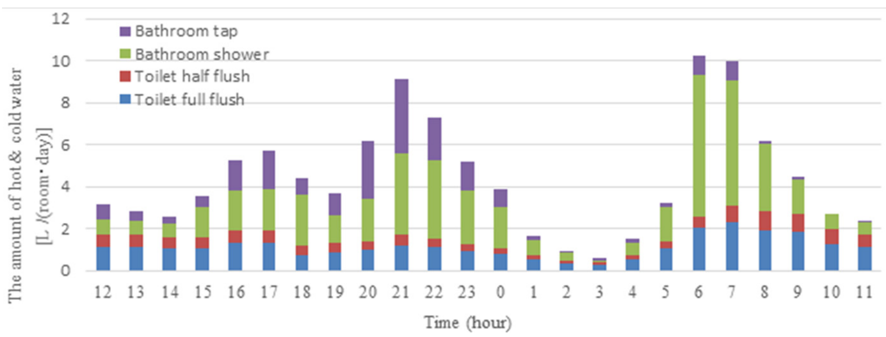

Figure 5. The breakdown of the hourly hot and cold water use.

The average amount of hot and cold water use is 144.6 L/(room per day), of which the full toilet flush accounts for 27.3 L, the half toilet flush for 17.3 L, the shower for 69.6 L, and the tap of the bath for 30.3 L. Although the tap for the sink is not included in the hot and cold water usage amount, its share in the room's total hot and cold water usage is seemingly very low. Previous studies in Japan show that the use of the sink accounts for just 5% of the total water usage. The data also reveals that each action has a high usage rate in the morning time and a low rate in the daytime. A peak in showering activity was seen twice; both in the morning and at night, because there was a second high usage rate between 21:00 and 23:00. The time of shower usage is more concentrated than the toilet usage, suggesting that the peak of hot and cold water use at the hotel is mainly caused by shower usage.

4. Conclusions

In conclusion, this study measured and assessed toilet and shower usage in the context of a Vietnamese hotel. By modeling the frequency of toilet usage and water consumption, as well as usage time and shower temperature, this study provides valuable data relevant to improving water-saving strategies and comprehending the impact of water-saving devices. The modeled mean values can be summarized as such: a full toilet flush occurs 3.3 times/day, a half flush 3.0 times/day, the water consumption from shower usage is 48.1 L/day, showering time is 7.3 min/day and the shower water temperature is 37.7 °C. This data can be utilized for the management of hotels, as it foregrounds the estimation of water consumption and the associated running costs. Future research should attempt to quantify the CO_2 emission reduction effect achieved by the introduction of water saving toilets and showers in Vietnamese hotels by using the modeled values from this report.

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Author Contributions: Yasutoshi Shimizu designed the experiments; Kanako Toyosada performed the experiments; Kanako Toyosada and Takayuki Otani analyzed the data; Kanako Toyosada wrote the paper.

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