Research on Hot Water Issues in Residential Buildings in Subtropical Taiwan

Cheng-Li Cheng*1 and Meng-Chieh Lee2

1 Dr. Professor, Department of Architecture, National Taiwan University of Science and Technology, Taiwan R.O.C.
2 Ph.D. Candidate, Department of Architecture, National Taiwan University of Science and Technology, Taiwan R.O.C.

Abstract
Countries in subtropical areas always overlook the issue of building hot water supply systems due to the short winter and high average temperature. However, the hot water supply system is still identified as requisite residential building equipment in subtropical countries such as Taiwan. Previous research with an overview of residential water usage revealed that building hot water consumes a great amount of energy and some critical problems are disregarded. This paper focuses on the residential building hot water supply system using Taiwan as a subtropical area example. Several significant hot water supply system features are presented with the quantitative parameters from Taiwan.

Keywords: residential building; hot water; subtropical country; energy consumption; water supply and drainage; investigation

1. Introduction
Hot water supply systems are part of a buildings’ water supply and drainage network, commonly identified as one of the most important equipment areas in residential building properties. Countries located in high latitude areas or Frigid Zones always place importance on hot water supply systems for water conservation and energy savings. Owing to the multiple uses of hot water in residential buildings, many kinds of hot water systems were produced.

Countries in subtropical areas or Torrid Zones due to the short winter and high average temperatures ignore the issues involving hot water supply systems. However, hot water supply systems are identified as requisite equipment in residential buildings in subtropical countries such as Taiwan. Government and the public have gradually noticed the hot water supply issues in recent years. The initial concerns were concentrated in energy consumption. The problems of security were then raised to the public. Therefore, considerable development progress has been made in energy conservation, such as applying solar heaters or other substitution energy to the hot water supply system within buildings.

The hot water supply issues include the water demand, energy consumption, amenity and public security of residents within buildings. Previous research presented an overview of the residential water usage process [1], and provided a simple equation for analyzing energy consumption with regard to electric power in urban water treatment and drainage systems. The partial results revealed that hot water consumed a great amount of energy. The essential information on hot water supply systems is insufficient and more research needs to be conducted for subtropical countries. Accordingly, this paper focuses on residential building hot water supply systems and reports on Taiwan as a subtropical country example.

2. Investigation
According to the previous research document [2], the average water consumption is approximately 250.0 l water per person per day in Taiwan with 50.0 l (20%) consumed for bathing. This investigation included two observation phases. We arranged questionnaires to interview residents about the types of heaters, water use behavior and decisions on hot water supply system installation. We arranged questionnaires to interview residents about the types of heaters, water use behavior and decisions on hot water supply system installation. The second phase was a field survey on the current water use situation including length of piping, bathing volume and temperature.

Building hot water is used primarily in the bathroom in Taiwan. Generally, the use volume for the kitchen is comparably small. We found fewer cases with hot water for the kitchen. The resident’s interview followed previous researches [3][4] and referred to the Directorate-General of Budget, Accounting & Statistics of the ROC reports (DGBAS) [5]. Statistical methods and software were conducted for this analysis. The field survey included measuring the pipe length from the heater to faucets; use volume for bathing and temperature variation in the supply process. This investigation was carried out using a random sample and one residential unit is seen as a survey unit. Two hundred questionnaires were sent out and 152 effective answers were returned. Seventy-seven individual houses and 75 apartments were among the effective samples. The hot water energy consumption was examined in connection with the...
installed equipment, water use volume, and water temperature. Two topics were identified in this phase. The first was the installed equipment such as hot water equipment. The second topic was the water use volume behavior and plumbing system.

(1) Hot water equipment

According to the interview results, 80% of the residential building hot water supply systems use gas heaters (Figure 1). Gas heaters are seen as a convenient and clean utility in Taiwan. However, gas explosions and carbon monoxide poisoning occasionally happen and sometimes raise public security concerns. The investigation results reveal that most of the gas heaters are set outdoors for security reasons and only 11.8% of gas heaters are set indoors.

Installing gas detectors reduces carbon monoxide poisoning, but some accidents still happen due to gas explosions. According to National Fire Agency of R.O.C. reports 2% of fires were caused by gas explosions in 2001 (Figure 2) [6].

Most people (89%) regard safety as their premier consideration when they choose heaters. Seven point one percent considered economics as the priority (Figure 3). Whatever they choose, they still worry about gas (46.5%) and electrical leakage (36.9%). Both gas and electric heaters have their own risks, but considered as energy resource, gas is cheaper and more efficient than electricity. Solar heaters are another option, but it’s still expensive and needs heating auxiliaries when the solar radiation is insufficient.

Table 1 shows the current water supply systems for residential buildings in Taiwan. Gravity water supply systems that serve water downward from a rooftop tower are mostly adopted in Taiwan. However, there are often

<table>
<thead>
<tr>
<th>Diagram</th>
<th>Types</th>
<th>Illustration</th>
<th>Defect</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td>Direct water supply system</td>
<td>Water is supplied by direct urban water system and is controlled by water department.</td>
<td>Users at the end of the system may not be served with normal water pressure.</td>
</tr>
<tr>
<td><img src="image2.png" alt="Diagram" /></td>
<td>Gravity water supply system</td>
<td>Water supply system serves water downward from rooftop tower by gravity.</td>
<td>Water pressure upstairs is smaller than downstairs, causing of low water head.</td>
</tr>
<tr>
<td><img src="image3.png" alt="Diagram" /></td>
<td>Pressurized water supply system</td>
<td>Water supply system serves water upward from underground level or basement tank.</td>
<td>Water pressure is unstable when other faucets are used.</td>
</tr>
</tbody>
</table>

Table 1. Feature of Water Supply System and Defect
lack pressure system installation and relay pumps. Some plumbing is improperly set. Therefore, residents on different floors suffer imbalanced pressure. The water pressure upstairs is reduced when water is used downstairs, or the water pressure in the bathroom decreases when water is used in the kitchen on the same floor. Accordingly, the hot water may get cooler when the gas heater shuts down due to unstable water pressure.

Most twin-head faucets have been improved into single faucets for convenience in recent years (current utility rate is 70.8%). Thus, hot and cold water can be mixed instantly in a one-head faucet. However, cold water pressure is much greater than hot water pressure. Too much hot water pressure would extinguish the gas heater. A small compression pump should be installed before the heater water entrance to balance pressure between the cold and hot water.

(2) Utilization behavior

Human bathing behavior is mostly seen as a very private activity. As a water consumption issue, individual behavior greatly dominates the water use volume. Therefore, hot water usage behavior must be considered as one of the factors for water consumption in the bathroom.

As we know, people that take showers consume less water than those that take baths. According to the investigation results, 77.7% of people take a shower, while 22.3% take a bath (Figure 4).

The utilization behavior includes washing hair, turning the water off while using soap, or doing other things (like teeth brushing, clothing washing, etc.) during bathing time. All of these bathing activities influence the volume of water consumed. The investigation results (Figure 5) show that 15% of the people do other things while taking bath and 14% of the people do not turn off water while applying soap. These two behaviors consume greater amounts of water. The 15% of the people are considered as water wasters for evaluating energy consumption in the following section.

(3) Plumbing system

The last issue considered in this paper for building hot water use volume is the plumbing system. The plumbing system includes the building utilities service design and construction. Improper plumbing design would cause the increased loss of both energy and water. Good utility performance requires a simplified system and shorter plumbing lines. The existing residential building plumbing system in Taiwan is complicated due to a poor design process. Figure 6 shows the typical plan for a residential building in Taiwan. The distance between the gas heaters, which are often put on balcony, and terminal facility is always inefficient for this long supply plumbing line. Accordingly, the comfort control for the hot water supply is often invalid due to the temperature drop. This investigation shows that the water temperature from the heater is around 55.0˚C and the hot water pipe length is approximate 6.5m on average.

We hypothesize that all faucets are 0.5 inch (1.3 cm) in caliber, and the pipe cross section for matching these faucets is 1.3E-4 m². We get the following equations:
From the eq.1 we calculate the water volume that remained in the pipe after utilization is 0.8 l in Taiwan.

3. Experimental survey

A bathtub was installed to collect bathing water, and was used ruler to measure the water depth. One hundred fifty users were used to determine the water volume \( Q_T \) after bathing. The water use volume includes the bath water \( Q_B \) and the cold water remaining in the pipe \( Q_P \). The experimental set up is shown in Figure 7.

The bath water volume correlated to the individual behaviors. This experimental survey recorded the bathing water consumed by each sample. A statistical method was adopted to check the correlation between the quantity of bath water and user behaviors as shown in Figure 8.

According to the observations, bathing behaviors reveal saving and wasting mode. The results showed that both modes followed a normal distribution. There was about 15% water waste in bathing, where 15% was the average between summer 9% and winter 22%. The mean quantity consumed by waste was 53.2 l and standard deviation is 11.4 l, while volume of water consumed by saving mode is 28.8 l and standard deviation is 9.4 l. Using the following equation, we get the average bathing volume to approximate 40.0 l.

\[
Q_{(\text{Evaluation})} = 0.85 \times Q_{(\text{Economical})} + 0.15 \times Q_{(\text{Wasted})} \tag{1}
\]

Hot water temperature is the other important factor, which is always discussed in lectures. We install a temperature sensor on the shower faucet, and turn on the cold water for getting \( T_c \) before bathing. Then we get temperature of bathing water \( T_b \) during shower time or bath time. The experiment is set up as shown in Figure 9.

This experiment was preceded with 150 samples from March to April 2003. The mean air temperature was 25.0˚C and the means cold-water temperature was 22.5˚C. According to the statistical analysis, we acquired the bathing temperature as shown in Figure 10. The major bathing temperature is between 35.0˚C and 40.0˚C and the mean bathing temperature is 38.4˚C, median is 40.0˚C, standard dev. is 4.7˚C.

Another experiment involved 763 samples from October to December 2003. The mean hot water temperature was around 38.5˚C with a peak in the range between 35.0˚C to 40.0˚C, as shown in Figure 11. Although the bathing temperature range was between 20.0˚C and 50.0˚C, it is harmful and uncomfortable for skin to touch water over 50.0˚C for more than one minute. The water temperature range in this practice was 22.0˚C to 45.0˚C. According to JSHASE [7], the suitable bathing temperature for Japanese is 40.5˚C, and for Taiwanese who are living in the subtropical zone, the suitable bathing temperature is around 38.5˚C.
4. Energy consumption

An overview of residential water use was reported in previous research, and a basic calculation for describing electricity consumption from water supply to sewerage treatment was provided [1]. Most of this energy consumption comes from water heating equipment. When a building utilizes a great deal of hot water, energy consumption by water heaters will be considerable, and should not be ignored.

Fig. 11. Temperature of Bathing Water in Winter in Taiwan

According to previous research, eq.3 as used for conservative calculating energy consumption of hot water utilization:

\[
E_g = Q_g \times c \times \rho \times (T_g - T_c) \quad \text{(kcal)}
\]

(3)

The survey measured the bathing water volume \(Q_g\), bathing water temperature \(T_g\), cold water temperature \(T_c\), and then gets bathing water energy consumption \(E_g\) from eq.4.

\[
E_g = Q_g \times c \times \rho \times \Delta T
\]

(4)

Some hot water that remained in the linking pipes will cool down before the next bathing time and always be released out. In long-term observation, a great amount of water and energy are wasted in this condition. Thus, eq.5 is introduced to calculate the energy consumption \(E_p\) within this part of water:

\[
E_p = Q_p \times c \times \rho \times \Delta T \quad \text{(kcal)}
\]

(5)

The result of our previous research [1], cold water per 1.0 m\(^3\) equals to electric power 0.948 kWh, i.e. 817.0 kcal. Therefore, the total energy consumption of hot water \(E_T\) of each person per bath may be determined by the following eq.6, a process of energy consumption calculation was conducted as shown in Figure 12.

\[
E_T = E_g + E_p + 0.817 \times Q_I
\]

(6)

Following the usage volume results with 40.0 l and temperature with 38.5°C of bathing water, the energy consumption in Taiwan was estimated. While the cold water temperature is 22.5°C and hot water temperature is 55.0°C, based on the results of this research. Bathing water energy consumption \(E_g\) is 0.728 kWh, pipes remained water energy consumption \(E_p\) is 0.03 kWh, and total energy consumption of hot water \(E_T\) is 0.798 kWh/person (i.e. 19.948 kWh/m\(^3\)).

According to previous review in volume and temperature of bathing water utilization in Japan which is located in the temperate zone, one person consumes about 1.311 kWh/person as assumed bathing water 51.0 l [8], temperature 40.5°C for bathing water, 20.0°C for cold water, 60.0°C for hot water, and linking pipes remained water volume in 1.0 l. As a result, it is obvious that the energy consumption in Japan is much more than it in Taiwan, located in a subtropical area.
5. Conclusion

Hot water energy consumption is connected with the installed equipment, water use volume, and water temperature. According to this investigation, some significant features of residential building hot water supply system in Taiwan with quantitative parameters were concluded as the following statement.

(1) Individual hot water supply system with instant gas heater for each residential unit is the most popular in Taiwan caused of energy resource, which is accompanied with unstable water pressure or unanticipated gas heater shut down.

(2) Human bathing behavior directly influenced hot water utilization. Bathing behavior reveals saving and wasting mode, and there is around 15% samples in wasting mode.

(3) Schematic observation reveals the average length of hot water supply piping within residential building is around 6.5m that are the factor of utilization efficiency and energy loss.

(4) Personal bathing volume was 40.0 l with temperature 38.5˚C on average. This is relatively lower than that for countries in high latitude Frigid Zone.

(5) This study determined an estimation equation to calculate energy consumption with hot water utilization, and total energy consumption of hot water in Taiwan is around 0.798kWh/person and it is smaller than 1.311kWh/person in Japan, located in a temperature zone.

Energy conservation is another critical issue in hot water supply system especially in countries in high latitude Frigid Zones. Considerable progress has been made to find new solutions for hot water energy, such as applying solar heaters or co-generation systems in residential buildings. However, the essential knowledge and information on hot water supply systems are still insufficient. More research is needed to help countries in subtropical Torrid Zones.

Nomenclature

\[A : \text{Cross section area (m}^2\text{)}\]
\[c : \text{Specific heat (kcal/kg•˚C)}\]
\[E : \text{Energy consumption (kcal)}\]
\[L : \text{Length (m)}\]
\[Q : \text{Water volume (l)}\]
\[T : \text{Temperature (˚C)}\]
\[\Delta T : \text{Temperature variation (}T_H-T_C\text{)}\]
\[\rho : \text{Density (kg/l)}\]

Subscript:

\[P : \text{Pipe}\]
\[T : \text{Total}\]
\[B : \text{Bathing water}\]
\[H : \text{Hot water}\]
\[C : \text{Cold water}\]

References