A pilot study on use of hot water in a bathtub as a heat resource for floor heating

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ABSTRACT

Although bathing in a bathtub is very popular in Japan, the hot water used is usually discarded. In this study, the prototype of floor heating units was tested to confirm the practical utilization of hot water in the bathtub for floor heating of a toilet room. Water temperature, floor surface temperature (FST) and air temperature in the toilet room were measured throughout the night in winter. The results showed that FST was in the range of 24–27°C in the case of floor heating. Thermal sensations voted by a young male monitor were well associated with floor surface temperature. Additional adiabatic materials installed in the sidewalls had no effects on air temperature in the toilet room. Therefore, the prototype may be practically used for floor heating of a toilet room and comfortable for particularly elderly people who often use a toilet room a few times during night.

INDEX TERMS

Floor heating; Hot water in bathtub; Toilet room

INTRODUCTION

In our society, the population of elderly people has continuously increased during the past decade. For this reason, it is now required that houses for elderly people must be built or renovated according to the 'barrier-free' concept or the 'universal-design' concept. Both concepts allow handicapped and elderly people to live without inevitable physical barrier. On the other hand, the requirement of minimizing energy consumption in our daily life promotes the use of heating, ventilation and cooling systems with as low energy consumption as possible.

To comply with the barrier-free concept and requirement of minimizing energy consumption, hot water in a bathtub is considered as a heat resource because the majority of Japanese people take a bath almost every night, particularly in winter. Hot water left in a bathtub may be utilized for floor heating because the water temperature is in the range of 38–40°C. In this study, we have tested a system that uses hot water left in a bathtub as a heat resource for floor heating of a toilet room.

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EXPERIMENT

Experimental Conditions

The apartment house is located in the Research Institute of Technology Center, Hachioji-shi, Tokyo, Japan. Its floor plan is indicated in Figure 1. The toilet room is situated in the middle part of the house. As indicated in Figure 2, one large and two small heating units were installed in the toilet floor. The experimental conditions are listed in Table 1. A young male monitor woke up every 2 h to use the toilet room under condition 3. The ventilation fan was operated throughout the test period under condition 4 and additional adiabatic materials were installed in the sidewalls and ceiling under condition 5.

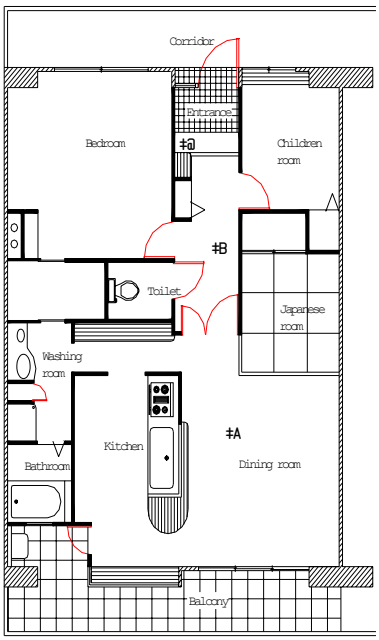

Figure 1 Floor plan of the apartment house.

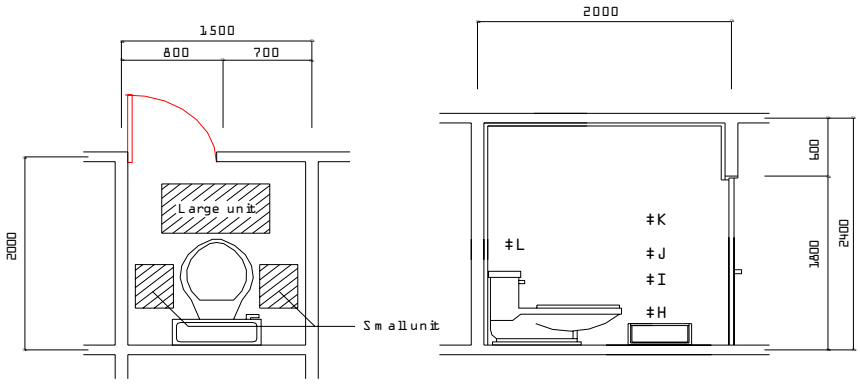

Figure 2 Floor heating units installed in the toilet room.

Table 1 Experimental conditions

Conditions	Floor heating	The toilet room	Fan	Adiabatic materials
Cond. 1	No heating	Not used	Not operated	Not installed
Cond. 2	Heating	Not used	Not operated	Not installed
Cond. 3	Heating	Used every 2 h throughout night	Operated when the toilet was used	Not installed
Cond. 4	Heating	Not used	Operated during the test period	Not installed
Cond. 5	Heating	Not used	Not operated	Installed

Floor Heating Units

The floor heating units consist of one large unit (L = 85 cm, W = 51 cm, D = 27.5 cm) and two small units (L = 30 cm, W = 45 cm, D = 27 cm). These units were made of 15 cm thickness wood panels coupled with adiabatic materials. Six vinyl bags were prepared and filled with 40°C hot water. The total volume of hot water was 120 l. This volume corresponds to 80% of hot water left in a typical bathtub used in Japan. Four bags and two bags were incorporated into the large unit and the small unit, respectively (see Figure 3).

Experimental Protocol

Each test was conducted from 10:00 p.m. to 6:00 a.m. next morning. Temperatures at different locations listed in Table 2 were measured throughout the test period. Under condition 3, considering the real life of elderly people who often use a toilet room a few times during night due mainly to diuresis, a young male monitor woke up every 2 h to use the toilet where its floor was heated with the units.

Table 2 Measurement locations

1	Outdoor air temperature	8	Side part of floor surface
2	Center part of dining	9	10 cm above floor surface of the toilet room
3	Center part of corridor	10	60 cm above floor surface of the toilet room
4	Top part of hot water	11	80 cm above floor surface of the toilet room
5	Middle part of hot water	12	120 cm above floor surface of the toilet room
6	Bottom part of hot water	13	Globe temperature in the toilet room
7	Center part of floor surface		

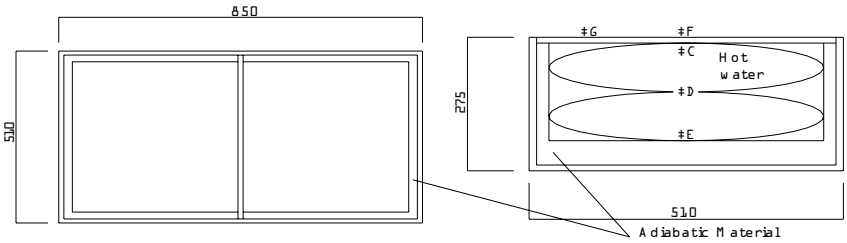

Figure 3 Detail of the large heating unit.

RESULTS

Change in Water and Air Temperatures

Under condition 1, air temperatures at four different heights showed no marked difference during the test period as compared with outdoor air temperature. Changes in water and air temperatures in condition 2 are shown in Figure 4. Floor surface temperature was initially 27°C and gradually decreased to 23°C at 8:00 a.m. the next morning. The initial water temperature was 40°C and also gradually decreased to 30°C at 8:00 a.m. the next morning. Air temperatures and globe temperature in the toilet room was initially 14°C and slightly dropped to 12°C. Although these temperatures were 3 or 4°C higher than air temperature on the corridor adjacent to the toilet room, the heat dissipated from the units induced little elevation of the toilet room temperature.

Under condition 4, the ventilation fan was operated throughout the test period to estimate an effect of heat loss with ventilation. The ventilation rate was measured with a tracer method using carbon dioxide. As a result, the ventilation rate was found to be 0.5 and 1.9 (times/hour) when the ventilation fan was not operated and operated, respectively. Under condition 5, adiabatic materials were installed in the sidewalls and ceiling to estimate an effect of increased resistance to heat loss through the walls. It was then found that water temperature, floor surface temperature and room temperature showed no significant difference as compared with those under other conditions.

Relationship between Thermal Sensation Votes and the Thermal Index

The young male monitor entered the toilet room and sat on the toilet for 1 min every 2 h for simulating the real life of elderly people. The monitor voted on total thermal sensation and local thermal sensation on sole before entering the toilet room and while sitting on the toilet room. The scales of the thermal sensation vote are listed in Table 3.

An operative temperature in the toilet room was calculated from air temperature and mean radiant temperature in consideration of an effect of radiation. The relationship between total thermal sensation votes and operative temperatures in the toilet room is indicated in Figure 5

and the relationship between local sensation votes at sole and floor surface temperatures is indicated in Figure 6. Before the monitor entered the toilet room, i.e. while standing on the corridor, the operative temperature was in the range of 8–10°C. Therefore, 'very cold' or 'slightly cool' were dominantly voted. While the monitor was sitting on the toilet, total thermal sensation votes changed to 'slightly cool' or 'neutral' although a floor temperature difference between the corridor and the toilet was less than 4°C. An effect of floor heating on local thermal sensation vote on sole was more clearly distinguished. While sitting on the toilet, the monitor voted 'neutral' or 'slightly warm' because of direct heating from floor heating units.

CONCLUSIONS

In order to avoid skin burn due to prolonged floor heating at moderate temperature (Suzuki *et al.*, 1991), it is currently recommended that a floor temperature must be maintained below 30°C (Zhang *et al.*, 1998). Recently, Maeda *et al.* (2000) reported that floor heating of 25°C might be sufficient for elderly people from the physiological point of view. In this study, the floor heating in the range of 23–27°C was sufficient from subjective evaluation. Thus, it has been proved that hot water left in a bathtub may be a potential heat resource for a floor heating system incorporated into a small room such as a toilet room.

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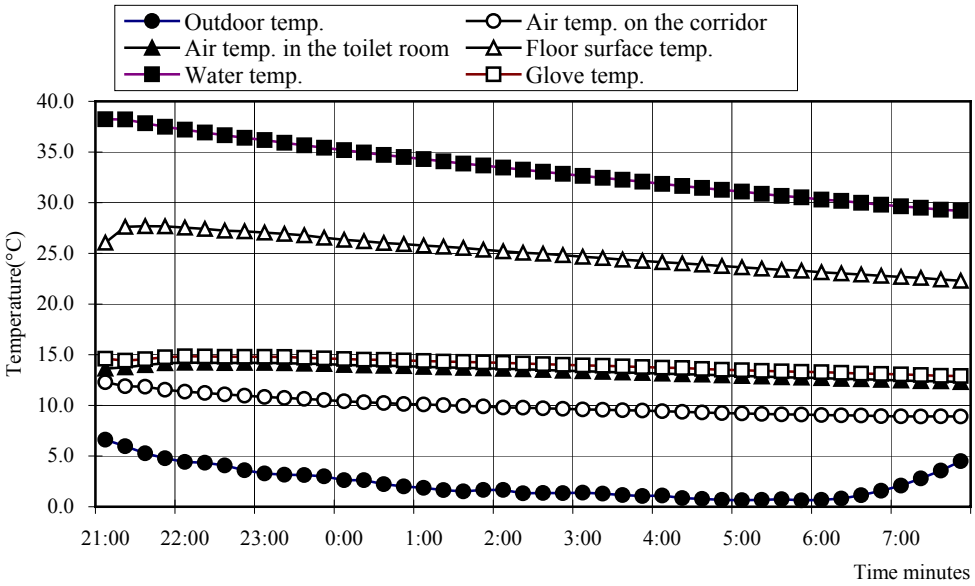

Figure 4 Change in water, air and glove temperatures during the test period under condition 2.

Table 3 Scales for thermal sensation votes

Total and local thermal sensation vote	Scales
1. Warm	+2
2. Slightly warm	+1
3. Neutral	0
4. Slightly cool	–1
5. Cool	–2
6. Cold	–3
7. Very cold	–4

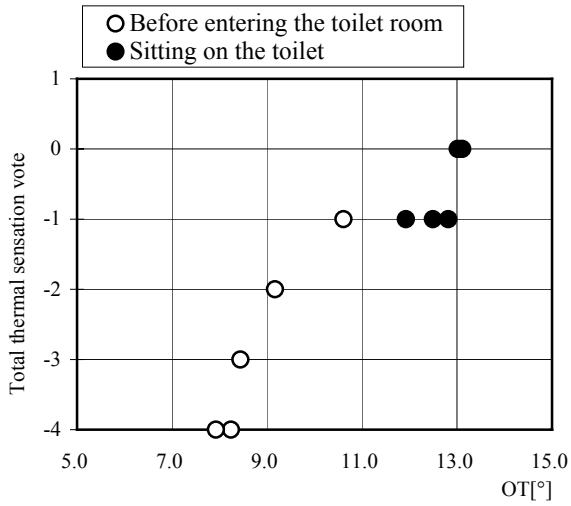

Figure 5 Relationship between total thermal sensation votes and operative temperatures.

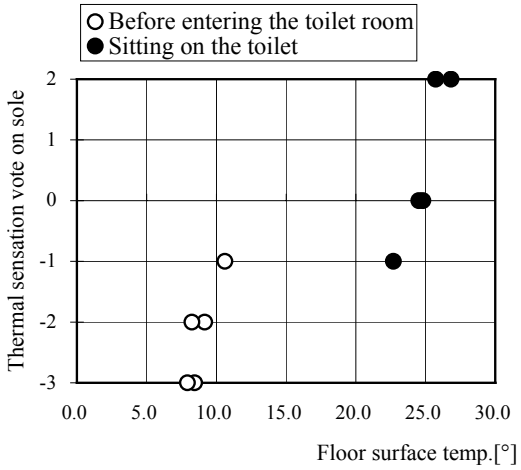

Figure 6 Relationship between local thermal sensation votes on sole and floor surface temperatures

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