

# Showering Thermal Sensation in Residential Bathrooms

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**Abstract:** The thermal energy consumed by showering to the satisfaction of the showering subject, is largely dependent on the water temperature, shower duration, water flow rate, and bathroom air temperature. A research gap, between human thermal preferences and the smart use of thermal energy in high-rise urban residential bathroom environments, has been identified. This study examines the influence of a bathroom's thermal environment on the showering subject's thermal sensation. Of the 98 invited respondents, a total of 31 volunteers (12 females and 19 males) participated in the showering experiments, under three thermal conditions (control, colder, and warmer); their subjective thermal responses, including thermal sensation, thermal comfort, and thermal acceptability votes, were recorded. The results showed a non-linear trend of thermal sensation vote (TSV) against the bathroom air temperature. The predicted dissatisfied (PD) was asymmetrical, and the showering subjects preferred a slightly warm environment. Although the female TSV values were more sensitive than the male ones, in both the colder and warmer experiments, there were no significant gender differences. The findings of this study—including the expressions derived from the shower-water and bathroom air temperatures for the thermal comfort zone in a bathroom environment—can be used as a reference to enhance our understanding of thermal energy consumption in environmental design, and to help optimize the thermal environment in bathrooms.

**Keywords:** thermal sensation; thermal environment; showering; residential bathroom; hot water



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## 1. Introduction

The concept of optimizing domestic hot water usage is often overlooked, especially in subtropical cities, where winters are relatively short, and ambient temperatures are generally higher [1,2]. Statistics of residential energy consumption show that 20% of the end-use energy is for water-heating, especially for personal hygiene, such as bathing and showering. It is known that the amount of thermal energy consumed by showering—the most common form of bathing—is related to water temperature, shower duration, water flow rate, and bathroom temperature [3].

A study found that the preferred shower-water temperature, which is affected by seasonal climate change, is inversely proportional to the bathroom air temperature [4]. A hot shower is usually taken not only for maintaining body temperature but also for achieving thermal comfort. Thermal sensation and comfort estimates for humans under showers have been investigated under warmer environmental conditions. The experimental results revealed that, in the same thermal environment, many subjects feel colder and more uncomfortable in a shower than in a whole-body bath [5]. In other words, extra heat-energy is required for meeting the thermal comfort demand resulting from a shower. A study found that if both the bathroom air and bathwater temperatures required for a neutral thermal preference are reached, then further air and water temperature adjustments in the bathroom are not necessary [6].

Studies have also demonstrated that the range of desirable shower-water temperatures is 36–41 °C [3,7]. A study by Masuda et al. [8] reported that when the skin temperature was about 40 °C, different subjects had similar thermal perceptions at bathroom temperatures

15 °C and 25 °C. However, the skin temperature measurements before and after bathing in a bathroom controlled at 15 °C were significantly lower than those in a bathroom controlled at 25 °C. Moreover, a study by Herrmann et al. [9], that used lower shower-water temperatures (32–39 °C), recorded a thermal neutral level at a higher bathroom air temperature of 28 °C.

In fact, research efforts have focused on the thermophysiological responses to shower-water temperatures (e.g., 40–42 °C), rather than neutral air temperatures ( $\leq 25$  °C) [5,10,11]. Although the air temperature in a bathroom affects both energy and human health [12], the thermal responses of showering subjects at different air temperatures were not studied in detail.

There is a gap in our knowledge of human thermal preferences and the smart use of thermal energy in high-rise urban residential bathroom environments. To meet sustainability challenges in cities dominated by high-rise housing developments, the modelling of factors affecting the use of energy in buildings must be based on thermal sensation studies reflecting realistic bathroom conditions. The objective of this study was to examine the influence of a bathroom's thermal environment on the showering subject's thermal sensations. This study generated new data on the thermal response of showering subjects, based on measurements and experimental data available from open literature. The survey subjects and the experimental procedure are described in Section 2. The measurement results are presented in Section 3, with the thermal responses of the showering subjects estimated at a range of air and water temperatures. Concluding remarks are presented in Section 4.

## 2. Materials and Methods

To generate new data on the thermal response of showering subjects at a new air-temperature range, this study recruited volunteers for the experiment, using a protocol described in this section.

### 2.1. Subjects of Investigation

A pre-screening interview survey was conducted, to collate details of showering habits. Shower-water temperature, time spent in the shower, and time spent on other activities in the bathroom were recorded for a year. A sample of the survey questions is shown in Appendix A. Invitations were sent via online platforms, and 98 participants completed the survey. The showering habits of these participants covered all the possible options; therefore, they can be seen as representative samples. Among those participants, 12 females and 19 males (corresponding to an acceptance rate of 32%) took part in the subsequent showering experiments, and their details are summarized in Table 1. The average heights and weights were 1.56 m and 54.6 kg for the females (body mass index (BMI) = 22.6) and 1.74 m and 66.8 kg for the males (BMI = 22.2), respectively. The showering experiments included three different experiments (control, colder, and warmer) arranged on different days in different bathroom air temperatures. None of the showering subjects were told about the experimental conditions, to minimize participant bias. Ethical approval was obtained for the study protocols from the Human Subjects Ethics Sub-Committee of the Hong Kong Polytechnic University (Reference Number HSEAR20201015003).

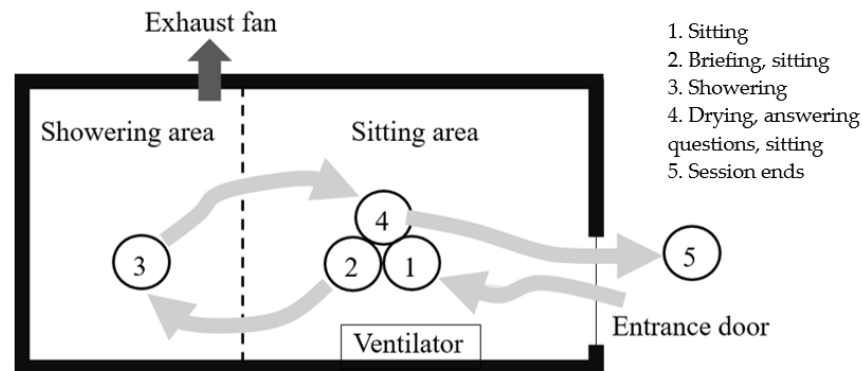
**Table 1.** Subject information.

Gender	Count	Height (m)	Weight (kg)	BMI	Age
Female	12	1.47–1.62	43–64	19.3–27.3	24–45
Male	19	1.65–1.84	52–86	17.2–26.6	24–55

### 2.2. Conditions and Procedures

The size of the bathroom used in the experiments was 2.1 m × 1.5 m—the typical size of a local residential bathroom in high-rise buildings. It comprised two areas (sitting and showering) separated by a showering curtain, as shown in Figure 1. Inside the bathroom,

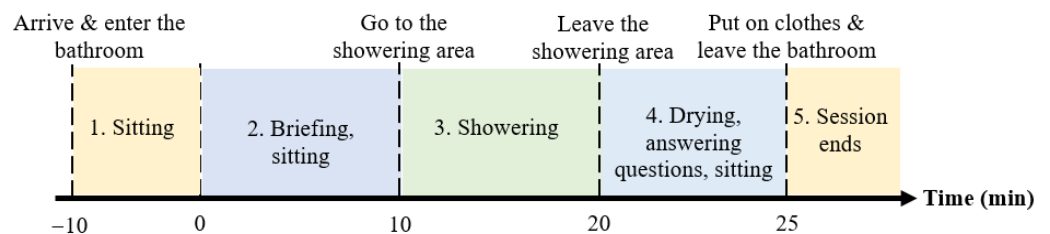
there was an exhaust fan for ventilation, and a thermal ventilator for indoor temperature and velocity controls.



**Figure 1.** The bathroom (2.1 m × 1.5 m).

The air temperature in the bathroom could be set to: the control condition (mean air temperature ≈ 26 °C); the colder condition (mean air temperature ≈ 18 °C in the colder months, from December to March); or the warmer condition (mean air temperature ≈ 30 °C in the warmer months, from March to September).

Figure 2 illustrates the 35 min experimental procedure, based on an experimental protocol adopted in previous studies, that required the subject to sit for at least 15 min, shower for at least 10 min, and spend at least 10 min on after-shower drying [11]. Upon entering the sitting area of the bathroom, the showering subject was briefed on the experiment details. Sitting in the bathroom for at least 20 min enabled the subject to reach a thermally stable state, in which the thermal sensation vote was estimated to be 0, −3, and 1 for the control, colder, and warmer conditions, respectively, based on the environmental conditions, and on the metabolic rate of 1.1 Met and clothing value of 0.6 clo [13].



**Figure 2.** Experimental procedure.

The physical environmental parameters (air temperature  $T_a$  in °C; black globe temperature  $T_g$  in °C; relative humidity  $RH$  in %; and air velocity  $V_a$  in  $\text{ms}^{-1}$ ) and shower-water temperature  $T_c$  (°C) at the showerhead outlet were recorded continuously throughout the experimental procedure. The shower-water temperature, measured at the showerhead outlet, was set according to the choice of the showering subject. The outdoor air temperature was also measured. The indoor mean radiant temperature  $T_r$  (°C) was determined by [14]:

$$T_r = T_g + 2.35\sqrt{V_a}(T_g - T_a) \quad (1)$$

The thermal sensation of the showering subject was recorded after each showering session, using a 7-point semantic differential scale for thermal comfort [13], i.e., Cold (−3), Cool (−2), Slightly Cool (−1), Neutral (0), Slightly Warm (+1), Warm (+2), and Hot (+3). In addition, the showering subject was required to describe the feeling of comfort (Comfortable/Slightly Uncomfortable/Uncomfortable/Very Uncomfortable) and the overall thermal acceptability (Acceptable/Unacceptable).

### 3. Results and Discussion

#### 3.1. Pre-Screening Interview

A total of 98 participants (55 females and 43 males) completed the pre-screening interview survey. Table 2 summarizes the survey results. The total time spent in the bathroom (21.6–27.4 min) was similar to the design experiment time of 25 min. The average time spent in the bathroom before showering (including using the toilet, washing up, brushing teeth, etc.) was 8.9 min ( $SD = 5.2$ ); this was comparable to the pre-showering time of 7–10 min adopted by a previous study [5]. While the female participants spent a longer time on the pre-showering activities than the male participants ( $M = 9.3$  min,  $SD = 5.6$  vs.  $M = 8.3$  min,  $SD = 4.6$ ), there was no significant difference relating to gender ( $p = 0.34$ ,  $t$ -test).

**Table 2.** Screening interview aspects and responses.

Gender	55 Females	43 Males
Time spent in the bathroom before taking a shower (including using the toilet, washing up, brushing teeth, etc.)	9.3 min ( $SD = 5.6$ )	8.3 min ( $SD = 4.6$ )
Time spent in the shower	14.4 min ( $SD = 6.4$ ), Summer 18.1 min ( $SD = 6.9$ ), Winter	13.3 min ( $SD = 7.1$ ), Summer 16.3 min ( $SD = 7.1$ ), Winter
Time spent in the bathroom	23.7 min ( $SD = 9.7$ ), Summer 27.4 min ( $SD = 10$ ), Winter	21.6 min ( $SD = 9.7$ ), Summer 24.7 min ( $SD = 9.4$ ), Winter
Prefer a higher shower-water temperature in winter than in summer	Yes = 44 No = 4 Maybe = 7	Yes = 31 No = 4 Maybe = 8
Prefer a lower shower-water temperature in summer than in winter	Yes = 27 No = 14 Maybe = 14	Yes = 29 No = 6 Maybe = 8

The average times spent in the shower were 13.9 min ( $SD = 6.7$ ) in summer and 17.3 min ( $SD = 7.0$ ) in winter. A previous field measurement study reported that, with an outdoor temperature drop of 6 °C, the shower duration was 10% [15]. In this study, there was no significant difference in the showering time relating to gender, either in summer ( $p = 0.42$ ,  $t$ -test) or in winter ( $p = 0.23$ ,  $t$ -test).

Although 75 participants preferred a higher shower-water temperature in winter than in summer, 8 participants expressed otherwise. Furthermore, 56 participants preferred a lower shower-water temperature in summer than in winter, while 20 participants did not. The results indicated that the preferred shower-water temperature could be seasonally influenced. However, in a previous field measurement study, no significant difference in the preferred shower-water temperature had been found, with an outdoor temperature drop of 7 °C [15].

#### 3.2. Thermal Responses

Table 3 summarizes the experimental results of the control, colder, and warmer case averages, with standard deviation given in brackets. Determined by the following expression, where  $V_a$  ( $\text{ms}^{-1}$ ) is the average air velocity,  $T_a$  (°C) is the indoor air temperature and  $\bar{T}_r$  (°C) is the indoor mean radiant temperature, the operative temperature  $T_{op}$  (°C) in the bathroom was [14]:

$$T_{op} = \frac{\bar{T}_r + (T_a \sqrt{10V_a})}{1 + \sqrt{10V_a}} \quad (2)$$

Table 3. Results.

Parameter		Control	Colder	Warmer
Outdoor daily mean temperature $T_{od}$ (°C)		17.4 (0.7)	17.7 (0.7)	30.7 (1.4)
Indoor air temperature $T_a$ (°C)		25.8 (0.3)	17.7 (0.7)	29.8 (0.2)
Indoor mean radiant temperature $\overline{T}_r$ (°C)		25.4 (0.2)	17.3 (0.6)	29.4 (0.2)
Average air velocity $V_a$ (ms <sup>-1</sup> )		0.57 (0.02)	0.55 (0.05)	0.57 (0.02)
Operative temperature $T_{op}$ (°C)	Overall	25.7 (0.3)	17.6 (0.6)	29.7 (0.2)
	Female	25.6 (0.2)	17.6 (0.7)	29.7 (0.2)
	Male	25.7 (0.3)	17.6 (0.7)	29.7 (0.2)
Relative humidity $RH$ (%)		80 (4)	81 (3)	80 (2)
Shower-water temperature $T_w$ (°C)	Overall	38.8 (0.7)	38.8 (0.7)	38.8 (0.7)
	Female	39.2 (0.6)	39.2 (0.6)	39.2 (0.6)
	Male	38.6 (0.7)	38.6 (0.7)	38.6 (0.7)
Thermal sensation vote $TSV$	Overall	0 (0)	-0.71 (0.64)	0.68 (0.65)
	Female	0 (0)	-0.90 (0.67)	0.80 (0.62)
	Male	0 (0)	-0.60 (0.61)	0.60 (0.68)
Thermally comfortable	Female	12	5	7
	Male	19	17	16
Slightly thermal uncomfortable	Female	0	7	5
	Male	0	2	3
Thermally acceptable	Female	12	10	11
	Male	19	19	19
Thermally unacceptable	Female	0	2	1
	Male	0	0	0

Note: Standard deviation in brackets.

In the experiments, the  $T_{op}$  and relative humidity ( $RH$ ) values were maintained between 25.2–26.1 °C and 75–85% for the control cases, 16.7–18.8 °C and 76–85% for the colder cases, and 29.4–30.0 °C and 78–83% for the warmer cases. The findings revealed that females preferred a higher shower-water temperature (39.2 °C,  $SD = 0.6$ ) than males (38.6 °C,  $SD = 0.7$ ) ( $p = 0.016$ ,  $t$ -test). In the control cases, the most preferred shower-water temperature—a temperature at which all showering subjects felt thermally neutral (i.e., thermal sensation vote  $TSV = 0$ ), comfortable, and acceptable—was 38.8 °C ( $SD = 0.7$ ). It was also employed in the subsequent colder and warmer experiments.

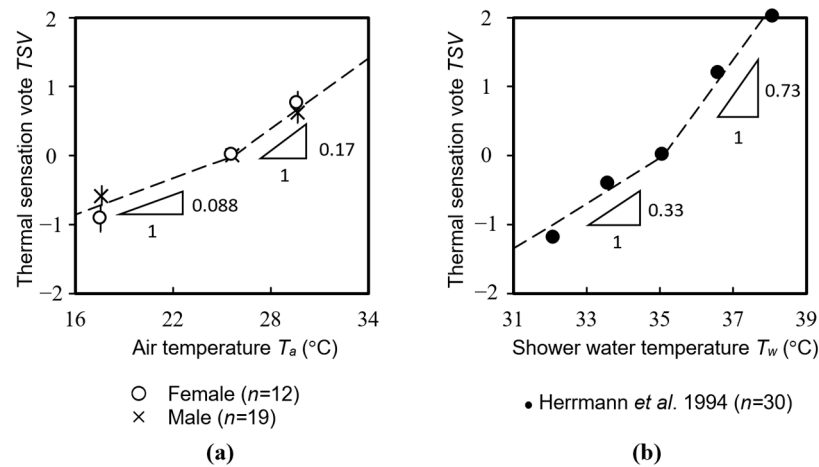
All subjects in the control cases expressed that the thermal environment was neutral, comfortable, and acceptable. In the colder cases, however, 9 (out of 12) females and 10 (out of 19) males felt slightly cool or cool. Among those female subjects, 7 stated they were slightly uncomfortable, while 2 expressed that the thermal environment was unacceptable. Among those male subjects, only 2 felt cool, yet they accepted the thermal environment.

In the warmer cases, 8 (out of 12) female subjects felt slightly warm or warm. While 5 of them were slightly uncomfortable, only 1 of them expressed that the thermal environment was unacceptable. Although 3 (out of 19) male subjects felt slightly uncomfortable in the warmer environment, no male subjects found the thermal environment unacceptable.

As exhibited in Table 3, even though the female  $TSV$  values in both the colder and warmer experiments ( $TSV = -0.90$ ,  $SD = 0.67$ , and  $TSV = 0.80$ ,  $SD = 0.62$ , respectively) were more sensitive than the male ones ( $TSV = -0.60$ ,  $SD = 0.61$ , and  $TSV = 0.60$ ,  $SD = 0.62$ , respectively), there were no significant gender differences ( $p = 0.21$ ,  $t$ -test).

According to Figure 3,  $TSV$  was more sensitive in a warm environment than in a cold one. Figure 3a shows a non-linear trend of  $TSV$  against the air temperature. An average  $TSV$  drop of -0.71 was recorded for an average air temperature drop of 8.1 °C from a neutral air temperature  $T_a = 25.8$  °C, with an average shower-water temperature  $T_w = 38.8$  °C, corresponding to a  $TSV$  gradient of -0.088 °C<sup>-1</sup>. An average increment of

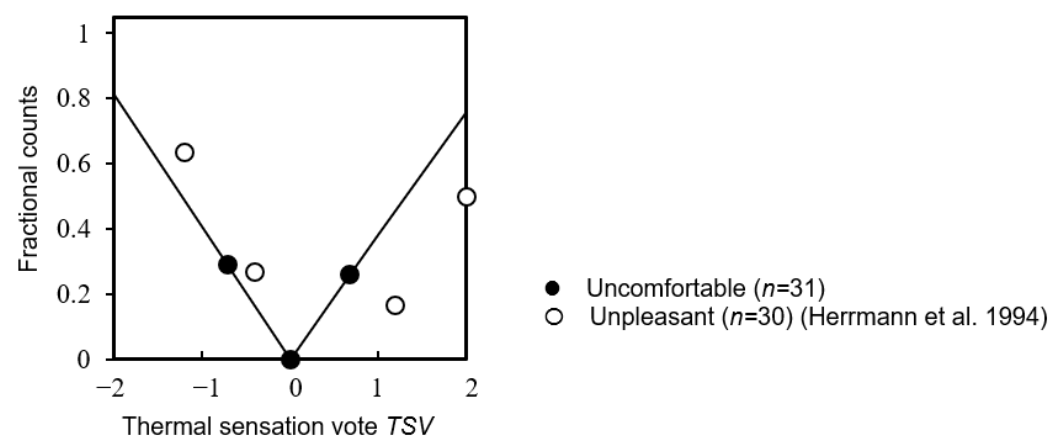
$TSV = +0.68$  was recorded for an increment of  $4\text{ }^{\circ}\text{C}$  for both  $T_a$  and  $T_{op}$ , corresponding to a  $TSV$  gradient of  $+0.17\text{ }^{\circ}\text{C}^{-1}$ .



**Figure 3.** Subjective thermal responses to the showering environment: (a) thermal sensation votes of 12 females and 19 males at  $T_w = 38.8\text{ }^{\circ}\text{C}$  ( $SD = 0.7\text{ }^{\circ}\text{C}$ ) and at  $T_a = 17.7, 25.8, 29.8\text{ }^{\circ}\text{C}$ ; (b) thermal sensation votes of 30 subjects at  $T_w = 32.4, 33.9, 35.4, 36.9, 38.4\text{ }^{\circ}\text{C}$  and at  $T_a = 28\text{ }^{\circ}\text{C}$ ; the values reported by Herrmann et al. [9] are shown for comparison.

Figure 3b illustrates the results from a previous experimental study by Herrmann et al. [9] ( $T_w = 32.4, 33.9, 35.4, 36.9, 38.4\text{ }^{\circ}\text{C}$ , and at  $T_a = 28\text{ }^{\circ}\text{C}$ ); the  $TSV$  gradient estimates were  $-0.33\text{ }^{\circ}\text{C}^{-1}$  for the colder test conditions and  $+0.73\text{ }^{\circ}\text{C}^{-1}$  for the warmer test conditions [9].

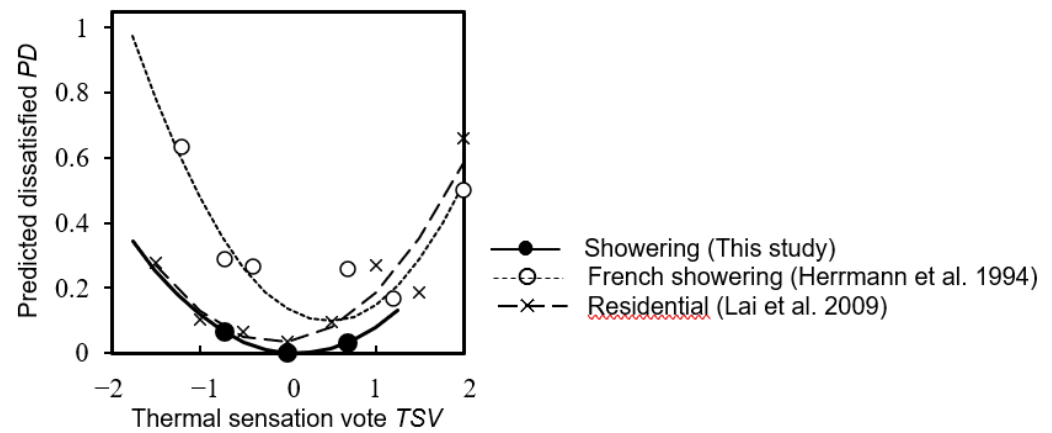
Figure 4 shows the fractional counts of the showering subjects, who felt slightly uncomfortable with the thermal environment they were exposed to, against  $TSV$ . The results gave a more sensitive  $TSV$  in a colder environment, i.e., 41% at  $TSV = -1$  (slightly cool and uncomfortable) vs. 38% at  $TSV = +1$  (slightly warm and uncomfortable). Similarly, the above-mentioned previous study reported a more sensitive  $TSV$  in a colder environment, i.e.,  $\sim 50\%$  at  $TSV = -1$  vs. 20% at  $TSV = +1$  [9].



**Figure 4.** Fractional counts of thermal discomfort; the values reported by Herrmann et al. [9] are shown for comparison.

Figure 5 graphs the predicted dissatisfied ( $PD$ ) as the fractional counts of the unacceptable votes for the thermal conditions in the bathroom. An asymmetrical  $PD$  was recorded, and there were more sensitive responses in a colder showering environment than in a warmer one. Comparatively, the  $PD$  values on the warm side were lower than those reported by Herrmann et al. [9]. Moreover, the  $PD$  in a residential environment is shown in

the figure for comparison [16]. For the positive *TSV* values, lower *PD* values were found in this study, indicating a slightly warm environment was favored.



**Figure 5.** Predicted dissatisfied *PD*; the values reported by Herrmann et al. [9] and by Lai et al. [16] are shown for comparison.

### 3.3. Thermal Comfort Zone

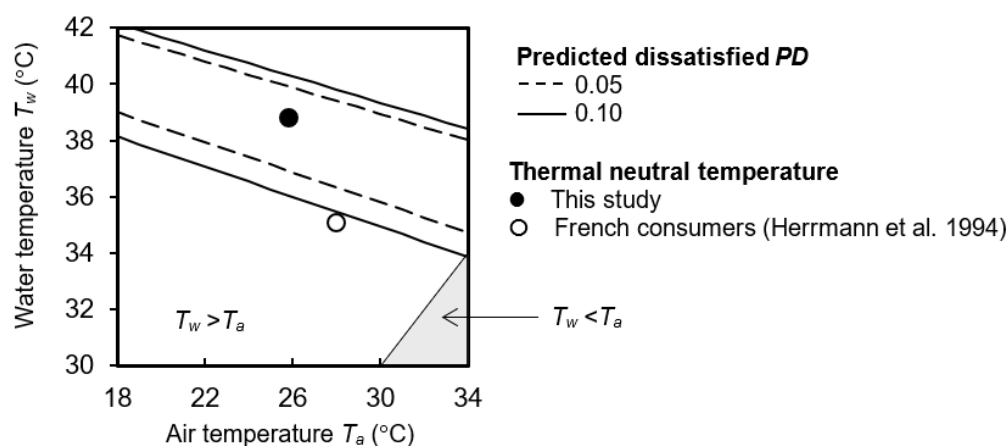
The *TSV* for a showering environment is given by the following expression, where  $T_a$  (°C) and  $T_w$  (°C) are the air and shower-water temperatures, respectively, with  $T_{a,o}$  (°C) and  $T_{w,o}$  (°C) representing their respective values in a state of thermal neutrality (i.e.,  $TSV = 0$ ) [17]:

$$TSV = c_a(T_a - T_{a,o}) + c_w(T_w - T_{w,o}) \tag{3}$$

Determined experimentally in this study,  $c_a$  and  $c_w$  are the unit changes of *TSV* for the air and shower-water temperatures, respectively:

$$c_a = \begin{cases} 0.17 & T_a > T_{a,o} \\ 0.088 & T_a < T_{a,o} \end{cases}, c_w = \begin{cases} 0.73 & T_w > T_{w,o} \\ 0.33 & T_w < T_{w,o} \end{cases} \tag{4}$$

By applying  $T_a = 25.8$  °C and  $T_w = 38.8$  °C in a state of thermal neutrality to Equations (3) and (4), two thermal comfort zones for  $PD = 0.05$  ( $TSV = -0.62$  and  $0.82$ ) and  $PD = 0.10$  ( $TSV = -0.91$  and  $1.11$ ), as shown in Figure 6, were determined. The higher thermal neutral temperature found in this study—as compared with the thermal neutral temperature reported by Herrmann et al. [9] for French consumers—indicated that the showering subjects in this study generally preferred a warm showering environment. This is consistent with the findings of some previous local survey studies, in which all winter showers and over 90% of summer showers were hot showers [3,4].



**Figure 6.** Estimates of predicted dissatisfied  $PD = 0.05$  and  $PD = 0.10$  at thermal neutral  $T_a = 25.8$  °C and  $T_w = 38.8$  °C; the value reported by Herrmann et al. [9] is shown for comparison.

#### 4. Conclusions

This study examined the influence of the thermal environment in a bathroom on the thermal sensations of the showering subjects, who comprised 12 females and 19 males. The showering subjects participated in the showering experiments under three thermal conditions, i.e., the control, colder, and warmer experiments. The results showed a non-linear trend of thermal sensation vote ( $TSV$ ) against the bathroom air temperature. An average  $TSV$  drop of  $-0.088$  °C $^{-1}$  was recorded for an average air temperature drop from the neutral air temperature  $T_a = 25.8$  °C, with an average shower-water temperature  $T_w = 38.8$  °C. An average  $TSV$  increment of  $+0.17$  °C $^{-1}$  was recorded for an increment air temperature. The predicted dissatisfied ( $PD$ ) was asymmetrical, and the showering subjects preferred a slightly warm environment. Two example thermal comfort zones at  $PD = 0.05$  and  $0.1$  were estimated, using Equation (3) for the shower-water temperature of 34–42 °C, and the air temperature of 18–34 °C. Despite the fact that the female  $TSV$  values were more sensitive than the male ones, in both the colder and warmer experiments, there were no significant gender differences. The expressions derived in this study for the thermal comfort zone in a bathroom environment can be used as a reference to enhance our understanding of showering subjects' thermal sensation in environmental design, and to help optimize the thermal environment in bathrooms.

**Author Contributions:** Conceptualization, L.-T.W.; Data curation, L.-T.W. and Y.-W.C.; Formal analysis, L.-T.W.; Funding acquisition, L.-T.W. and K.-W.M.; Investigation, L.-T.W.; Methodology, L.-T.W. and K.-W.M.; Project administration, K.-W.M.; Supervision, L.-T.W.; Writing—original draft, L.-T.W., K.-W.M. and Y.-W.C.; Writing—review & editing, K.-W.M. All authors have read and agreed to the published version of the manuscript.

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**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Conflicts of Interest:** The authors declare that they have not known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Sample Survey Questions

What is your gender? (Female/Male)

In the past 12 months, how long on average time you stay in the bathroom before taking a shower? (In minutes)

In the past 12 months, how long on average time you spend for a summertime shower? (In minutes)

In the past 12 months, how long on average time you spend for a wintertime shower? (In minutes)

Do you prefer a higher showering water temperature in winter than in summer? (Yes/No)

Do you prefer a lower showering water temperature in summer than in winter? (Yes/No)

## References

- Cheng, C.L.; Lee, M.C. Research on hot water issues in residential buildings in subtropical Taiwan. *J. Asian Archit. Build. Eng.* **2005**, *4*, 259–264. [[CrossRef](#)]
- McMahon, J.E.; Price, S.K. Water and energy interactions. *Annu. Rev. Environ. Resour.* **2011**, *36*, 163–191. [[CrossRef](#)]
- Wong, L.T.; Mui, K.W.; Guan, Y. Shower water heat recovery in high-rise residential buildings of Hong Kong. *Appl. Energy* **2010**, *87*, 703–709. [[CrossRef](#)]
- Wong, L.T.; Mui, K.W.; Zhou, Y. Carbon dioxide reduction targets of hot water showers for people in Hong Kong. *Water* **2017**, *9*, 576. [[CrossRef](#)]
- Hashiguchi, N.; Ni, F.; Tochiara, Y. Effects of room temperature on physiological and subjective responses during whole-body bathing, half-body bathing and showering. *J. Physiol. Anthropol. Appl. Hum. Sci.* **2002**, *21*, 277–283. [[CrossRef](#)] [[PubMed](#)]
- Kanda, K.; Ohnaka, T.; Tochiara, Y.; Tsuzuki, K.; Shodai, Y.; Nakamura, K. Effects of the thermal conditions of the dressing room and bathroom on physiological responses during bathing. *Appl. Hum. Sci.* **1996**, *15*, 19–24. [[CrossRef](#)]
- McNabola, A.; Shields, K. Efficient drain water heat recovery in horizontal domestic shower drains. *Energy Build.* **2013**, *59*, 44–49. [[CrossRef](#)]
- Masuda, Y.; Marui, S.; Kato, I.; Fujiki, M.; Nakada, M.; Nagashima, K. Thermal and cardiovascular responses and thermal sensation during hot-water bathing and the influence of room temperature. *J. Therm. Biol.* **2019**, *82*, 83–89. [[CrossRef](#)]
- Herrmann, C.; Candas, V.; Hoeft, A.; Garreaud, I. Humans under showers: Thermal sensitivity, thermoneutral sensations, and comfort estimates. *Physiol. Behav.* **1994**, *56*, 1003–1008. [[CrossRef](#)]
- Ohnaka, T.; Tochiara, Y.; Kubo, M.; Yamaguchi, C. Physiological and subjective responses to standing showers, sitting showers, and sink baths. *Appl. Hum. Sci.* **1995**, *14*, 235–239. [[CrossRef](#)] [[PubMed](#)]
- Munir, A.; Takada, S.; Matsushita, T.; Kubo, H. Prediction of human thermophysiological responses during shower bathing. *Int. J. Biometeorol.* **2010**, *54*, 165–178. [[CrossRef](#)] [[PubMed](#)]
- Ying, Y.; Shi, P.C.; Li, Y.N.; Tan, X.; Li, Y.H.; Hokoi, S. Study on a thermophysiological model for health assessment of showering environment in China. *J. Phys. Conf. Ser.* **2021**, *2069*, 012179. [[CrossRef](#)]
- Fanger, P.O. Assessment of man's thermal comfort in practice. *Occup. Environ. Med.* **1973**, *30*, 313–324. [[CrossRef](#)] [[PubMed](#)]
- Moss, K.J. *Heat and Mass Transfer in Buildings*; Routledge: Oxfordshire, England, 2015.
- Wong, L.T.; Mui, K.W.; Zhou, Y. Impact evaluation of low flow showerheads for Hong Kong residents. *Water* **2016**, *8*, 305. [[CrossRef](#)]
- Lai, A.C.K.; Mui, K.W.; Wong, L.T.; Law, L.Y. An evaluation model for indoor environmental quality (IEQ) acceptance in residential buildings. *Energy Build* **2009**, *41*, 930–936. [[CrossRef](#)]
- Mui, K.W.; Tsang, T.W.; Wong, L.T. Bayesian updates for indoor thermal comfort models. *J. Build. Eng.* **2020**, *29*, 101117. [[CrossRef](#)]