Gender Differences in Thermal Comfort and Responses to Skin Cooling by Air Conditioners in the Japanese Summer

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Abstract

We examined 200 college students, at rest in a sitting position in an air-conditioned classroom, to investigate the differences in physiological and psychological responses between men and women in the thermoneutral zone of SET*. The percentage of women who reported suffering from the cold more often in an air-conditioned environment was higher than that of men. The number of clothing items and the clothing insulation value, estimated using International Organization for Standardization (ISO) 9920 were higher for the women than for the men, based on the students’ own everyday clothing choices as worn during the experiments. However, the percentage of body surface area covered by clothing worn by the women was significantly lower than that for the men. Although oral and skin temperature decreased in both men and women after 60 min of exposure to a temperature of 25 °C, the oral and skin temperatures of the women’s forehead and palms were significantly lower than those in the men. Moreover, the decrease in the women’s oral temperature was greater than that of the men. Women felt cooler and more uncomfortable than men did in the ASHRAE comfort zone, with SET* of 22.2–25.6 °C. Gender differences in physiological responses, and differences in the clothing typically worn by men and women, might affect psychological responses to the moderate thermal environment encountered in daily life.

Keywords: gender differences, physiological response, thermal comfort, clothing, air conditioner

1. Introduction

Numerous studies have been conducted on gender differences with regard to thermal comfort. A laboratory study showed that women felt more uncomfortable than men at high and low temperature extremes (Beshir et al., 1981), and women reported feeling colder than men at low temperatures (Parsons 2002). Women were more sensitive to thermal stimulation than men (Golja et al., 2003). Moreover, a recent review article found that women express more uncomfortable than men in the same thermal environments from more than half of the laboratory and field studies (Karjalainen, 2011). These reported differences are shown to have resulted from differences in body dimensions, body composition, thermoregulatory abilities, or thermal sensitivities between men and women.

Approximately 30 % of young Japanese women have been shown to experience unusual coldness in daily life (cold syndrome); augmented thermal sensitivity of the body to cold, and activated vasoconstriction of the extremities during cold weather are considered to be the mechanisms responsible for such severe coldness (Nagashima et al., 2002). Although less well studied, a cold syndrome has been on the rise among Japanese men in recent years. Sakaguchi reported that 27% of young men and 55% of young women experienced the cold syndrome (Sakaguchi et al., 1998). In addition, individual differences exist in thermoregulation responses and thermal comfort among individuals of the same gender or age in moderate thermal environments, as experienced in daily life. Previous studies have examined the relationship between comfort and physical environment in naturally ventilated and air-conditioned schools (Kwok et al., 2003) or investigated
indoor thermal environments and residents’ behavior in controlling cooling and heating systems (Bae et al., 2009). In addition, individual differences exist in thermoregulatory responses and thermal comfort among individuals of the same gender or age in moderate thermal environments, as experienced in daily life (Yasuoka et al., 2012) However, relatively few studies have examined gender differences with regard to thermal comfort in air-conditioned rooms. Thus, it is necessary to examine the physiological and psychological responses of men and women to various temperatures in order to moderate thermal environments encountered in daily life.

To investigate the physiological and psychological responses to an air-conditioned environment in daily life, we examined 200 college students in air-conditioned rooms during the summer, and evaluated the differences in responses between men and women.

2. Material and methods

2.1 Subjects and clothing

The present study included 200 Japanese college and graduate students (100 men, 100 women; 18–29 years of age); informed consent was obtained from all the participants. The gender difference was defined as the biological difference. No subjects were born in cool or hot regions, such as Hokkaido or Okinawa, respectively. The subjects wore their own everyday clothing during the experiments. They were asked to identify their clothing items, and the insulation provided by each item was factored into the analysis. The clothing insulation (clo) value of each item was estimated using the ISO 9920 (ISO 2007).

Table 1 shows the physical characteristics of the subjects. The man and woman values were both similar to the national averages. The height, mass, BMI, and body surface area values of the women were significantly lower than those of the men.

2.2 Conditions and procedure

The experiment was conducted in four university classrooms in August 2009. Table 2 details the experimental conditions and the outdoor conditions. The data source for the outdoor conditions was the Japan Meteorological Agency. The experimental periods commenced at 10:00, 13:00, 15:00, and 17:00. Subjects participated in the experiments on a specific day, and at a particular time. Therefore the number of the subject was different each experiments.

Figure 1 shows the layout of the test rooms. The subjects waited in pre-test rooms that were connected to the test rooms by an adjoining classroom or passage. These rooms were chosen specifically to ensure that the subjects were exposed to neither direct sunshine, nor the cooling effect of the air conditioner.

The temperature in the air-conditioned test rooms was set to 25 °C. Subjects sat in the test room for 60 min. The length of class in most Japanese universities is 90 min; thus, the 60-min testing period was shorter than the typical Japanese university class duration. However, we gave priority to recruiting subjects and set the experiment time to 60 min in the present study for the convenience of the participants. Subjects were seated 50 cm apart from one another, in the area of the room subject to the least horizontal temperature variation. The subjects remained in a sitting position (1.1 Met) without moving vigorously at the test room.

2.3 Measurement

Air temperature ($T_a$), globe temperature ($T_g$), and relative humidity ($rh$) measurements were taken at a distance of 1 m from the subjects using a thermistor probe and data logger (RS-11; ESPEC) at 30-s intervals. Air temperature was measured at four different heights (0.1, 0.6, 1.1, and 1.6 m). Air velocity ($v$) was measured at 1-s intervals using a hot-wire anemometer (MODEL6533-01; KANOMAX).

Height and body mass were measured using standard techniques. The body surface area ($A_b$, m²) of all of the subjects was estimated using their height ($h$, cm) and body mass ($mass$, kg) data according to the following equation from Kurazumi: body surface area=100.3 $15\times weight^{0.383}\times height^{0.693}$ (Kurazumi et al., 1994).

We measured skin temperature ($T_s$) using the thermography system (TVS-500EX; NEC Avio Infrared Technologies) at the beginning and the end of the experiment. Oral temperature ($T_o$) and blood pressure ($BP$) were measured every 30 min to document physiological responses; they were measured using an oral thermometer and a wrist-cuff blood pressure monitor, respectively.

The subjects were asked to report on the following psychological sensations...
every 30 min: thermal sensation (TS), comfort sensation (CS), and satisfaction sensation (SS). The following scale was used for evaluating TS: +4, very hot; +3, hot; +2, warm; +1, slightly warm; 0, neutral; −1, slightly cool; −2, cool; −3, cold; and −4, very cold. Thermal sensation was surveyed for the entire body and eight skin areas (head, chest, back, arm, hand, thigh, calf, and instep). The following scale was used to report CS: +3, very comfortable; +2, comfortable; +1, slightly comfortable; 0, neutral; −1, slightly uncomfortable; −2, uncomfortable; and −3, very uncomfortable. The following scale was used to report SS: +3, very satisfactory; +2, satisfactory; +1, slightly satisfactory; 0, neutral; −1, slightly unsatisfactory; −2, unsatisfactory; and −3, very unsatisfactory. This nine-point TS scale was developed by modifying the seven-point scale used by the ISO and ASHRAE by adding the parameters “very hot” and “very cold” at the two ends of the scale. The seven-point thermal CS scale modifies the four-point scale (comfortable, slightly uncomfortable, uncomfortable, and very uncomfortable) used by the ISO (ISO 1995) and ASHRAE (ASHRAE 2001) to a
bipolar scale with a qualitative difference. It specifies “neither comfortable nor uncomfortable” as a neutral assessment between comfortable and uncomfortable. These TS and CS scales have been validated by a large number of human subject experiments in Japan. Moreover, TS has been shown to have a linear relationship with $t_s$, $t_p$, or heat storage in the human body, whereas CS has a two-dimensional correlation with $t_s$, TS, and $t_c$.

The subjects answered questionnaires about their daily lives during the experiments.

All experiments were performed by the same investigator using the same measuring instruments.

2.4 Analysis

The chi-square test was used to determine whether there was a significant difference between the men and women in the percentage of TS, CS, SS, and on the questionnaire. The differences in comfort sensation between the comfortable group and uncomfortable group were also compared using a chi-square test. Gender differences in the parameters measured during the experiments were evaluated using a t-test. All differences referred to in the results section are ones that were significant at $P < 0.05$ and $P < 0.01$.

3. Results

3.1 Subjects

Approximately 50% of men and women in the present study answered that they were “somewhat bothered by the heat of summer” or “very bothered by the heat of summer.” The subjects who were “weak to the heat of summer” or “very weak to the heat of summer” tended to report that they “preferred the air conditioner.” This was especially true for men. In contrast, 50% of men and 70% of women answered that they were “weak to the coldness of summer air conditioner” or “very weak to the coldness of air conditioner.” Those subjects who were “weak to the coldness of summer air conditioner” tended to answer that they “prefer not to use an air conditioner in the summer” and report greater “sensitivity to changes in air temperature.” Both men and women answered that symptoms of their intolerance to air conditioner-use in the summer included headaches, stomachaches, and listlessness. Women had a greater incidence of headaches and stomachaches. Approximately 20% of men had no symptoms.

3.2 Clothing

Table 3 shows the characteristics of the subjects’ clothing. The average clo value (SD) of the subjects was 0.45 (0.10) clo. The average clo value (SD) of the men was 0.43 (0.10) clo, and that of the women was 0.47 (0.09) clo. These values fall within the range typical of summer clothing. The average clo value of the clothing worn by the women was significantly higher than that of clothing worn by the men ($P < 0.01$). The number of clothing items, excluding underwear and shoes, and their clo values, were significantly higher for the woman subjects, as compared to those of the man subjects ($P < 0.01$). The body surface area covered by clothing was calculated by comparing it with the regional body surface area (Lee et al., 2009). The percentage of body surface area covered by clothing in men was 71.3 (7.3) %, whereas that in women was 67.6 (8.9) %. The percentage of body surface area covered by clothing in women was significantly lower than that in men ($P < 0.01$).

3.3 Thermal environment

Because there were no significant differences in thermal environment between two measured points, it was calculated the average of them. Table 4 shows the

| Table 3 Characteristic of the clothing |
|----------------------------------------|
| **Clo Value (clo)** | **Man** | **Woman** |
|---------------------|---------|-----------|
|                     | 0.43 (0.10) | 0.47 (0.09) |
| **Number of clothing items** | **2.8 (0.8)** | **4.2 (0.8)** |
| **Covered by clothing (%)** | **71.3 (7.3)** | **67.6 (8.9)** |

**Significant differences between man and woman $P < 0.01$**

| Table 4 Thermal environment of the experiments |
|-----------------------------------------------|
| **Air temperature ($^\circ$C)** | **Pre-test room** | **Test room (0 min)** | **Test room (30 min)** | **Test room (60 min)** |
|-------------------------------------|-----------------|---------------------|---------------------|---------------------|
| **Height: 0.6m** | **30.4 (0.4)** | **30.3 (0.6)** | **24.7 (0.3)** | **25.0 (0.5)** |
| **Height: 1.1m** | **30.2 (0.3)** | **30.1 (0.6)** | **24.7 (0.5)** | **25.2 (0.4)** |
| **Height: 0.6m** | **29.8 (2.0)** | **29.6 (1.5)** | **24.8 (1.1)** | **25.4 (1.0)** |
| **Height: 0.1m** | **29.6 (0.4)** | **29.6 (0.6)** | **24.2 (0.2)** | **24.8 (0.6)** |
| **Height: 1.6m** | **29.7 (1.9)** | **29.0 (1.6)** | **25.2 (1.4)** | **25.4 (1.4)** |
| **Height: 0.6m** | **25.2 (1.4)** | **25.4 (1.4)** | **25.5 (0.9)** | **25.3 (0.9)** |
| **Height: 0.1m** | **24.8 (1.1)** | **25.4 (1.0)** | **25.1 (0.8)** | **24.8 (0.9)** |
| **Height: 0.6m** | **24.8 (0.6)** | **24.8 (0.6)** | **24.6 (0.4)** | **24.6 (0.4)** |
| **Height: 0.1m** | **24.6 (0.2)** | **24.8 (0.6)** | **24.5 (0.4)** | **25.3 (0.4)** |
| **CLO of clothing** | **0.47 (0.09)** | **0.43 (0.07)** | **0.47 (0.09)** | **0.47 (0.09)** |

**Significant differences between man and woman $P < 0.05$, $**P < 0.01$**

1. $^\text{1}$ Height: 0.6m
2. $^\text{2}$ Calculated from air temperature, globe temperature, humidity at height of 0.6m, predicted resting metabolic rate (=1.1met) and clo value (which was derived from individual clothing item shown in Table 3)
There were no significant differences in the thermal environment across the experimental periods. The average (SD) \( t_a \) and \( rh \) values in the pre-test room were 29.7 (0.5) °C and 65.9 (2.1) %, respectively. The average (SD) \( t_a \) and \( rh \) values in the test room during the experimental period of 60 min were 25.0 (0.1) °C and 60.3 (3.2) %, respectively. \( v \) was 0.16 (0.02) m・s\(^{-1}\).

It rained only on August 10, when the experiment was conducted in room D (with 36 men). There were significant differences in \( t_a \) and \( rh \) values among the rooms because of the weather. Thus, SET* was calculated using \( t_a, t_g, rh, v, \) resting energy expenditure, and clo values. The average (SD) SET* of the men was 24.1 (0.1) °C, while that of the women was 24.4 (1.5) °C, as measured at the 60 min time point. The SET* of the men was significantly lower than that of the women (\( P < 0.05 \)). This difference was largely affected by the \( t_a \) and the clo values.

### 3.4 Gender differences in thermal sensation and comfort sensation

Table 5 shows the average (SD) physiological responses for men and women at 30 or 60 min intervals. The results of each measurement are as follows:

#### 3.4.1 Oral and skin temperature

The average (SD) \( t_o \) of the men was 36.98 (0.3) °C, and that of the women was 36.92 (0.3) °C at the 0 min time point, i.e., the difference was not significant at the outset. At the 60 min time point, the average (SD) \( t_o \) of the men was 36.82 (0.3) °C, whereas that of the women was 36.67 (0.4) °C; these results were significantly different (\( P < 0.01 \)). The decrease in \( t_o \) of the women was greater than that of the men (\( P < 0.01 \)).

The average (SD) \( t_{s-\text{forehead}} \) of the men was 34.4 (0.6) °C, and that of the women was 34.2 (0.7) °C at 0

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| Measured Value | 0 min | 30 min | 60 min | 0 min vs 60 min | P<0.01 |
|----------------|-------|--------|--------|----------------|--------|
| **T_o (°C)** |       |        |        |                |        |
| Man            | 36.98 (0.30) | 36.89 (0.26) | 36.82 (0.30) | 0 min vs 60 min | P<0.01 |
| Woman          | 36.92 (0.27) | 36.81 (0.30) | 36.67 (0.35) | 0 min vs 60 min | P<0.01 |
| **Change**     |       |        |        |                |        |
| Man            | -0.09 | -0.07  | -0.16  |                |        |
| Woman          | -0.11 | -0.13  | -0.24  |                |        |
| **T_{s-\text{forehead}} (°C)** | 0 min | 60 min |       |                |        |
| Man            | 34.4 (0.56) | 33.9 (0.61) | 33.6 (0.67) | 0 min vs 60 min | P<0.01 |
| Woman          | 34.2 (0.68) | 33.6 (0.67) | 0 min vs 60 min | P<0.01 |
| **Change**     |       |        |        |                |        |
| Man            | -0.48 |       |        |                |        |
| Woman          | -0.57 |       |        |                |        |
| **T_{s-palm} (°C)** |       |        |        |                |        |
| Man            | 34.2 (0.68) | 33.2 (0.99) | 33.1 (0.92) | 0 min vs 60 min | P<0.01 |
| Woman          | 34.0 (0.70) | 33.6 (0.92) | 0 min vs 60 min | P<0.01 |
| **Change**     |       |        |        |                |        |
| Man            | -0.94 |       |        |                |        |
| Woman          | -0.94 |       |        |                |        |
| **T_{s-back of hand} (°C)** | 0 min | 60 min |       |                |        |
| Man            | 33.4 (0.87) | 32.6 (1.12) | 32.5 (0.87) | 0 min vs 60 min | P<0.01 |
| Woman          | 33.4 (0.69) | 32.5 (0.87) | 0 min vs 60 min | P<0.01 |
| **Change**     |       |        |        |                |        |
| Man            | -0.47 |       |        |                |        |
| Woman          | -0.96 |       |        |                |        |
| **Systolic Pressure (torr)** |       |        |        |                |        |
| Man            | 114 (14) | 110 (16) | 110 (13) | 0 min vs 30 min | P<0.05 |
| Woman          | 98 (13)  | 96 (16)  | 96 (11)  | 0 min vs 60 min | P<0.05 |
| **Change**     |       |        |        |                |        |
| Man            | -4.0   | -0.1   | -4.1   |                |        |
| Woman          | -2.0   | 0.8    | -1.2   |                |        |
| **Diastolic Pressure (torr)** |       |        |        |                |        |
| Man            | 73 (13) | 69 (13) | 71 (12) | 0 min vs 30 min | P<0.05 |
| Woman          | 61 (9)  | 61 (10) | 62 (9)  |                |        |
| **Change**     |       |        |        |                |        |
| Man            | -3.9   | 1.5    | -2.4   |                |        |
| Woman          | -0.3   | 1.2    | 0.8    |                |        |

Significant differences between man and woman: P<0.05*, P<0.01**, P<0.05***

\( T_o \): Oral temperature, \( T_{s-\text{forehead}} \): Skin temperature of forehead

\( T_{s-palm} \): Skin temperature of palm, \( T_{s-back of hand} \): Skin temperature of back of hand
Women felt significantly cooler than men at the distal extremities at the 30 min and the 60 min time points. However, there were no significant differences in the trunk portion, such as the chest or the back, at the 30th min.

Women felt significantly more comfortable than men in the pre-test room (P < 0.01). However, women felt significantly more uncomfortable than men in the test room irrespective of time (P < 0.01). The difference in CS between the men and women became greater from the 30th min to the 60th min.

### 3.5.2 Percentage of thermal sensation (TS), comfort sensation (CS), and satisfaction sensation (SS)

The SET* in the ASHRAE comfort zone was 22.2–25.6 °C (ASHRAE 2001). The gender differences in psychological responses were revealed in this zone at the 60th min. This result was analyzed by cross tabulation, and we investigated the gender differences of each TS zone using the χ² distribution.

Figure 2 shows the percentage of TS for the whole body for both groups in the test room at the 60th min. Thermal sensation of “−4, very cold” to “−2, cool” was reported by 29% of the men and 58% of the women. Thermal sensation of “+1, slightly cool” to “+4, very warm” was reported by 70% of the men and 40% of the women. There were significant differences between

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3.4.2 Blood pressure

The systolic, diastolic, and mean pressures of the men were higher than those measured in the women, irrespective of the time point. The systolic and diastolic pressures measured in the men decreased significantly (P < 0.05) between the 0 min and 30 min time points; furthermore, they decreased significantly (P < 0.05) between the 0 min and 60 min time points. The mean pressure measured in the women decreased significantly between the 0 min and 60 min time points (P < 0.01).

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3.5 Gender differences in psychological response to the thermal environment

#### 3.5.1 Changes in thermal sensation (TS) and comfort sensation (CS) over the course of time

The thermal sensation of the whole body in women reportedly felt significantly hotter than that in men in the pre-test room, which had no air conditioner (P < 0.01). There was no significant difference in the TS of the whole body between the men and women at the 0 min time point. However, the TS of the whole body in women showed that they felt significantly cooler than men at the 30 and the 60 min time points. There were no significant differences in TS of the head, neck, chest, and calf in the pre-test room. However, the TS of women in the back, instep (P < 0.05), and thigh (P < 0.01), felt significantly hotter than those of men.
men and women in each zone ($P < 0.01$).

Figure 3 shows the percentage of $CS$ for both groups in the test room at the 60th min. Comfort sensation of “−3, very uncomfortable” to “−1, slightly uncomfortable” was reported by 11% of the men and 30% of the women. Comfort sensation of “0, neutral” was reported by 24% of the men and 11% of the women. Comfort sensation of “+1, slightly comfortable” to “+3, very comfortable” was reported by 65% of the men and 58% of the women. There were significant differences between the men and women in uncomfortable ($P < 0.01$) and neutral ($P < 0.05$) zones.

Satisfaction sensation of “−3, very unsatisfactory” to “−1, slightly unsatisfactory” was reported by 11% of the men and 21% of the women. Satisfaction sensation of “0, neutral” to “+3, very satisfactory” was reported by 89% of the men and 79% of the women. There were no significant differences between the men and women at any zone. However, the women felt more dissatisfaction than the men.

3.5.3 Relationship between the thermal sensation (TS) and the comfort sensation (CS)

We classified the subjects as “0, neutral or more (comfortable group)” and “−1, slightly uncomfortable or less (uncomfortable group)” in the present study. Figure 4 shows the number of subjects in TS for the whole body in both groups in the test room at the 60th min.

Both men and women felt “−2, cool” to “0, neutral” in the comfortable group. As such, this showed that the subjects felt comfortable when they felt cool below the neutral level. On the other hand, the subjects felt “−3, cold” and “−2, cool” in uncomfortable group, and the overwhelming majority were women. Among the women who felt cool, there were some who felt comfortable and others who felt uncomfortable. The number of women who felt cool was significantly higher than the number of men who reported the same.

The average (SD) $t_{pulm}$ of the women in the comfortable group was 33.1 (0.9) °C, and that of the women in the uncomfortable group was 32.6 (0.9) °C at the 60th min. The average (SD) $t_{pulm}$ of the women in the comfortable group was 32.7 (0.7) °C, and that of the women in the uncomfortable group was 32.1 (1.0) °C at the 60th min. The average (SD) systolic pressure of the women in the comfortable group was 97 (10) torr, and that of the women in the uncomfortable group was 91 (11) torr at the 60th min. These values were lower for the women in the uncomfortable group than for those in the comfortable group ($P < 0.01$). However, there were no significant differences between the physiological responses of the men in the comfortable and uncomfortable groups.

4. Discussion

To investigate the physiological and psychological responses to air conditioner use in daily life, we observed the responses of 200 subjects in air-conditioned classrooms in the summer, and we evaluated the differences in responses reported by man and woman test subjects.

In the present study, although both the men and the women tended to feel uncomfortable when an air conditioner was not used, the women felt significantly hotter and more uncomfortable than the men did in such an environment. In addition the women felt significantly cooler, and experienced greater discomfort, than the men in the air-conditioned environment, where the temperature was set at 25 °C. This results of the Parsons’ study corroborate this finding, which is that women felt cold more readily than men (Parsons, 2002). And the result shows similar findings to the review article, which is that women express more uncomfortable than men in the same thermal environments (Karjalainen, 2011.) However, the finding in the present study, that the women felt more comfortable than the men in the hotter environment, is not supported by Benshir et al., in which women felt more
uncomfortable than men at extremes of both high and low temperatures (Beshir et al., 1981). Benshir et al. selected a temperature of 43.3 °C, which was much higher than that selected in the present study. There were some differences in the psychological responses between the moderate thermal environment and the hot thermal environment.

The SET* of the women was significantly higher than that of the men due to the clo values inherent in the present study. However, the rh of the women was lower than that of the men, which might affect the thermal and comfort sensations.

Both the men and the women felt “−2, cool” to “0, neutral” in the comfortable group. On the other hand, the subjects felt “−3, cold” and “−2, cool” in the uncomfortable group, and women constituted the majority in this group. Among the women who reported feeling “−3, cold” and “−2, cool”, there were some who felt comfortable, and others who felt uncomfortable. This result is not necessarily supported by Mui’s study, which showed that the thermal neutral temperature for air-conditioned offices in subtropical climates was 23.6 °C in summer. The preferred thermal environment in Hong Kong should be slightly cool, approximately 1 °C below the neutral temperature, to satisfy most office occupants’ needs (Mui, 2007). The air temperature in Mui’s study, which measured 19.0–25.4 °C, was lower than that in the present study. In addition, the metabolic rates and lifestyles of participants in subtropical climates were different from those in the present study. These differences might affect the differences in neutral temperature and the comfort TS. Nakano et al. found that the differences in the neutral temperature had been affected by the differences in the comfort t_e between the Japanese occupants and the non-Japanese occupants (Nakano et al., 2002). This has previously been postulated; however, it might be necessary to consider the relationship between the comfort t_e and the comfort TS in daily life.

TS of “−4, very cold” to “−2, cool” was reported by 29% of the men in this study, and TS of “−1, slightly cool” to “+1, slightly warm” was reported by 70% of the men, who fell within the ASHRAE comfort zone. This result is supported by that of Kwok’s study, which measured the thermal environment and TS in an air-conditioned junior high school classroom (10 men and 21 women; t_e 24 °C; rh, 50.7%) (Kwok et al., 2003). However, in the present study, the women felt significantly cooler than the men within the ASHRAE comfort zone. In Kwok’s study, the average clo value of the subjects was 0.33 clo, and the metabolic heat production was assumed to be “light activity while seated” (1.2 Met or 70 W·m⁻²) in that study. Although the clo value was lower, the metabolic rate in Kwok’s study was higher than that in the present study. Heat production in men is generally higher than that in women. The differences in heat production might affect the gender differences in TS.

The ASHRAE standard defines conditions or comfort zones as being those in which 80% of sedentary or slightly active persons find the environment thermally acceptable (ASHRAE 2001). The percentage of men reporting neutral or comfortable in this study reached 80%, thereby satisfying the conditions for an ASHRAE comfort zone. The result demonstrated by the men in the present study supports the result of Kwok’s study (82.6%) (Kwok et al., 2003). However, in the present study, the percentage of women reporting neutral or comfortable did not reach 80%. There were significant differences in reported sensations of comfort between the men and the women in this study. Moreover, there were also significant differences between the genders in sensations of uncomfortable. The ASHRAE comfort zone, as defined above, might be inapplicable to Japanese women.

The clo value in women wearing layered clothing was higher than that in men. However, the percentage of body surface area covered by clothing in the woman study participants was significantly lower than that in the men participants in the present study. In an earlier study, the rectal temperature decreased the most in subjects with the highest percentage of exposed skin. On the other hand, exposure of the instep in the lower body stimulated vasoconstriction, which limited the decrease in rectal temperature (Lee et al., 1998). This type of clothing was common in men. Rectal and instep skin temperatures were not measured in the present study. However, the decrease in t_r in the women was larger than that in the men. Typical gender differences in clothing might affect the core temperature.

Although the t_e-back of hand of the women was lower than that of the men irrespective of time, the decrease over 60 min did not differ between the men and the women. There was no difference in vasoconstriction of the hand between the men and the women when exposed to a temperature of 25 °C. However, the decrease in t_r of the women was greater than that of the men. Women felt cooler than men at both the body trunk and the distal portions of the extremities in the test room. It might be possible that the women could not maintain their core temperature; the difference in metabolic heat production might be a factor contributing to the maintenance of core temperature. This result suggests that gender differences ascribed to both thermoregulation and type of clothing might affect psychological responses.

In the present study, men, who had higher t_e and t_r values, preferred the cool environment, and women, who had lower t_e and t_r values, did not. This finding is supported by that of Grivel’s study, in which gender
differences in body temperature affected the preferred $t_a$ (Grivel et al., 1991). Physiological responses affected psychological responses in the present study as well. When investigating the thermal comfort environment, it is necessary to consider gender differences in physiological and psychological responses.

In the present study, 50% of the men and 70% of the women answered “weak to the coldness of summer air conditioner” or “very weak to the coldness of air conditioner.” Sakaguchi’s study reported that 27% of young men and 55% of young women reported experiencing the cold syndrome. The results of the present study are higher than those reported by Sakaguchi (Sakaguchi et al., 1998). However, Imai’s study showed that 74% of young Japanese women felt chills over their body (Imai et al. 2007), which supports the results of the present study. Approximately 30% of young Japanese women experienced the cold syndrome in Nagashima’s study (Nagashima 2002), in contrast to the 70% in the present study. Nagashima had determined which subjects felt the cold syndrome by using a 10-question interview. However, in the present study and those conducted by Imai and Sakaguchi, subjects were classified according to their subjective responses. The percentage of cold syndrome may affect the gender difference of the thermal comfort in the present study. However, the percentage of individuals experiencing the cold syndrome is believed to be increasing every year. Monobe showed that the cause of “sensibility of cold” in men was an irregular lifestyle, while in women it was attributed to an unstable autonomic nerve system (Monobe, 2009). The association between the cold syndrome and daily life is an issue to be addressed in future studies.

The subjects remained in a sitting position in the present study. However, the metabolic rate of office workers moving within a real office environment is higher than that of subjects in a resting position. We chose to expose the subjects to the test environment for 60 min, in an effort to recruit as many subjects as possible for the present study. However, most Japanese university classes are 90 min long. Thus, the gender differences in physiological and psychological responses to variations in thermal conditions may be more pronounced in offices and classrooms. These results suggest that it is imperative to take gender differences into account when considering human response characteristics, even in thermally neutral indoor environments.

5. Conclusion

In summary, the women felt significantly colder and more uncomfortable than the men did in the thermoneutral zone of SET*. The number of men who reported feeling neutral was significantly greater than that of women in the comfortable group. Though there was no significant difference between the number of men and women who reported feeling neutral, the number of women who felt cooler and colder was significantly greater than that of men in the uncomfortable group. It was differ in comfortable thermal sensation in the thermoneutral zone between the men and women.

The average clo value in the women was significantly higher than that in the men: 0.47 clo and 0.43 clo respectively. However, the percentage of body surface area covered by clothing in the women was significantly lower than that in the men (67.6% vs71.3%). Such a difference in clothing might affect body temperature regulation and thermal comfort.

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Abbreviated word

| Acronym | Description |
|---------|-------------|
| $t_a$   | Ambient temperature |
| $t_s$   | Globe temperature |
| rh      | Relative humidity |
| v       | Air velocity |
| $A_s$   | Body surface area |
| h       | Height |
| mass    | Body mass |
| clo     | Clothing insulation |
| $t_s$   | Skin temperature |
| $t_o$   | Oral temperature |
| BP      | Blood pressure |
| TS      | Thermal sensation |
| CS      | Comfort sensation |
| SS      | Satisfactory sensation |
| $t_{s-\text{forehead}}$ | Skin temperature of the forehead |
| $t_{s-palm}$ | Skin temperature of the palm |
| $t_{s-\text{back of hand}}$ | Skin temperature of the back of hand |

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