Summer clothing characteristics and indoor-outdoor thermal comfort of Japanese youth

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Abstract

This study aimed to investigate clothing characteristics and indoor-outdoor thermal comfort of Japanese youth for an air-conditioned room in summer. A field investigation was conducted on the clothing and thermal comfort of 90 participants in Fukuoka, Japan. The main results concerning clothing were that six and five summer clothing types constituted typical summer ensembles for males and females, respectively; there was some stability in clothing characteristics over time. Concerning thermal feelings, females felt cooler or colder and felt more airflow in the room compared with males. Females also felt that conditions were significantly more comfortable and tolerable, and with less airflow, outside and were more sensitive to perceived the local differences. Males tended to adapt to the indoor environment more easily, but had difficulty in perceiving local differences in thermal feelings. Concerning the relationships between clothing and thermal feelings, the local thermal sensation was affected by the clothing conditions of different body parts and the humidity feeling was affected by clothing insulation, especially for males. Accordingly, stability, relationships, gender and local differences should be taken into account in the design solutions for summer clothing and living environments.

Keywords: clothing, gender, local difference, air conditioner, thermal comfort, variation

Abbreviations and symbols

| Abbreviation  | Description                      |
|---------------|----------------------------------|
| WBGT          | Wet bulb globe temperature       |
| Ta            | Ambient temperature              |
| RH            | Relative humidity                |
| Va            | Air velocity                     |
| TS            | Thermal sensation                |
| TC            | Thermal comfort                  |
| TH            | Humidity feeling                 |
| PF            | Thermal preference               |
| AP            | Acceptability                    |
| TL            | Tolerance                        |
| AF            | Airflow feeling                  |
| A             | Clothing amount                  |
| cl            | Overall clothing                 |
| chu           | Upper-body clothing              |
| cll           | Lower-body clothing              |
| U-arm         | Upper arm                        |
| F-arm         | Forearm                          |

1. Introduction

With air-conditioned rooms and hot outdoor conditions representing the main Japanese summer living environments, especially for young people such as students (MEXT, 2017), thermal comfort has been attracting growing attention, such as the risk of heatstroke outdoors (FDMA, 2017) as well as thermal responses indoors (Yasuoka et al., 2015). Although the Japanese government recommended a summer air-conditioning temperature of 28°C, over 60% of Japanese respondents set the temperature at 27°C or below (Jyukankyo, 2015). However, 2/3 of Japanese respondents were dissatisfied with summer office
setting temperatures and most indicated using clothing to prevent coldness or cooling down (Daikin, 2005).

As in this case, clothing is often used to adapt to the thermal environment, due to its function to preserve the body’s thermal balance and a comfortable microclimate (Takashi, 1996). Significant correlations were reported to exist between thermal parameters (e.g. thermal sensation, clothing humidity) and clothing characteristics (e.g. weight, insulation) in some body parts (Morooka, 2006). Clothing insulation, as one of the principal factors for thermal comfort (Schiavon, 2013), could be changed to adapt to different climates and seasons, e.g. 0.5 clo in summer was recommended by ASHRAE (2013). However, clothing insulation is determined by clothing ensembles (types and amount of clothing), and is also correlated with other characteristics (e.g. thickness and weight) (ISO, 2007). Accordingly, it is necessary to identify the main summer type factors of clothing ensembles.

Furthermore, gender and local differences exist in thermal responses, due to different thermal perceptions and temperature distributions according to body morphology and physiology (Neves et al., 2017), especially with varying temperatures and clothing ensembles (e.g. Yasuoka, 2015; Liu et al., 2018). For example, females tend to feel colder and more dissatisfied at lower temperatures, whereas males feel more dissatisfied at higher temperatures (Zhai et al., 2014; Parsons, 2002). However, according to the study of Liu et al. (2018), more males than females added warmer or additional pants at 10–16 °C, because females had larger ranges of acceptable local skin temperature than males in the leg area.

Additionally, different thermal responses and some relationships have been reported to exist between summer indoor and outdoor environments (Jihad et al., 2016), for example the temperature difference of 5°C-7°C recommended by Kum et al. (2002). The thermal environment is characterized by temperature, humidity, air flow, etc., which also affect thermal comfort (ASHRAE, 2013). However, most of the previous studies were mainly focused on either indoor or outdoor thermal sensation, separately. In this study, indoor-outdoor thermal feelings (e.g. thermal sensation and airflow feeling) related to thermal comfort are investigated. Moreover, given the short-period thermal variation in summer (Inoue et al., 2014), the variability or stability of clothing and thermal comfort are also taken into account in this study.

There were therefore two phases of investigation in this research project. To reflect the state of summer thermal comfort for an air-conditioned room and for the outdoors, the present study carried out field research on clothing and indoor-outdoor overall and local thermal feelings by gender, on which few studies exist. In addition, the effects of a short-period variation on summer clothing and thermal comfort were studied, on which few studies have previously been conducted. Accordingly, the present study is aimed at providing relatively comprehensive information on summer dressing behavior and design solutions for clothing and thermal environment for Japanese youth, in order to promote better adaptation to summer environments.

2. Methods
2.1. Participants and clothing

All the participants in this research, consisting of 90 Japanese undergraduates (57 males, 33 females), had been living in Fukuoka, for over two years. Most participants were from Kyushu and nearby areas and their basic physical characteristics were as follows (subdivided by males / females, respectively): age, 20.5 ±1.4 / 20.4 ±1.1 years old; height, 173.4 ±5.9 / 158.7 ±6.4 cm; weight, 63.4 ±9.8 / 50.2 ±6.4 kg; basal metabolic rate (BMR), 1664.9 ±155.3 / 1326.6 ±69.4 kcal/day. The participants wore their clothing as usual during the investigation, and the clothing information was recorded using questionnaires.

2.2. Conditions and procedures

This investigation was carried out in summer in Fukuoka during the period 10-25 July 2017, after the rainy season with a hot-humid climate. Four surveys were carried out in and outside the test classroom (Fig. 1) with air-ceiling cassette type air conditioners. Thermal conditions are given in Table 1.

In order to reduce the impact of variation in time, we conducted two surveys continuously during the first phase on July 10 and July 11, and obtained a valid single sample of 90 subjects. Meanwhile, in order to study the impact of variation in time, we conducted another two surveys on the overall thermal feelings and clothing characteristics on July 18 and July 25.
respectively, using the participants from the July 11 survey. In this second phase, we obtained three valid data samples for a total of 20 screened participants (10 males, 10 females).

In cooperation with teachers and students, we started each survey at 5:40 pm after 60 min of class in the classroom. We first measured indoor environmental parameters and investigated participants’ clothing information and indoor thermal feelings using questionnaires. After 10 min, at 5:50 pm, all the participants quickly moved outside and remained standing and walking randomly for 10 min. From 6:00 pm, outdoor environmental parameters and thermal feelings were recorded.

Most Japanese people live within a distance range of 400-800 meters during daily life and choose to live less than a 10-min walking distance from stations (Matsuhashi et al., 2002; MLIT, 2007). In order to reflect real daily life conditions after work or school in summer, the participants were required to keep standing or walking for 10 min outside as described above.

2.3. Survey questionnaire

The questionnaire mainly consisted of two parts: clothing information and thermal feelings. The questionnaire on clothing information including clothing type, thickness and weight, and was designed based on ISO9920 (2007), as well as Japanese dressing habits and style characteristics. In order to record more detailed information concerning clothing styles, we listed different types for subjects to choose from, including upper-body clothing (e.g. shirt, T-shirt, outerwear and hat) and lower-body clothing (e.g. trousers, underpants and shoes), according to clothing details such as sleeve length and fabrics. Clothing not included in the list was required to be described in detail or recorded using photographs. In addition, clothing thickness and weight were recorded by subjective votes on two 5-point scales: 1-very thin, 2-thin, 3-neutral, 4-thick, 5-very thick, and 1-very light, 2-light, 3-neutral, 4-heavy, 5-very heavy, respectively.

The questionnaire on thermal feelings included thermal sensation (TS), thermal comfort (TC), humidity feeling (TH), thermal preference (PF), acceptability (AP), tolerance (TL) and airflow (AF), and was designed based on the ISO10551 (2001) and ISO7730 (2005). TS, TC and TH were surveyed for the overall feelings and 11 local body areas (head, neck, back, chest, upper arm, forearm, hand, hip, thigh, calf, foot) by using, respectively, the 7-point scale: 3-hot, 2-warm, 1-slightly-warm, 0-neutral, -1-slightly cool, -2-cool, -3-cold; the 4-point scale: 0-comfortable, 1-slightly uncomfortable, 2-uncomfortable, 3-very uncomfortable; and the 7-point scale: 1-very wet, 2-wet, 3-slightly wet, 4-neutral, 5-slightly dry, 6-dry, 7-very dry. PF, AP, TL and AF were surveyed only for the overall feelings, by using, respectively, the 7-point scale 3-much warmer, 2-warmer, 1-a little warmer, 0-neutral, -1-a little colder, -2-colder, -3-much colder; the 2-point scale: 0-acceptable, 1-unacceptable; the 5-point scale: 0-perfectly tolerable, 1-slightly difficult, 2-fairly difficult, 3-very difficult, 4-intolerable; and the 4-point scale: 1-no, 2-weak, 3-normal, 4-strong.

2.4. Measurement and calculation

We measured wet-bulb globe temperature (WBGT), ambient temperature (Ta) and relative humidity (RH) using a WBGT meter (WBGT-103; KEM, Kyoto, Japan), as well as air velocity (Va) using an air velocity meter (VelociCheck Model 8330; TSI, Minnesota, USA). All the parameters were recorded every 2 min inside the room and outside, and the WBGT meter and air velocity meter were placed at the same height as the desks (around 0.6 m) inside the room and at a height of 1.1 m outside.

The values of upper-body and lower-body clothing ensemble insulation were computed using the ISO9920 (2007) equation (12) \[ I_{cl}=\sum I_{clu}, \] and the overall clothing ensemble insulation was computed using the ISO9920 (2007) equation (11) \[ I_{cl}=0.161+0.835\sum I_{clu}. \] Predicted Mean Vote (PMV) was calculated using the computer program of ISO7730 (2005) annex D.

2.5. Statistical analysis

The statistical analysis was performed mainly using SPSS software (Ver.19; IBM SPSS). The subjective votes data were not normally distributed (p<0.05), as shown using a normality test. The quartile and nonparametric analysis methods were therefore used, especially for subjective feelings. The median and interquartile range were used to describe the sample distribution. The Mann-Whitney U test was used to analyze differences in subjective feelings between two groups, such as gender groups. The Friedman rank ANOVA test was used to examine the differences of subjective feelings between two groups. Other methods such as the Pareto analysis and chi-square test (Fisher’s exact test, if appropriate) were also used. All significant differences referred to in the results section were shown at levels of 0.05, 0.01.

3. Results

3.1. Summer thermal environment

Table 1 shows the results for the mean values and standard deviations of indoor/outdoor WBGT, Ta, RH and Va during the investigation. The ranges of mean indoor WBGT, Ta, RH and Va were 22.1-23.8°C, 23.9-25.2°C, 68.7-77.7% and 0.19-0.23 m/s, and the mean outdoor ranges were 26.7-28.8°C, 29.2-30.3°C, 67.0-78.3% and 0.21-0.42 m/s. All the results were within the acceptable ranges according to environmental
temperatures, humidity and airflow recommended by ASHRAE (2013), and indoor parameters were in the comfortable zone. These results are similar to the results of the study of Yasuoka (2015) on the summer thermal environment.

3.2. Clothing characteristics

Table 2 shows the proportions for each category of clothing worn by participants, and the distributions of clothing types, as well as subjective votes on clothing thickness and weight using the medians and interquartile ranges (IQR, 25% & 75%). Fig. 2a-2b shows the distributions of clothing types by frequency and Fig. 3a-3b shows the clothing amount (the number of clothing items) and clothing insulation according to the surveys on 10-11 July.

### 3.2.1. Clothing categories and types

As shown in Table 2, the summer clothing worn by participants was divided into nine categories. Most of the males wore six categories of clothing (>60%): undershirts, shirts, underpants, trousers, socks, shoes. The other categories (e.g. jackets) account for very small proportions (<10%) and none of the male participants wore skirts, which are usually considered as female clothing. However, over 60% of females wore five categories of clothing: undershirts, shirts, underpants, trousers, shoes, and some wore skirts and socks. Only a few participants wore jackets or other clothing items.

### Table 1 Thermal conditions

| Period       | Participants | Thermal items | Place | WBGT(°C) | Ta(°C) | RH(%) | Va(m/s) | Mean(s) |
|--------------|--------------|---------------|-------|----------|--------|-------|--------|---------|
| 1st week     | Male 34      | Indoors 23    | 25.0(2) | 77.7(0.6) | 0.23(0.07) |
|              | Female 16    | Outdoors 26   | 29.2(2) | 69.2(1.2) | 0.42(0.26) |
| (2017/7/10)  |              | Indoors 23    | 24.0(5) | 75.4(2.4) | 0.21(0.02) |
| 2nd week     | Male 23      | Indoors 27    | 29.8(0) | 68.5(0.7) | 0.44(0.11) |
|              | Female 17    | Outdoors 27   | 29.0(5) | 67.0(2.0) | 0.21(0.17) |
| (2017/7/11)  | (10)         | Indoors 22    | 23.0(0) | 72.7(3.5) | 0.21(0.11) |
| 3rd week     | Male 14      | Indoors 23    | 23.1(0) | 78.3(0.7) | 0.31(0.13) |
|              | Female 14    | Outdoors 27   | 29.0(5) | 68.5(1.4) | 0.19(0.11) |
| (2017/7/18)  | (10)         | Indoors 22    | 23.0(0) | 72.7(3.5) | 0.21(0.11) |
| 4th week     | Male 15      | Indoors 22    | 22.1(0) | 78.3(0.7) | 0.31(0.13) |
|              | Female 14    | Outdoors 28   | 30.0(1) | 78.3(0.7) | 0.31(0.13) |

Note: (10) means the number of the screened participants used to analyze the variation among 11, 18 and 25 July; Thermal items were presented by mean value (standard deviation).

### Table 2 The proportions of clothing categories worn, and clothing types, thickness and weight

| Items          | Gender | Undershirts | Shirts | Jackets | Underpants | Trousers | Skirts | Socks | Shoes | Others | Overall |
|----------------|--------|-------------|-------|---------|------------|----------|--------|-------|-------|--------|---------|
| Proportion     | Male   | 63.2%**     | 98.2% | 5.3%    | 100.0%     | 100.0%** | 0.00%**| 73.7%**| 100.0%| 7.0%   | 100.0%  |
| Type           | Female | 93.9%*      | 90.8% | 6.1%    | 100.0%     | 63.6%    | 36.4%  | 30.3% | 100.0%| 3.0%   | 100.0%  |
| Thickness      | Male   | 2(1,2)      | 1(1,1) | 3(2,1)  | 1(1,1)     | 5(4,5)   | 1(1,1) | 2(2,3) | 3(2,3) | 1(1,1) |        |
| Weight         | Female | 1(1,2)      | 1(1,2) | 4(1,6)  | 1(1,1)     | 4(3,5)   | 1(1,1) | 2(2,3) | 3(2,3) | 1(1,1) |        |

Note: Significant difference among main categories (>60%) *p<0.01; Significant gender difference *p<0.05, **p<0.01; No data about these items (\).
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According to the chi-square test, there were very significant differences (p<0.01) within all the categories and within the main categories (six for males, five for females) worn by males and females, and there were also very significant gender differences (p<0.01) in the proportions of underpants, trousers, skirts and socks.

Every category of clothing included at least six types in the questionnaire, and according to the medians and IQR there were significant gender differences (p<0.01) in the categories of shirts, underpants and shoes. Males tended to wear boxer-briefs (labeled as “3” in the underpants category in Table 2, and similarly hereafter), short sleeve T-shirts and shirts (labeled “1” and “4” in the shirts category) and sneakers (labeled “3” in the shoes category). Females preferred to wear panties (labeled “1” in the underpants category), short sleeve T-shirts and blouses (labeled “1” and “4” in the shirts category) and slippers (labeled “5” in the shoes category).

The Pareto charts (Fig. 2a-2b) are used to analyze the main type factors of clothing ensembles in summer, and show the frequency (proportion) of each type of clothing worn by each gender (57 males, 33 females) and the cumulative frequency of the clothing types worn, accounting for the number of all the clothing items worn by each gender. There were 22 types of clothing worn by males and 26 types of clothing worn by females, accounting for 37.9% and 44.8% of all the clothing types in the list (58 types in total), respectively. As shown in the charts, there were six clothing types (boxer-briefs, sneakers, ankle socks, short sleeve T-shirts, short sleeve undershirts, long pants) for males and 5 clothing types (panties and bra, sleeveless under T-shirts, sandals, short sleeve T-shirts, long pants) for females. These types represent more than 60% of the cumulative frequency, have the largest proportions in the corresponding clothing categories described above, and could be considered as the typical clothing ensembles. Ten and nine clothing types account for around 80% of all the summer clothing types worn by males and females, respectively, and are considered as the main clothing types according to the Pareto principle (20/80 rule) (Box et al., 1986; Marshall, 2013).

As Table 3 shows, there were almost no significant differences in the proportions of clothing categories and types among the results of the 11, 18 and 25 July surveys, except for a slightly significant difference (p ≲ 0.05) in the type of females’ socks.

3.2.2. Clothing thickness and weight

According to the medians and IQR in Table 2, most of the males reported “3” (neutral) for the thickness of overall clothing and “2” (thin) for most of
the categories, except for socks and undershirts. However, they reported “2” (light) for the weight of overall clothing and “3” (neutral) for half of the categories. Most of the females reported “2” (thin) for the thickness of overall clothing and for over half of the categories, and they reported the weight as “3” for trousers, socks and overall clothing. There were very significant differences (p<0.01) in thickness and weight sensations among the main categories. Females felt that the overall clothing (p<0.05) and undershorts (p<0.01) were significantly thinner than males. However, no significant gender differences were found in weight sensation.

As shown in Table 3, there were no significant differences in the thickness and weight sensations recorded in the 11, 18 and 25 July surveys, although the thickness of men’s shirts and the weight of women’s shirts and undershorts were at the margins of statistical significance (p<0.1).

3.2.3. Clothing amount and insulation

The box-and-whisker plots in Fig. 3a-3b were used to depict the distributions of clothing amount and insulation, including upper-body, lower-body and overall clothing. According to the medians and IQR, the upper-body amount (A_{clus}), lower-body amount (A_{clls}) and overall amount (A_{cl}) were 2(1,2), 4(3,4) and 5(5,6) items of clothing worn by females. The ensemble insulation values of upper-body (I_{clus}), lower-body (I_{clls}) and overall clothing (I_{cl}) were 0.21(0.19, 0.26), 0.50(0.46,0.55) clo for males, and 0.21(0.21, 0.21), 0.50(0.50, 0.53) clo for females, respectively. As the plots show, the upper-body amount was significantly (p<0.01) larger than the lower-body amount for both genders, and there was a statistically significant gender difference (p<0.01) in the lower-body amount of clothing. However, there was no significant gender difference in lower-body clothing insulation and no upper-body/lower-body difference in clothing insulation. In addition, there were no significant gender differences in the amount and insulation of overall and upper-body clothing.

There was also no significant difference in clothing amount and insulation among the 11, 18 and 25 July surveys, which indicates that, to some extent, there was stability in clothing amount and insulation.

3.3. Thermal feelings

3.3.1. Overall thermal feelings and variation

Table 4 depicts the distribution characteristics of overall thermal feelings using the medians and IQR. As expected, apart from TC and AP for females, there were statistically significant differences (p<0.05) between indoor and outdoor feelings for all the other parameters, most of which showed very significant differences (p<0.01). Inside the room, both males and females felt comfortable (0) in overall TC, neutral (4) in overall TH, acceptable (0) in AP and slightly difficult (1) in TL. Compared with males, females felt significantly cooler or colder (p<0.05) in TS, felt more airflow (p<0.05) in AF and preferred to be warmer (p<0.01) in PF. In the outdoor environment, both genders felt slightly warm (1) in TS, slightly wet (3) in TH and acceptable (0) in AP, and there were statistically significant gender differences (p<0.01) in TS, TH and AP for females. In addition, there was no gender difference in the expected difference in indoor-outdoor feeling for all the other parameters. The results indicated that both males and females felt less comfortable (1) in the indoor environment, with a slight preference for wetness (1) in the outdoor environment. Overall, the thermal comfort of the subjects was influenced by their gender, with females generally experiencing cooler or colder conditions, while males were more likely to experience heat stress, particularly in the TS parameter.
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differences (p<0.05) in TC, PF, TL, and AF. Moreover, compared with females, males felt more uncomfortable in TC, more difficult in TL, felt more airflow in AF, and preferred a cooler environment in PF.

Table 5 shows the p-values of differences among the 11, 18 and 25 July surveys, which reflected the time variation of PMV and thermal feelings. As the results show, apart from indoor PMV for males, there were highly statistically significant differences (p<0.01) in PMV. The significance (p<0.05) (in indoor TC, outdoor TH and AF for males and indoor PF for females) showed that the participants felt significantly unstable in these parameters. Nevertheless, there were no significant differences in most of the thermal feelings, which implies that there was relative stability in thermal feelings. The interpretation for this is presented in section 4.2.

3.3.2. Local thermal feelings with respect to TS, TC and TH

As shown in Table 6, most of the local thermal feelings for participants were within a neutral state or comfortable state in the indoor environment and slightly deviated from the neutral state in the outdoor environment. Similar results in local TS and local TC were observed in the study of He et al. [35], however these results have been extended in the present study through the inclusion of environmental and gender differences.

Although local TS, TC and TH in different body parts seemed similar, many significant differences were observed to exist. In fact, apart from outdoor local TC, there were statistically significant differences (p<0.05) in local TS, TC and TH among different body parts for females. Compared with overall thermal feelings, in the indoor environment females felt very significantly (p<0.01) warmer in most of the body parts compared to the overall TS, more comfortable in the hip area compared to the overall TC, and wetter in the foot area compared to the overall TH. In the outdoor environment, females felt very significantly (p<0.01) cooler in the head area and calf area compared to the overall TS, and drier in the calf area compared to the overall TH. There were only significant differences in indoor local TS for males, and compared with overall thermal feelings, males felt very significantly (p<0.01) cooler in the hands, and warmer in the hip and thigh areas compared to the overall TS.

3.4. Correlations between clothing insulation and thermal feelings

As shown in Table 7, there were significantly (p<0.05) positive correlations between Icl and indoor TH (overall and local) in most of the body parts for males, and negative correlations between Icl and local TH in the hip area (indoors) and chest area (outdoors) for females. This result shows that the males wearing more clothing felt dryer in these parts than the other males in the room. The females wearing more clothing felt wetter in the hip area (indoors) and chest area (outdoors) than the other females, which may be caused by more insulation, or physiological factors. Similarly, as for TL, the correlations show that males felt that conditions were more intolerable outside and the females wearing more clothing felt that conditions were more tolerable indoors. Some thermal feelings were also affected by Icl and Icl. For example, females wearing more upper-body clothing indoors could better tolerate the environment and felt wetter in the chest area. Both genders had significant (p<0.05) correlations in the hip and foot areas between local TS and Icl indoors.

Apart from the results above, there were no significant differences in most of the conditions. A reasonable explanation is that there were no large

| Table 6: Distributions of local thermal feelings in TS, TC and TH |
|---------------------------------------------------------------|
| **Item** | **Gender** | **Overall** | **Head** | **Neck** | **Back** | **Chest** | **U-arm** | **F-arm** | **Hand** | **Hip** | **Thigh** | **Calf** | **Foot** |
|---------|-----------|-------------|-----------|----------|----------|-----------|-----------|-----------|----------|--------|-----------|----------|---------|
| **Indoors** | Male | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** |
| **TS** | Female | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** |
| **Outdoors** | Male | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** |
| **TC** | Female | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** |
| **Outdoors** | Male | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** |
| **TH** | Female | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** |
| **Outdoors** | Male | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | 0 (1,0) | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** | **0 (1,0)** |

Note: Significant difference among local thermal feelings, 0.01 p<0.05; Significant difference between local and overall feelings by Mann-Whitney U test, 0.01 p<0.05, 0.05 p<0.01; Significant indoor-outdoor difference 0.01 p<0.05, 0 p<0.01.
deviations either in clothing insulation (see Fig. 3a) or in thermal feelings (see section 3.3). More interpretations are discussed in section 4.4.

4. Discussion

4.1. Clothing and variation

The clothing investigation showed that males wore six typical types (with 0.51 clo for ensembles), corresponding to six categories. In contrast, females preferred to wear five typical types (with 0.5 clo for ensembles), corresponding to five typical categories. This result is consistent with a previous survey in Tokyo (Tamura et al., 2004), in which the largest proportion of participants wore short sleeve T-shirts and long pants, for both females and males in summer. As in a study in Beijing and Tianjin (Li et al., 2015), the participants in the air-conditioned room tended to wear short sleeve T-shirts and long pants in summer, although these studies differed for sandals and leather shoes, probably as a result of the difference in participants' occupations (students versus staff). Furthermore, there were very significant gender differences in the proportions and types of some clothing items. Apart from the gender differences in underwear due to clothing styles (e.g. panties and bra), it is unclear why the gender differences existed for shoes and socks. A tentative explanation is that some females wore skirts, which are usually worn with sandals and leather shoes, probably as a result of the difference in participants' occupations (students versus staff).

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4.2. Overall thermal feelings and variation

The results of the investigation on thermal feelings showed that participants were in or close to comfortable conditions, which conformed with the thermal conditions recommended by ASHRAE (2013). Accordingly, significant indoor-outdoor differences in thermal feelings indicate that participants were sensitive to the step-change transient thermal environments in summer, which also serves to extend the results of the study of Jin (2016)

| Place   | Gender | Head | Neck | Back | Chest | U-arm | F-arm | Hand | Hip | Thigh | Calf | Foot | Overall |
|---------|--------|------|------|------|-------|-------|-------|------|-----|-------|------|------|---------|
| Indoors | Male   | 0.28 | 0.33 | 0.31 | 0.29  | 0.29  | 0.29  | 0.29  | 0.30| 0.30  | 0.34 | 0.29 |
|         |        | TH/Icl| TH/Icl| TH/Icl| TH/Icl| TH/Icl| TH/Icl| TH/Icl| TH/Icl| TH/Icl| TH/Icl| TH/Icl|
|         | Female |      |      |      |       |       | -0.36 |       | 0.36|       |      |      |
|         |        |      |      |      |       |       |       |       |     |       |      |      | -0.49  |
|         |        |      |      |      |       |       |       |       |     |       |      |      | TL/Icl |
|         |        |      |      |      |       |       |       |       |     |       |      |      | -0.30  |
| Outdoors| Male   |      |      |      |       |       |       |       | -0.37|       |      |      | 0.48   |
|         |        |      |      |      |       |       |       |       |     |       |      |      | AC/Icl |
|         | Female |      |      |      |       |       |       |       |     |       |      |      |       |
|         |        |      |      |      |       |       |       |       |     |       |      |      |       |

Note: Significances on correlations 0.01<p<0.05, 0<p<0.01; No data about these items (?).
concerning thermal sensations and the physiological response in step-change environments.

As for the results of most previous studies, we found no significant gender difference in indoor TC. A meta-analysis study by Karjalainen (2012) showed that females were more likely to express thermal dissatisfaction in the same environment. However, in the present study, compared with males, females felt that conditions were significantly more comfortable and tolerable outside and significantly cooler or colder inside the room, and significantly preferred a warmer environment in an acceptable range. These results are partly due to females’ lower basic metabolic rate and lower skin temperatures, as in the study of Liu et al. (2018), and this may also be a plausible explanation for the finding of no significant differences in TC and AP for females between the indoor and outdoor environments. Moreover, these findings are compatible with the results of the study by Yasuoka (2015) for Japanese students, and have important consequences for the idea that women are generally likely to feel colder and more sensitive to coldness than males (e.g. Parsons, 2002; Karjalainen 2012). These findings seem to contradict the results of the study of Tung (2014), who found that females were less tolerant of hot outdoor environments because of sensitivity to radiation. Nevertheless, it may be important that the surveys in the present study were conducted at around 6 pm, with less sun exposure than in the study of Tung (2014), which was conducted in a hot region.

In the present study, there were significant indoor-outdoor differences in TH and most of the participants felt neutral and slightly wet in the indoor and outdoor environments, respectively. The current findings may extend the results of the study of Tan (2012), who found significant differences in TH (between 60% and 80%) when temperatures are above 30°C, as air temperature may affect TH. In the previous study on AF, some researchers (e.g. Toftum et al., 2012) found no gender significance, whereas others found some gender significance (e.g. Griefahn et al., 2001). Our results support the latter, and according to the IQR females felt a little more airflow inside the room and less airflow outside than males.

This study shows that, to a certain extent, there was stability in thermal feelings for both genders despite slight changes in PMV and the environment in summer. It is plausible from the results that no significant change existed in most of the thermal feelings, and the relatively stable environmental conditions and clothing characteristics, including dressing behavior, could reasonably account for this observation. However, males felt a significant change in indoor TC over time, and as shown in Fig. 4a, the values of indoor TC for males decreased steadily with time and approached “0” (comfortable), indicating that males adapted to the indoor environment more readily than females. This finding may support the results of Parsons (2002), who found that females made more changes in clothing insulation than males as they wanted to achieve thermal comfort. The reasons why females showed significant instability (Table 5, Fig. 4b) or trends in indoor and outdoor PF are not established. An acceptable explanation may be found in the results of the study by Karjalainen (2012), who found that in order to adapt to the thermal environment, females are more sensitive than males to a deviation from an optimal temperature, especially in cooler conditions. Moreover, the physiological cycle of females may also be an important factor. Participants felt that the differences in outdoor TH were slight or at the margin of significance, which may also be due to the substantial change (67%-78.3%) in humidity. This range is also similar to the range between indoors and outdoors described above. Additionally, the significance in the changes in outdoor AF over time indicates that males were sensitive to changes in outdoor airflow, which is also consistent with the result described above that males are more sensitive to airflow than females.

4.3. Local thermal feelings with respect to TS, TC and TH

According to the results described in section 3.3.2, there were clearly some gender differences in the different local thermal feelings. As in previous work (e.g. Karjalainen, 2012; Liu et al., 2018) and as mentioned above, females were more sensitive to a cooler environment and tended to prefer a warmer environment, which was supported and extended by the significant gender differences in local thermal feelings (e.g. indoor local TS in the F-arm area, outdoor local TS in the head area and local TC in the hand area). Moreover, our study implies that females were more sensitive to perceived differences in thermal feelings in
different body parts. This is evident from the results comparing males with females, which showed that females felt significant differences among different body parts in terms of all the thermal feelings in all the conditions (whereas males only felt differences in TS), and more significant differences between the overall and local TS.

According to the study of He et al. (2016), the differences could be mainly attributed to three factors: physiological factors, environmental factors and locally disturbed factors. The gender differences exist because females have a lower percentage of body fat in the head and a lower basic metabolic rate, which might have a more significant influence on the temperatures in some body parts (Zhou et al., 2013). As Table 6 shows, there were significant differences in some thermal feelings between the overall body and the body parts, such as in the F-arm area for the indoor TS for males, for the indoor TS in the head area, for the outdoor TC in the hip area, for the indoor TH in the hand area, etc., because there were different sensitivities, neutral temperatures and other physiological characteristics for individual body parts (He et al., 2016). Participants felt more differences in indoor TS than outdoor TS among body parts. The hand area was reported as the warmest body part by He et al. (2016), due to locally disturbed factors (e.g. touching warm laptop). Similarly, in the present study, most of the participants felt cool in the arm area and it may be the case that the arm area was almost bare, touched the cooler desk and felt airflow from air-conditioners more easily. As for the influences of the body parts on the overall thermal feelings, a comprehensive consideration of the factors above should be taken into account (Tan, 2012). For example, the overall sensation was reported to be determined by the body parts directly exposed to airflow and solar radiation (Hagino et al., 2013), upper body (Li et al., 2002), the head (He et al., 2016) and body parts where the local TS shows a larger difference (Zhang, 2003). These interpretations, to some extent, could be used to explain and support our results that most of the body parts (e.g. the head and F-arm area) affecting overall TS were bare and in the upper body (Zhang, 2003). Furthermore, although there were gender differences in the influence of local and overall TC, such as arms for females and legs (indoors) for males, which seemingly were more comfortable than other body parts, this finding does not contradict the finding by He et al. (2016) that the most and the second most comfortable body parts determined overall TC. As for TH, it is uncertain whether there were similar relationships as TC. Nevertheless, the values in the body parts which determined the overall TH seemed closer to neutral, despite the different indoor and outdoor humidity.

### 4.4. Relationships between clothing and thermal feelings

No significant difference was found in clothing insulation but there were some differences in the clothing amount that relate to thermal feelings (see sections 3.2 and 3.3). This indicates that rather than clothing insulation, the thermal comfort of participants was mainly affected by other clothing factors, such as clothing type and dressing method in summer. As shown in Table 6, in the indoor environment, besides the observation that the arm area was in a cool state for most of the participants, the foot area was also reported to be cool by females, who felt significantly cooler than males in the arm and foot. However, the hip and thigh areas were reported to be a little warmer than the other body parts. Besides physiological factors, another good explanation is that the local TS was affected by the clothing conditions in those body parts. It is evident that according to the typical clothing types (see sections 3.2 and 4.1), the arm area was almost naked due to T-shirts being worn by both genders. Males also had more insulation in the arm and foot area than females as a result of wearing short sleeves under the T-shirts, as well as sneakers and ankle socks, whereas females wore sleeveless under T-shirts, as well as sandals and no socks. As shown in table 2, males had more weight in the shirts and underwear than females. Furthermore, there was more insulation in the thigh and hip area than in other body parts because of touching the chairs, as well as more clothing layers, more clothing thickness and more clothing weight. Besides, as mentioned in section 3.4, we found that lower-body clothing insulation affected local TS in some body parts, for example in the hip area for males and the foot area for females, which is in line with the results of Morooka (2006).

However, no significant relationship between thermal comfort and clothing was found, and this implies that there was a comfortable or acceptable range of clothing insulation for local TC. This finding is in line with the results of this study on environmental conditions and thermal feelings, and the comfortable or acceptable zone recommended by ASHRAE (2013). Furthermore, clothing insulation affected TH, especially for males indoors. The males wearing more clothing felt dryer in most of the body parts inside the room, while females felt wetter in the hip and chest areas. This result could be explained by the idea presented in previous work (e.g. Woodcock, 1962; Takashi, 1996) that the inner humidity of clothing was affected by clothing insulation, fabrics, openings, etc. It is likely that when participants were in a cooler and comfortable state during rest, the inner clothing humidity was lower than in high environmental humidity, and inner clothing humidity also decreased with more clothing. In contrast, the opposite was true while participants were moving, and in the warmer or hot environment outside.
TL and AC were also clearly affected by clothing insulation. As shown in Table 7, females preferred more clothing in an indoor environment. However, in an outdoor environment, more clothing was not preferred by males but accepted by females, and this was because females were more likely to be uncomfortable in a cooler environment and tended to prefer a warmer environment (e.g., Bae et al., 1999; Parsons 2002), as mentioned above.

5. Conclusions
This paper described the results of a field study of summer clothing characteristics in indoor-outdoor settings, and the overall and local thermal feelings related to the thermal comfort of young people by gender. The main conclusions of this study can be summarized as follows:

• Clothing
  (1) There were six and five clothing types worn as typical summer ensembles for males and females, respectively. Male clothing typical ensembles (0.51 clo) comprised: boxer-briefs, sneakers, ankle socks, short sleeve T-shirts, short sleeve undershirts and long pants. Female clothing typical ensembles (0.5 clo) comprised: panties (and bra), sleeveless under T-shirts, sandals, short sleeve T-shirts and long pants.
  (2) Both genders wore almost the same amount and same insulation of overall clothing, but females wore a greater amount of clothing than males. No significant upper-body/lower-body differences in clothing insulation were found. There was some stability in clothing items over time, despite a slightly significant difference in the type of females’ socks.

• Thermal feelings
  (3) Participants felt significant differences in most of the thermal feelings between the indoor and outdoor environments. Compared with males, females felt significantly cooler or colder, and felt more airflow in an air-conditioned room, whereas they felt less airflow, more comfortable and tolerable conditions outdoors, and significantly preferred a warmer environment. Females were more sensitive than males to perceived local differences. It seemed difficult for males to perceive local differences especially in a warmer outdoor environment.
  (4) Males seemed to adapt to an indoor environment more easily than females. Females showed more instability in PF. However, to some extent, there was some stability in most of the thermal feelings for both genders.

• Relationships
  (5) Local TS was easily affected by the clothing conditions of the body parts for individuals, and correlations between local TS and lower clothing insulation were found in the hip area (for males) and the foot area (for females). Clothing insulation also affected TH, especially for males in the indoor environment.

In summary, there were some differences and relationships not only in clothing but also in thermal feelings between different conditions (e.g. genders and indoor-outdoor environments). Especially for thermal feelings, the characteristics of clothing, gender and variation should be taken into consideration to better adapt to summer thermal environments in the future.

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