Effects of gender on thermal comfort of stratum ventilation with pulsating air supply

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Abstract
Physiological and psychological differences between males and females can lead to differences on thermal comfort. A novel ventilation strategy, stratum ventilation with pulsating air supply, have potentials to improve thermal comfort in warm conditions. Experiments were conducted in a classroom mock-up with dimensions of 8.4 m (L)×5.4 m (W)×2.6 m (H) served by stratum ventilation with pulsating air supply. There are two rows, and each row can hold six occupants. Twenty-five healthy subjects (i.e., 10 males and 15 females, aged 21-36 years) were recruited to attend the experiments. All the subjects were exposed to four test conditions with different combinations of supply air temperatures, air velocities and/or periodic time. Subjects’ perceptions on thermal comfort, thermal sensation and draft perception were obtained via the questionnaires. The longer cycle time will eliminate the difference on thermal sensation between genders. The difference on draft sensation disappeared at high velocity. Males show good tolerance to thermal environment. For all the cases, more than 80% of subjects voted thermal comfort as comfortable which shows that the thermal environments produced by stratum ventilation with pulsating air supply were acceptable.

Keywords: Stratum ventilation; Pulsating air supply; Gender difference; Thermal comfort; Draft

1. Introduction
The issue of whether there are differences between males and females in perception of thermal comfort has evoked many researches, most of which were carried out in steady environment. Based on the literature review, it was found that there was no consistent conclusion on the effects of gender on thermal comfort. Some studies found that there was a significant difference between genders. Females tended to feel more uncomfortable than males at both high and low temperature extremes [1]. Males tended to prefer cool and fast airflow while females tended to prefer warm and slow airflow [2]. Griefahn and Künemund [3] found that females felt significantly more uncomfortable and cooler with draft and preferred a higher temperature than males. However, some other studies showed that no significant differences were found between genders. Karyono [4] found that the differences on thermal neutral temperature and comfort range between males and females was very small and statistically insignificant. Liu et al. [5] found that the differences on mean skin temperature and thermal sensation between genders were statistically insignificant. It was found that females’ comfortable operative temperature (26.3°C) is higher than male comfortable operative temperature (25.3°C), although males and females have almost the same neutral temperature and in the effects of gender on thermal sensation were negligible for neutral conditions [6].

Stratum ventilation was proposed to accommodate the elevated room temperatures. A number of studies were conducted to investigate thermal comfort of stratum ventilation. Cheng et al. [7] suggested that the supply air temperature should not be below 20°C to minimize draft complaints and stratum ventilation can provide a thermal comfortable environment with low draft ratings at a room temperature
up to 27°C. The supply air temperature of 21°C are found to perform better as compared with supply air temperature of 19°C [8]. Dynamic airflows have potentials to provide better thermal comfort than steady airflows. Wigo [9] found that people exposed to velocity variation perceived the airflow as cooler and fresher as compared with those exposed to constant low velocity and very few people classified the air movement as draft. It is possible to use intermittent airflows for cooling and reducing the percentage of occupants who are dissatisfied with the room temperature, without creating draught problems, through [10].

There are few studies on the effects of gender on thermal comfort under stratum ventilation with pulsating airflow. The objective of this study is to analyze whether there exist some differences on thermal sensation, thermal comfort and draft sensation between males and females. A novel ventilation strategy, stratum ventilation combined with pulsating air supply, were used to condition indoor thermal environment.

2. Methods

2.1. Room conditions

The experiments were conducted in a classroom mock-up with dimensions of 8.4 m (L)×5.4 m (W)×2.6 m (H) severed by stratum ventilation with pulsating air supply. It was located in City University of Hong Kong Chengdu Research Institute, China. It had two windows located on the right exterior wall. There were two rows in the classroom, and each row could hold six occupants. There were six lights mounted on the ceiling, each with a thermal load of 15 W. Temperature fluctuations of the exterior wall and the windows during the experiment were small (within 1°C). The fresh air was supplied from six grilles at the height of 1.35 m above floor to the breathing zone horizontally, and then exhausted through six exits at the height of 0.49 m above floor. The air inlets/exhausts had the same dimensions of 0.17 m × 0.17 m each. The room was carefully sealed with rubberized fabric to make sure there was little air leakage from windows and doors.

2.2. Cooling system

The supply air temperature and the supply airflow rate could be modified by changing the opening of the cold-water valve and the frequency of the supply fan, respectively. For pulsating air supply, the time of the whole cycle, the duty period where the air velocity was high, the idle period where the air velocity was low, and the frequencies of the supply fan for the duty period and the idle period can be set by the control system.

2.3. Experimental time

The experiments were conducted in daytime (i.e., 10:00 – 17:00) of the days with a sunny weather, and they all conducted in August 2018.

2.4. Participants conditions/background:

A total of 25 subjects (i.e., 10 males and 15 females) aged between 21 and 36 years were recruited to attend the experiments. This was enough to get accurate results, a similar sample size of subjects was applied in many related studies [2, 5, 6]. The participations were voluntary and they were paid. Some of the subjects were staff of the institute. And the others were students from a nearby university. They have been lived in the city for more than half a year. They are all healthy. All the subjects were exposed to four test conditions with different supply air temperatures, air velocities and/or cycle time. They were unaware of the exposure. The subjects did sedentary work and thus the activity level was estimated to be 1.1 met. The subjects were required to wear typical summer clothes (t-shirt, underwear, short socks, thin trousers and shoes) with about 0.51 clo. The basic demographic data of the subjects are summarized in Table 1.

2.5. Experimental design and procedures

The studied cases are listed in Table 2. A total of 25 subjects (15 females and 10 males) participated in the experiments. Among the 25 people, whoever had time will be present, and 12 subjects participated in each session. If there was a vacancy situation, the rectangular thermal simulator with dimensions of
0.40 m (length) × 0.25 m (width) × 1.20 m (height) will be placed there. A 100 W bulb was placed inside each thermal simulator to simulate body heat. The subjects were required to arrive 20 minutes before the formal experiment in order to have sufficient time to adapt to the environment. They chose seats randomly. During the experiments, the subjects were not allowed to stand or walk around. The total time of formal experiment was 90 min. Ten minutes after the formal experiment began, the subjects answered the first questionnaire. Thus, a total of 30 minutes for adaptation was designed. Each subject was assigned to answer 5 questionnaires during one test session. A total of 125 questionnaires were collected for each session. The procedure was summarized in Figure 2.

Table 1. Demographic data of respondents.

| Sex      | Number | Age (years) | Height (m) | Weight (kg) | BMI |
|----------|--------|-------------|------------|-------------|-----|
| Female   | 15     | 26.70±6.57a| 1.60±0.05  | 50.40±4.88  | 19.70±1.14 |
| Male     | 10     | 26.60±6.36  | 1.76±0.05  | 68.90±10.83 | 22.34±3.46 |
| Total    | 25     | 27.08±5.72  | 1.66±0.09  | 58.00±11.90 | 20.86±2.69 |

a. Standard deviation. b. Body Mass Index= weight (kg)/[height (m)]²

Table 2. Experimental conditions.

| Case       | A          | B          | C          | D          |
|------------|------------|------------|------------|------------|
| Room air temperature (℃) | 26.7±0.3   | 28.0±0.3   | 26.5±0.3   | 27.0±0.4   |
| Supply air temperature (℃) | 21.5±0.1   | 23.5±0.2   | 21.6±0.3   | 21.6±0.2   |
| Exhaust air temperature (℃) | 26.3±0.1   | 27.9±0.1   | 26.6±0.0   | 27.1±0.0   |
| Air changes per hour (ACH) | 9          | 9          | 9          | 7.9        |
| The whole cycle NOMINAL | 1.7        | 1.7        | 1.7        | 1.5        |
| Actual | 1.66±0.53  | 1.64±0.38  | 1.78±0.49  | 1.48±0.30  |
| Duty period NOMINAL | 2.21       | 2.21       | 2.21       | 1.7        |
| Actual | 2.07±0.29  | 1.99±0.13  | 2.21±0.27  | 1.75±0.15  |
| Idle period NOMINAL | 1.36       | 1.36       | 1.36       | 1.36       |
| Actual | 1.25±0.11  | 1.30±0.12  | 1.35±0.10  | 1.21±0.07  |
| Cycle time (min) | 5          | 5          | 2          | 2          |

2.6. Data analysis

A statistical analysis was carried out using IBM SPSS software version 2017. The normality of the data was tested with the Shapiro-Wilk test. The paired t-test and repeated measures analysis of variance were applied for normally distributed data, while differences among non-normally distributed data were assessed by the Mann-Whitney test. The results were considered statistically significant when p < 0.05.
3. Results and discussion

3.1. Data analysis results

The statistical tests showed that all the data did not comply with the normal distribution. Thus, the differences among these data were tested by the Mann-Whitney test. The statistical results tested were listed in Table 3.

Table 3. Statistical results on the effects of gender on thermal sensation, draft sensation and thermal comfort

| Case | Number of subjects | A | B | C | D |
|------|--------------------|---|---|---|---|
| Gender | Female | Male | Female | Male | Female | Male | Female | Male |
|       | 15 | 10 | 15 | 10 | 15 | 10 | 15 | 10 |
| Thermal sensation |          | P=0.2877 | Not significant | P=0.0118 | Significant | P=0.0086 | Significant | P=0.3 | Not significant |
| Draft sensation |          | p=0.379 | Not significant | p=0.687 | Not significant | p=0.725 | Not significant | p=1 | Not significant |
| Thermal comfort |          | p=0.254 | Not significant | p=0.71 | Not significant | p=0.528 | Not significant | p=0.234 | Not significant |

3.2. Thermal sensation

The difference of thermal sensation between males and females was statistically insignificant for Case A and Case D (p>0.05), while the difference was statistically significant for Case B and Case C (p<0.05). This can be attributed to the physical and psychological factors of the person. In different cases, people will have different physical and psychological states, and this change may eliminate the difference between genders. The most likely effect is the pulsating airflow. Compared with Case A and C, the longer the cycle time, the more the difference can be eliminated. According to Alan Kabanshi [13], it took about certain time for a human thermal plume profile to fully form or to be fully distorted from the time the inlets are switched on and off respectively. For the cycle time of 2 min, thermal plume is always in the process of form and distortion, because of the effect of thermal plume, the time for subjects were fully exposed to pulsating airflow is short, which lead to the obvious difference. When exposed to the cycle time of 5 min, the subjects were fully exposed to the supply airflow and the difference was insignificant.

3.3. Draft sensation

The Mann-Whitney tests showed no significant difference of draft sensation on the males and females for the four cases (P > 0.05) (Table 3). Fanger el. [11] studied draft risk under three kinds of turbulence...
intensity and six mean air velocities ranging from 0.05m/s to 0.4m/s. It was found that the females seemed to be slightly more draught-sensitive than the males at lower velocities, while this difference disappeared at higher velocities. Compared to this study, because of the high velocity in the duty time, combined with the possible impact on draft sensation in the idle time, the difference between genders was not statistically significant. As shown in Figure 4, for Case A, the percentage of subjects felt draft was the highest; the percentages of females and males felt draft were 17% and 10%, respectively. For Case D, the percentage of subjects felt draft was the lowest; the percentages of females and males felt draft were 7% and 6%, respectively.

3.4. Thermal comfort

Figure 5 shows the votes of overall thermal comfort for all the four cases. For Case A, the percentages of females and males who felt comfortable are 95% and 98% respectively. The effect of the gender on overall thermal comfort was insignificant (P = 0.254). The same statistical test results were also found for the other three cases (see Table 3). That might be considered somewhat surprising, however, it underscore the fact that genders had no obvious difference in thermal comfort when exposed to pulsating dynamic, so the influence of gender can be ignored under such a ventilation system or other similar ventilation system. Among these four cases, the interesting results were found for Case B. About 21% of females felt uncomfortable while none of males felt uncomfortable. Tanya Chcudhuri el. [12] founded that although the males were sensitive yet they were tolerant of the thermal conditions. In Case B, a part of males had a “cool or warm” sensation and 8% of males suffer draft, but all of them felt comfortable.
which showed good tolerance to thermal environment. In other cases, the proportion of males who were uncomfortable was also small. In addition, for all the cases, more than 80% of subjects voted thermal comfort as comfortable. This showed that the thermal environments produced by stratum ventilation with pulsating air supply were acceptable. This verified that the velocity variation can improve thermal comfort [5].

4. Conclusion

In this study, both males and females were exposed to indoor environment served by stratum ventilation with pulsating air supply. Based on the collected data, the significant differences of genders on thermal sensation were founded for Case B and Case C. The differences on draft sensation and thermal comfort between genders is statistically insignificant. The longer cycle time will eliminate the difference on thermal sensation between genders. The difference on draft sensation disappeared at high velocity. Males show good tolerance to thermal environment. For all the cases, more than 80% of subjects voted thermal comfort as comfortable which shows that the thermal environments produced by stratum ventilation with pulsating air supply were acceptable. Since there is no significant gender difference, it is unnecessary to consider the gender factor in the design of such a ventilation system.

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