Evaluation of task air conditioning system with convection, conduction, and radiation

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SUMMARY
In this study, a subjective experiment was conducted to evaluate thermal sensation and comfort, and usage of newly developed task conditioning system in different ambient temperatures. Gender differences were shown in task usage, and individual differences were significant at higher ambient temperatures. Data of how one uses task conditioning are crucial under practical use and when evaluating overall energy conservation, considering both task and ambient conditioning systems.

KEYWORDS
task usage, individual controlling, gender differences, steady rate, non-steady rate

1 INTRODUCTION
Diversity in the working style of office workers and thermal constitution has becomes more conspicuous in recent years, causing diversity in thermal sensation and comfort. Task ambient conditioning systems are being recognized as a technology to improve the thermal comfort of office workers. In this study, a newly developed task conditioning system named “task desk” was used. The purpose of this study is to evaluate how the task desk is used under different ambient conditions and to evaluate thermal comfort.

2 MATERIALS/METHODS

2.1 Task Desk
Figure 1 shows the image of task desk. Task desk is installed with three different types of personal conditioning systems (PCSs), depending on different modes of heat transfer: convective, conductive, and radiative. All of the PCSs are cooled by water at 16 °C, which is supplied by pipes connected to each desk.
A. Convective PCS
Two fans are installed in the front screen. The ambient air is induced by the inlet port and cooled by the cooling coils, which are cooled by cooling water. The cooled air is then supplied to the user by the outlet port. This PCS cools the user by the cooled air, which is expected to hit the upper body. Users can choose the three levels of air capacity supplied: OFF/Weak/Strong. At the Weak level, the cooled air hits the users’ arms, and at the Strong level, it hits the head and chest. Users cannot choose the temperature of the supplied air.

B. Conductive PCS
A cooling panel is installed on top of the desk surface, and the cooling water is directly supplied to the panel. This PCS is expected to cool the users by convective heat transfer when contact between the cooling panel and users’ arms occurs. Users can either choose ON/OFF of this PCS by the water supply and cannot change the surface panel temperature.

C. Radiative PCS
The same cooling panel used in the conductive PCS is installed under the desk surface, and it is expected to cool the users’ thighs by radiation. Users can either choose ON/OFF of this PCS and cannot change the surface panel temperature.

Figure 1. Image of Task Desk and each PCS installed.

2.2 Subjective Experiment
A subjective experiment was conducted to evaluate thermal comfort and task usage of each PCS under three different ambient temperatures: 26 °C, 28 °C, and 30 °C. This experiment was conducted in a research laboratory where a radiant conditioning system was used as the ambient conditioning system. In this room, both water and air supplied radiant cooling panels are used. Heating elements are set to simulate an office room. Figure 2 shows the image of the research laboratory and the location of the desks.

Figure 2. Image of the research laboratory and desk locations.
In this experiment, eight males and seven females in their twenties were chosen. The clothing level was 0.48 clo for males and 0.44 clo for females, which are normal clothing levels for office workers during summer in Japan.

Table 1 shows the measurement items. Measuring of ambient environment and the verification of the task desk was conducted to verify if the PCSs were at the temperatures shown in Figure A, and the ambient temperatures were controlled through the experiment.

<table>
<thead>
<tr>
<th>Measurement items</th>
<th>Location</th>
<th>No. of points</th>
<th>Measuring interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temp., humidity (°C, %)</td>
<td>1.1 m above floor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air temp. of convective PCS (inlet) (°C)</td>
<td>Inlet of fan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air temp. of convective PCS (outlet) (°C)</td>
<td>Outlet of fan</td>
<td>1</td>
<td>1 min</td>
</tr>
<tr>
<td>Surface temp. of conductive PCS (°C)</td>
<td>Panel surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface temp. of radiative PCS (°C)</td>
<td>Panel surface</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Before the experiment was performed, a questionnaire about gender, likes/dislikes of air conditioning, and body condition was distributed to each subject. First, a step exercise that was to simulate a 15-min walk at 2.0 met, was conducted in an outside air chamber, which was set at 30 °C. This step exercise was to simulate a situation where an office worker returns from a hot outdoor environment during summer. Then, the subjects were to enter the research laboratory and answer the questionnaire about their thermal sensation and comfort. The experiment began with all of the PCSs set at OFF. Subjects were allowed to arrange the PCSs once every 15 min and to report how they were arranged. Thermal sensation and comfort were reported at 1, 3, 6, 9, 12, 15, 30, 45, 60, 75, and 90 min after the experiment started. After the experiment, subjects were asked to answer the questionnaire about the PCSs. Data in the 0–30 min range were analyzed as data in the “non-steady rate”, indicating that the metabolic rate was not stable, and that in the 45–90 min range were analyzed as data in the “steady rate.”

3 RESULTS

3.1 PCS Usage

Figure 3 shows the percentage of PCS usage in different ambient temperatures. The upper graphs show the PCS usage of males, and the lower graphs show the PCS usage of females.

![Figure 3. PCS usage at different ambient temperatures (Upper: male, Lower: female) (n=15).](image-url)
A. Differences between ambient temperatures
When the ambient temperature was 30 °C, the PCS usage of the convective PCS was 100 %, both for males and females. The usage of the radiative PCS was almost 100 % for both genders, both in steady and non-steady rate. All of the subjects used the PCS more at 30 °C, compared to 28 °C and 26 °C. Thus, this can prove PCSs are needed for many subjects to improve their thermal sensation and comfort.

When the ambient temperature was 28 °C, the usage of the convective PCS was 100 % for males in steady rate. The usage of the conductive PCS was higher for males, which was approximately double that of females. When the ambient temperature was 26 °C, the usage of the convective PCS for females dramatically dropped in steady rate. The usage of the PCS dropped for both genders when the ambient temperature was lower; however, the male used the convective and conductive PCS more as compared to females.

B. Differences between PCSs
For all ambient temperatures, the usage of the convective PCS was higher for males compared to females, and the usage of the convective PCS (Strong) dropped at 26 °C. The usage of the conductive PCS significantly dropped for females in steady rate. The usage of the radiative PCS was higher compared to other PCSs in all conditions, and there were no significant drops for females as seen in the usage of other PCSs. This proved that convective and conductive PCSs were able to improve thermal sensation and comfort more quickly as compared to radiative PCSs.

3.2 Thermal Sensation and Comfort
Table 2 shows the scale of thermal sensation and comfort, Figure 4 shows the average changes in thermal sensation and comfort, and Figure 5 shows the percentage change in thermal sensation and comfort.

<table>
<thead>
<tr>
<th>Value</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal sensation</td>
<td>Very cold</td>
<td>Cold</td>
<td>Slightly cold</td>
<td>Neutral</td>
</tr>
<tr>
<td>Thermal comfort</td>
<td>Very uncomfortable</td>
<td>Uncomfortable</td>
<td>Slightly uncomfortable</td>
<td>Neutral</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value</th>
<th>+1</th>
<th>+2</th>
<th>+3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal sensation</td>
<td>Slightly hot</td>
<td>Hot</td>
<td>Very hot</td>
</tr>
<tr>
<td>Thermal comfort</td>
<td>Slightly comfortable</td>
<td>Comfortable</td>
<td>Very comfortable</td>
</tr>
</tbody>
</table>

Figure 4. Average changes in thermal sensation and comfort.
In this experiment, the scale shown in Table 2 was used to analyze thermal sensation and comfort. For thermal sensation, “Very cold” and “Cold” were regarded as “Cold side,” where “Slightly cold,” “Neutral,” and “Slightly hot” were “Neutral side,” and “Hot” and “Very hot” were “Hot side.” For thermal comfort, “Very uncomfortable” and “Uncomfortable” were regarded as “Uncomfortable side,” whereas “Slightly uncomfortable,” “Neutral,” and “Slightly comfortable” were “Neutral side,” and “Comfortable” and “Very comfortable” were “Comfortable side.”

On an average, there were no significant differences between ambient temperatures in average thermal sensation and comfort in steady rate, as shown in Figure 4. Thermal sensation was approximately neutral in ambient temperature at 30 °C and 28 °C, and slightly cold at 26 °C. Thermal comfort improved throughout the experiment for all ambient temperatures, scoring approximately +1.

However, there were differences in the percentage change of thermal sensation and comfort, as shown in Figure 5. When the ambient temperature was 30 °C, there were approximately 10% of “Hot side” in steady rate, whereas 0% at 28 °C and 26 °C. In addition, there were 50–75% of “Comfortable side” at 30 °C, whereas 65–90% at 28 °C and 26 °C. This proves that the use of the PCSs can improve one’s thermal sensation and comfort at 30 °C; however, it cannot reach to the same level as when the temperature is 28 °C or 26 °C. Regarding Figure 3, many subjects did not use PCSs at 26 °C. However, though thermal comfort still scores approximately the same or higher level at 28 °C. This proves that using PCSs at 28 °C can improve one’s thermal sensation and comfort to the same or higher level as when PCSs are not used at 26 °C.

As shown in Figures 4 and 5, by using PCSs at 30 °C, the average thermal comfort can score the same or higher level as that at 28 °C and 26 °C; however, the percentage of each side varied. Thus, it can be estimated that individual differences were significant at higher ambient temperatures, and there were a certain number of subjects feeling hot and uncomfortable at steady rate.
3.3 Opinions on PCSs

Figure 6 shows the opinions on which PCS had the most cooling effect and which was the most favorable.

The conductive PCS was reported as having the highest cooling effect among all PCSs. In addition, more subjects favored convective PCS at higher ambient temperatures. The opposite trend was shown for convective PCS, where more subjects favored the PCS at lower ambient temperatures. Few answered the radiative PCS as having most cooling effect, thus only a few answered they favoured. It can be guessed that many subjects could not feel a large cooling effect because of the position of the panel. The thighs are covered with clothes which made it difficult for subjects to feel the cooling. By several subjects, it was reported that they were not satisfied with the radiative PCS because of the small cooling effect.

4 DISCUSSION

The results show that the way subjects arrange each PCS varies between genders. Each subject arranged the PCS to improve their thermal sensation and comfort, and in average, achieved same level of comfort regardless of ambient temperatures. However, it was shown that the use of PCS at 30 °C cannot prevent all of the subjects from feeling hot.

5 CONCLUSIONS

In this study, we evaluated thermal sensation and comfort and the task usage of PCSs. There were differences between genders on how and which PCS is used. In addition, individual differences about thermal sensation and comfort were significant under higher ambient temperatures. How task conditioning systems are used is dependent on the individuals, and knowing how these are used is an important information when operating, and saving the total energy consumption. In this study, variation between genders were shown however, further studies about the differentiation within genders are needed for optical operation.

6 REFERENCES

