ABSTRACT

It is difficult to satisfy all workers in an office with respect to thermal comfort by a total air conditioning system. An individually controlled system that can create a preferable thermal environment for each occupant is therefore needed. In the present study, a chair incorporating two fans under the seat and behind the backrest of the chair to provide isothermal forced airflow to the occupant was developed. Experiments were conducted in a climate chamber during summer. Seven healthy college students participated as subjects. The occupant was allowed to freely control the two built-in fans by adjusting dials on the occupant’s desk. The room air temperatures were set at 26°C, 28°C, 30°C, and 32°C. At a room air temperature of 28°C, the whole-body thermal sensations were near thermally neutral, regardless of the type of chair. At a room air temperature of 30°C, the occupants were able to create acceptable thermal environments from the viewpoints of whole-body thermal sensation and acceptability by using the chairs with fans. At a room air temperature of 32°C, the chairs tested in the present study were not able to provide acceptable thermal environments.

KEYWORDS

Chair, Task/Ambient conditioning, Isothermal Airflow, Thermal Comfort, Individually Controlled System

INTRODUCTION

Heating, ventilating, and air-conditioning of buildings are currently designed so as to provide a uniform thermal environment. However, large individual differences in physiological and psychological responses, clothing insulation, activity, air temperature preference, and air movement exist between individuals (Melikov 2004). Environmental conditions acceptable for most occupants in buildings may be achieved by providing each occupant with the possibility of creating and controlling his/her own microenvironment. An individually controlled microenvironment providing local heating/cooling of the body has the potential to satisfy more occupants of a space compared to a centrally controlled total volume environment (Melikov et al. 1998, Tsuzuki et al. 1999, Akimoto et al. 2003). In addition to the thermal effect of the individually controlled system, Bauman et al. (1998) indicated that the satisfaction of occupants increases when they are provided with individual control.

A number of studies have examined the development of task/ambient HVAC systems. Bauman et al. (1993) categorized task conditioning systems into three types: floor-based, desk-based, and partition-based. Floor-based task conditioning systems have been developed and evaluated by Spoormaker (1990), Sodec and Craig (1990), Li et al. (1994), and Bauman et al. (1995). With regard to the desk-based task conditioning systems, several types of task units and systems have been developed (Arens et al. 1991, Bauman et al. 1993, Loomans 1999, Levi 2002, Bolashikov et al. 2003, Lee et al. 2004, Hayashi et al. 2004, Song et al. 2004, Knudsen and Melikov 2005). The partition-based task conditioning systems have been reported by Imagawa and Mima 1991, and Sasaki et al. 2004. Recently, Nobe et al. (2004) developed a chair-mounted isothermal airflow generator system and evaluated the cooling performance through human-subject experiments.

† Corresponding Author: Tel: + 81-52-612-5571, Fax: + 81-52-612-5953
E-mail address: nabeshi@daido-it.ac.jp
Knudsen and Melikov (2005) developed and tested an individually controlled system (ICS) consisting of a personalized ventilation system, an under-desk air terminal device supplying cool air toward the front of the body, a chair with a convectively heated backrest, an under-desk radiant heating panel, and a floor radiant heating panel. Watanabe et al. (2005) conducted experiments using a thermal manikin to evaluate the performance of the individually controlled system developed by Knudsen and Melikov (2005) described above and reported that the chair that incorporated heaters and fans had the largest heating effect among the local heating components. The objective of the present study is to clarify through subjective experiments the cooling effect of a chair incorporating fans that generate an isothermal airflow toward an occupant.

METHODS

Subjective experiments were conducted in an artificial climate chamber with dimensions of 4.2 × 3.2 × 2.3 at Daido Institute of Technology from August 31 to October 3 in 2006. An office room with two identical workstations was simulated in the chamber (Figure 1). Two office chairs were redesigned to provide cooling to occupants (Figure 2). The seating face and the backrest of the chair were made of an open fabric through which air can flow. Two fans were installed under the seating face and behind the backrest of each chair. Two fans having diameters of 110 mm (maximum airflow rate of 31.9 L/s at 100 V) were installed in Chair A, and two fans with diameters of 75 mm (maximum airflow rate of 4.8 L/s at 100 V) were installed in Chair B. The airflow rates of the fans installed in the chairs were controlled separately by changing the voltage of a power transformer attached to the desk. All fans were installed such that the airflow faced the occupant through the open fabric of the chair.

Seven healthy college-age males participated in subjective experiments. The room air temperatures were set to 26°C, 28°C, 30°C, and 32°C, and the averages of the measured values were 25.9°C (SD 0.1), 27.9°C (SD 0.1), 29.9°C (SD 0.2), and 31.8°C (SD 0.2), respectively. The mean radiant temperature was approximately equal to the room air temperature, and the relative humidity was set at 50% (the average of the measured values was 48.7% with SD 2.4). The air in the chamber was still. At a room air temperature of 28°C, 30°C, and 32°C, subjective experiments with Chair A and Chair B were performed in order to evaluate their performance characteristics. At room air temperatures of 26°C, 28°C, 30°C, and 32°C, experiments using a normal chair (fans were not operated) were conducted as a reference. All subjects participated in a practical session to master control of the fans before the experiments. The subjects remained in the anteroom at an air temperature of 26.3°C (SD 1.2) and RH 55.5% (SD 6.4) and performed light work activities (e.g., reading books) in a sedentary posture for 30 minutes before entering the test room. In the test room, the subjects were requested to perform office...
task such as word processing and numerical manipulation. During the exposure time in the chamber, the subjects were required to fill out questionnaires every 10 minutes. The subjects were allowed to freely control two fans attached to the chair by adjusting dials on the desk. All of the subjects were dressed in summer clothing with thermal insulation of 0.63 clo.

The questionnaires consisted of the items of thermal sensation (+3: hot, +2: warm, +1: slightly warm, 0: neutral, -1: slightly cool, -2: cool, -3: cold), comfort sensation (+2: comfortable, +1: slightly comfortable, 0: neither comfortable nor uncomfortable, -1: slightly uncomfortable, -2: uncomfortable), and acceptability (1: acceptable, 0: unacceptable) for the whole body. In addition to the whole-body sensations, thermal sensation, comfort sensation, and airflow feeling of individual body parts (head, back, lower back, legs + feet, and hands + arms) were also included in the questionnaire. The physical environmental conditions of the test chamber were measured using an Assmann aspiration psychrometer and a globe thermometer. The surface temperatures of the floor, ceiling, and walls of the chamber were measured automatically every 30 seconds by T-type thermocouples, and voltages were recorded every 30 seconds to monitor the airflow rates from the fans controlled by the subjects.

RESULTS

Changes in mean whole-body thermal sensation with time are shown in Figure 3. At a room air temperature of 26°C, the subjects reported their thermal environment as ranging for slightly cool to thermally neutral during exposure. At a room air temperature of 28°C, the subjects reported their thermal environment as ranging from thermally neutral to slightly warm during exposure. The mean thermal sensations under all chair conditions shifted toward thermally neutral upon final assessment. At a room air temperature of 30°C, the subjects reported their environment to be warm when using the normal chair. In contrast, the subjects reported their environment to range from thermally neutral to slightly warm when using Chair A, which had larger fans. The greatest cooling effect of the chair with respect to the improvement of the whole-body thermal sensation occurred at a room air temperature of 30°C. At a room air temperature of 32°C, the thermal sensation was improved by using Chair A, but the subjects evaluated their thermal environment to range from warm to hot.

DISCUSSION

The relationship between room air temperature and whole-body mean thermal sensation upon final assessment is shown in Figure 4. At a room air temperature of 30°C, the subjects reported their thermal

![Figure 3](image-url) Changes of mean thermal sensation with the passage of time at room air temperatures of 26°C, 30°C, and 32°C. Normal Chair plots represent no control by the subject. Chair A has larger fans with free control by the subject, and Chair B has smaller fans with free control by the subject.
environment to be warm when they used the normal office chair, which had no fan controls. However, subjects assessed the environment to be thermally neutral to slightly warm when they used Chair A, which had two larger fans. This result indicates that whole-body thermal sensation can be improved greatly by using Chair A at a room air temperature of 30°C. The improvement of the whole-body thermal sensation as a result of using Chair A was also confirmed at a room air temperature of 32°C. However, since the subjects assessed the condition as warm, at a room air temperature of 32°C, it is not realistic to apply Chairs A and B to create a comfortable environment. At a room air temperature of 28°C, the whole-body thermal sensations were approximately thermally neutral, regardless of the type of chair. The improvements of the whole-body thermal sensation by Chairs A and B were not remarkable at 28°C.

The percentage of unacceptability for each chair condition is shown in Figure 5. According to ASHRAE Standard 55-1992, the acceptable thermal environment is defined as an environment that at least 80% of the occupants find thermally acceptable. In the present study, unacceptability represents the percentage of questionnaires in which the subjects reported the environment to be unacceptable. At a room air temperature of 28°C, the percentages of unacceptability were quite low: 8.2% for the normal chair, 2.0% for Chair A, and 2.0% for Chair B. At a room air temperature of 30°C, the percentages of unacceptability for the normal chair, Chair A, and Chair B were 24.5%, 8.2%, and 14.3%, respectively.

![Figure 4](image-url)

**Figure 4**  Relationship between room air temperature and whole-body mean thermal sensation upon final assessment.

![Figure 5](image-url)

**Figure 5**  Percentages of unacceptability for each chair condition at room air temperatures of 26°C, 28°C, 30°C, and 32°C.
Therefore, the subjects could create acceptable thermal environments by using Chair A or Chair B at a room air temperature of 30°C. At a room air temperature of 32°C, the use of fans improves the unacceptability of occupants. However, the percentages of unacceptability remained quite high at 57.1% for the normal chair, 32.7% for Chair A, and 42.9% for Chair B. Local discomfort rates at each body part are shown in Figure 6. This graph shows that the local discomfort rates at the back and the lower back, which the isothermal airflow directly affected, decreased greatly when using Chair A. Furthermore, the local discomfort rates at the head, hands+arms, and legs+feet improved slightly when using Chair A, although these body parts were not directly affected by the airflow from the fans. Analysis of the local airflow sensation data at the head, hands + arms, and legs + feet, revealed that the subjects felt an airflow on these body parts. However, the local discomfort rates at the head and hands + arms were relatively high at room air temperatures of 28°C to 32°C. Additional local systems to cool the head, the arms, and the hands of seated occupants are needed in order to provide a more comfortable environment.

CONCLUSIONS
Subjective experiments were conducted for the purpose of clarifying the performance of chairs that incorporated two fans in order to generate an isothermal airflow toward a seated occupant. At room an air temperature of 28°C, the whole-body thermal sensations were approximately thermally neutral, regardless of the type of chair. At a room air temperature of 30°C, the occupants were able to create acceptable thermal environments with respect to whole-body thermal sensation and acceptability by using the chairs with fans. At a room air temperature of 32°C, the chairs tested in the present study were not able to provide an acceptable thermal environment for the seated occupants. At 30°C, local discomfort rates at the back and lower back, which were affected by isothermal airflows, were greatly improved.

REFERENCES