The effect of temperature and air velocity change on human sensation

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ABSTRACT

This report is a part of a study to search whether comfort conditions can be attained by local airflow. In the present experiment, local airflow was directed to two locations of subjects' body and its effect was examined on which location percepts the airflow more strongly, responds physiologically more sensitively and feels more comfortable. The laboratory air temperature was set in a range of 26–28°C. This experiment was held in summer seasons at Toyohashi, Japan. Fifty-four male and female subjects were exposed to airflows of different temperatures or velocities directed to the back of the neck and the left ankle. The nozzles of the airflow were located at a distance of 0.4 m from the subject surfaces. In one of the experiment, the air velocity was kept at 0.5 m/s and its temperature was changed to have differences of –10, –5, 0, +5 and +10°C from the laboratory ambient air temperature. In the other experiment, the velocity of the airflow was changed at 0.00, 0.25, 0.50, 0.75 and 1.00 m/s, while its temperature was the same as that of the ambient temperature. In the former experiment, the temperature was changed from the lower to the upper temperatures or vice versa with an interval of 15 min. In the latter experiment, the velocity was raised or reduced. The subjects judged the effect of the airflow by voting in the questionnaire of semantic differential forms.

The results indicated that the necks were more sensitive than the ankles for the temperature change and air velocity change. The votes showed that the higher temperature airflow was more comfortable than the lower temperature airflow at the both locations. The necks felt more comfortably for the slow airflows, while the ankles were more comfortable at the fast airflows. The percentage of dissatisfied at the necks were smaller than the ankles.

INDEX TERMS

Local airflow; Natural convection; Sensation; Perception; Thermal comfort

INTRODUCTION

Air movement seems to generate comfortable and acceptable conditions in an air-conditioned space in summer for the majority of the people in temperate and tropical areas. This suggests that we will be able to maintain comfortable sensation with a combination of a higher temperature and a higher airflow than with the conditions that are suggested for people in colder areas by the ASHRAE or ISO standards. The ASHRAE or ISO standard indicates the higher airflow to be disagreeable for people in colder areas. Besides, it will be normal to consume more energy to maintain comfort with a lower temperature and a lower velocity than with a higher temperature and a higher velocity in a tropical climate. Further, it is more practical to send air to such a location where it is sensitive but not disturbed by the airflow than to a whole body.

Actually, a human body is enveloped by a natural convection boundary layer in a room (Fiedorowicz, 1975; Homma, 1988). A forced airflow of air-conditioning should travel across this layer before it reaches and stimulates a body surface. The strength of the natural convection is not equal over a body surface. So the stimulation by certain airflow is not equal

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over the body surface (Homma, 2001). Therefore, to find out a better location to stimulate, the mechanism of sensation caused by local airflow should be divided into two stages. The first stage is physical stimulation of a body surface by the airflow. The second stage includes physiological perception of the airflow at the surface and initiation of sensation from the perception. Most of the existing studies attempted to establish a psychophysical law that combined the physical stimulus and psychological sensation. Therefore, in the present study, a higher velocity air was directed to the back of necks and the ankles through the natural convection boundary layer, and we examined which part of the body surface feels comfort more effectively. If such allocation is found, airflow of air-conditioning can be concentrated to this location. The result from the summer of 2001 and 2002 is reported here.

METHODS

Arrangement

This experiment was carried out in the climate chamber of Building Environment Laboratory, Toyohashi University of Technology (TUT), Japan, in the summer seasons from July to August of 2001 and 2002. Four different conditions in temperature and air velocity were investigated. In the two conditions of temperature, the temperature of local airflow was changed by a step of 5°C while the air velocity was kept at 0.5 m/s. In one of them, the temperature was changed from lower to higher. The tested temperature differences from the laboratory temperature were –10, –5, 0, +5 and +10°C from the laboratory temperature. It was labelled as tuvc. When the temperature changed was opposed, it was labelled as tdvc. In the velocity change experiments, velocities of the local airflow were changed from zero to 1 m/s or vice versa by a step of 0.25 m/s while its temperature was the same as that of the ambient temperature. In the velocity rise experiment, which was labelled tcvu, the local airflow velocity started from zero and ended at 1 m/s. In the velocity fall experiment, the velocity change schedule was opposed, and was labelled tcvd. The schedules of the experiments are shown in Figure 1.

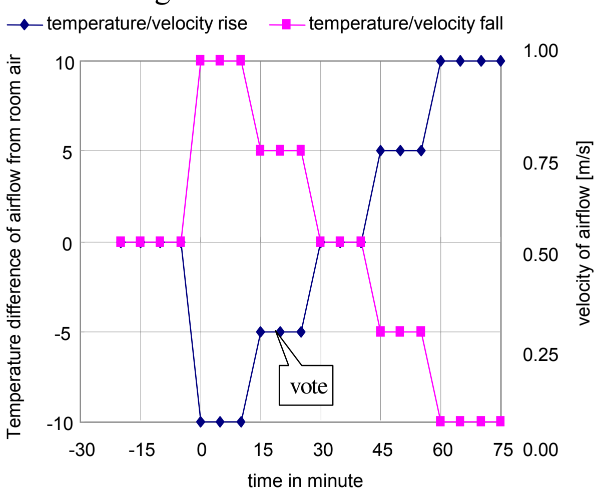


Figure 1 Schedules of temperature or velocity change and voting.

Figure 2 Experimental arrangement in the chamber.

The laboratory was thermally well insulated from the outdoor temperature change. The temperature was controlled between 26 and 28°C. The relative humidity was about 60% during the experiment. The temperature drift in an experiment of 95 min was less than 0.5°C. The temperature gradient between 0.1 and 1.1 m above floor was less than 0.3°C. The mean radiant temperature was same as the air temperature in the experimental spaces. The average outdoor temperature was 27°C. Temperature change of the airflow was completed in 5 min by supplying excessive power than what was required to hold a temperature difference in a steady state. The applied airflow had low turbulent intensity. The standard deviation of the airflow was 0.02 m/s when its velocity was 0.25 m/s at the nozzle face. It increased to 0.08 m/s when the face velocity was 1.00 m/s.

Procedure

Fifty-four TUT students (27 males and 27 females), in the age range of 18–24 years, were recruited and were paid for their participation. Each subject underwent the four types of the experiment. In summer 2001, 12 male and 12 female students participated. They were requested to wear usual cloths in the summer season with average thermal resistances of between 0.47 and 0.55 clo, respectively, for the males and females. In summer 2002, 15 male and 15 female students participated and they wore a uniform cloth with the average thermal resistance of 0.48 clo. During an experiment a subject sat sedentary in front of a desk and was allowed to read, see Figure 2. The first 20 min was allotted to acclimatize to the thermal conditions in the laboratory. During this period, the instructions for entry of the vote form were given. In the next 75 min, the subject was exposed to one of the above four conditions and asked to enter a questionnaire that had semantic questions on thermal sensation, perception of airflow and thermal comfort. It consisted of five consecutive 15-min periods of the step change of temperature or velocity. The subjects entered their vote three times in the 15 min, also see Figure 1. After the experiment, the entered semantics were converted into numerals to be treated statistically. The answers were later converted into the scale from –2 to +2.

One of the airflow producers was directed to the back of the neck horizontally. The other one was directed to the left side of the ankle also horizontally. The local airflow was blown from a nozzle of a diameter of 50 mm. The distance of the nozzle and the object location was adjusted to 0.4 m. The locations of the draft application were chosen because the natural convection by the body heat starts at the ankle level and it develops fully at the neck level. The base position of the neck measurement was chosen to the indent position on the back of the neck, while the ankle measurement was chosen at where the ankle protruded.

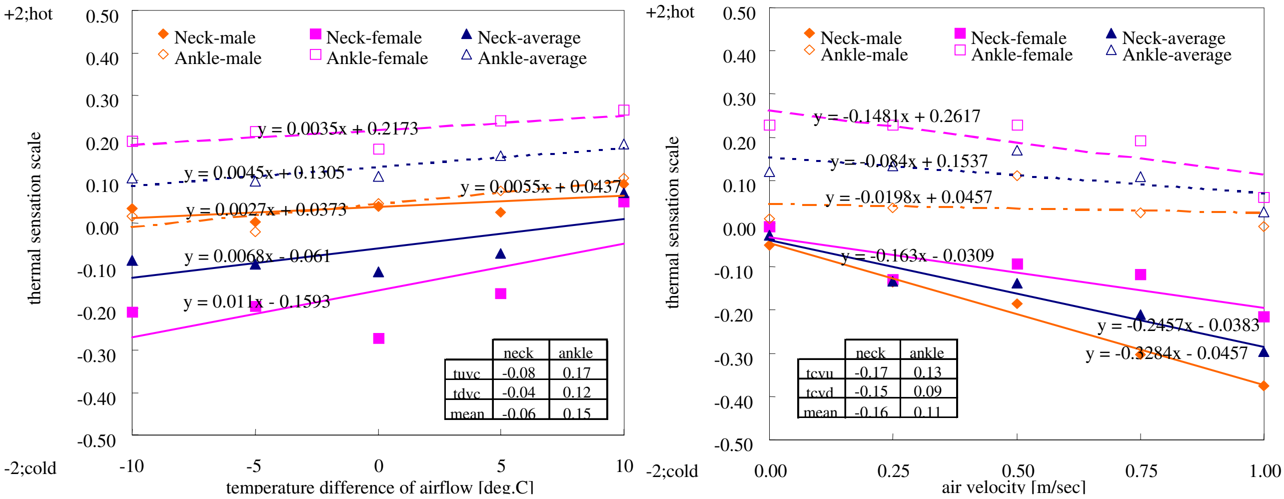
RESULTS

Thermal Sensation

Figure 3 indicates that most of the thermal sensation votes at the necks were lower than those of the ankles for the temperature and velocity changes. All of the lines for thermal sensation at the necks and the ankles increased with temperature. But it decreased with velocity. Figure 3(a) shows the results of the temperature change experiment. The sensation of the females was lower than the males at the necks, while at the ankles it was opposed for temperature change. At the low temperature airflow, the average of the neck votes was in a cool sensation. The votes increased with temperature rise, but it remained in a cool sensation even in the high temperature airflow. At the ankles, the average votes remained in a warm sensation throughout the airflow of all the temperature differences. The thermal sensation of females was higher than males for velocity change at both locations, as shown in Figure 3(b).

Velocity Perception

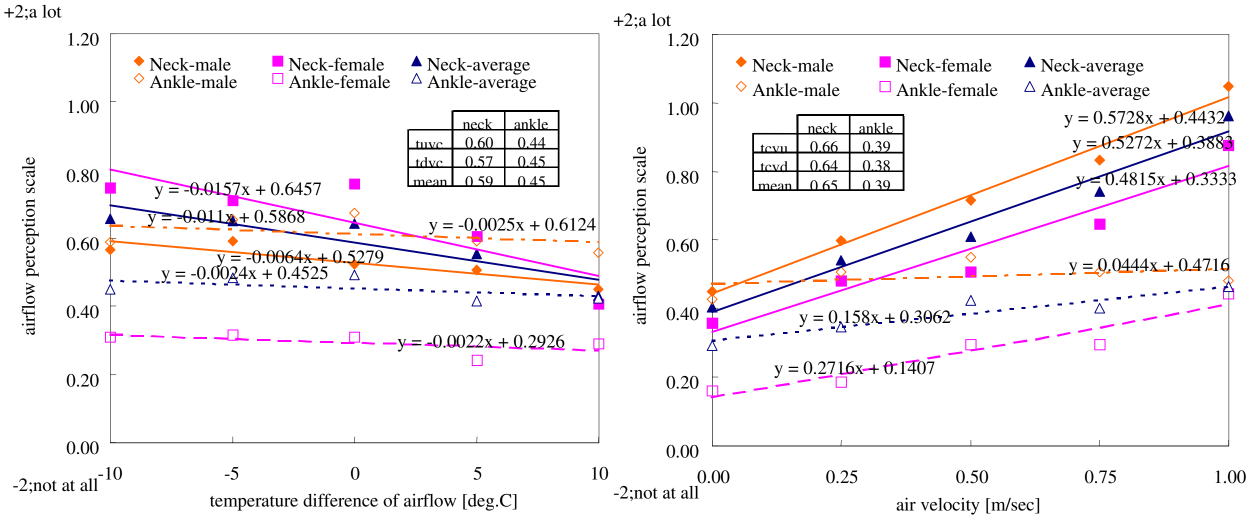
Figure 4 shows the perception of airflow by the females and males at the necks and the ankles in the temperature and velocity change experiments. The average votes of the airflow perception were more definite at the necks than at the ankles. The gradients of regression lines



(a) Temperature (b) Velocity

Figure 3 Thermal sensation votes by the temperature and air velocity changes.

of the necks and ankles were negative with temperature change, see Figure 4(a). The airflow perception of the females was higher than the males at the necks, while at the ankles it was the opposite. In Figure 4(b), the regression lines of the necks and ankles were positive with the velocity change. The regression lines increased more steeply at the necks than at the ankles. The airflow perception of the males was stronger than the females at the both locations.

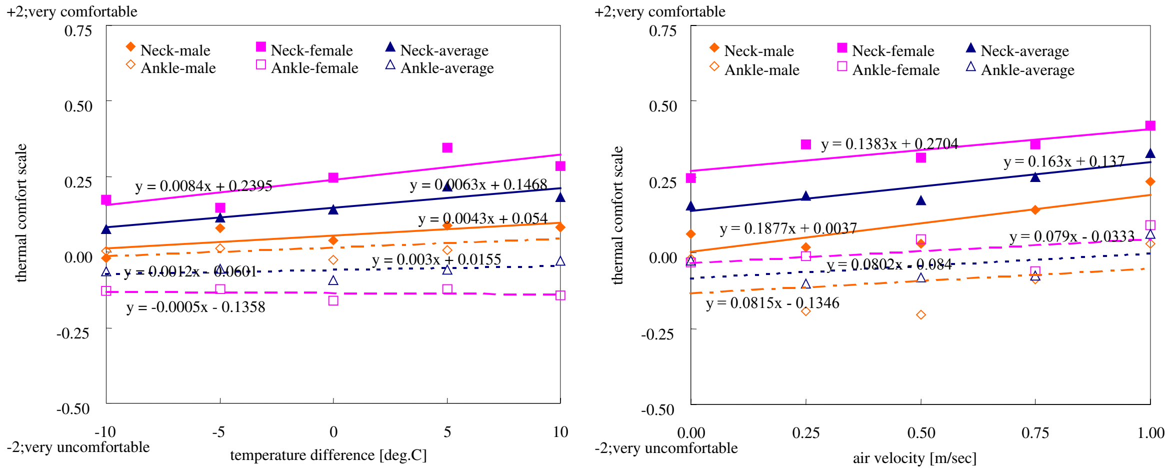


(a) Temperature (b) Velocity

Figure 4 Velocity perception votes by the temperature and air velocity changes.

Thermal Comfort

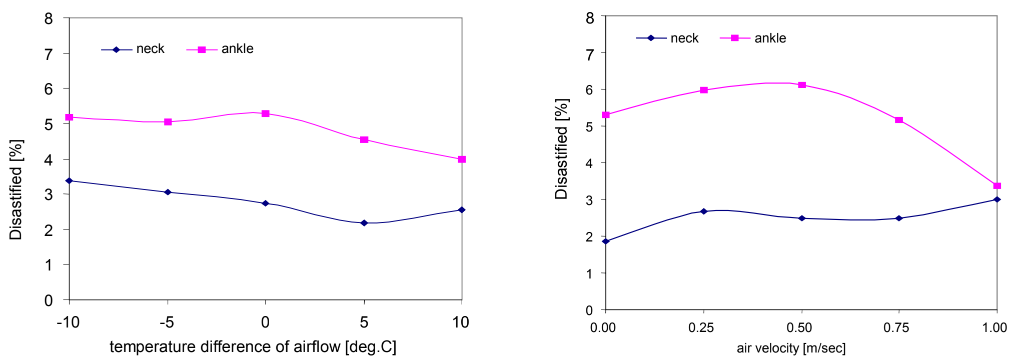
Most of the thermal comfort votes at the necks were more comfortable than those of the ankles for the temperature and the velocity change as shown in figure 5. All of the thermal comfort votes at the necks increased steeper than at the ankles by temperature difference, see figure 5 (a). The thermal comfort of the females felt more comfortably than the males at the necks, while it at the ankles was opposite. The average of thermal comfort vote increased with velocity at the necks and the ankles, see figure 5(b). The thermal comfort of the females was more comfortable than the males for the velocity change at both locations.



(a) Temperature (b) Velocity

Figure 5. Thermal Comfort Votes by the Temperature and Air Velocity Changes

The percentage of dissatisfied was calculated from the comfort votes. When an average vote was below –0.5 in the full scale of –2 to 2, this vote was assumed to be dissatisfied. Figure 6(a) shows the results in the temperature change experiment. The percentage of dissatisfied was in a range of 2–3% at the necks while it was 4–6% at the ankles. The range at the necks was lower than at the ankles. The necks felt the airflows more comfortably than the ankles through all temperature differences. But the higher temperature airflow was evaluated as more comfortable than the lower temperature airflow at both locations. Generally, the percentages of dissatisfied seemed to decrease as the temperature difference increased at both locations. Figure 6(b) shows that the percentages of dissatisfied increased with velocity at the necks, while at the ankles those decreased with velocity. And the percentages of dissatisfied of the two locations approached each other at the highest velocity. The necks responded more comfortably than the ankles for the slow airflows.

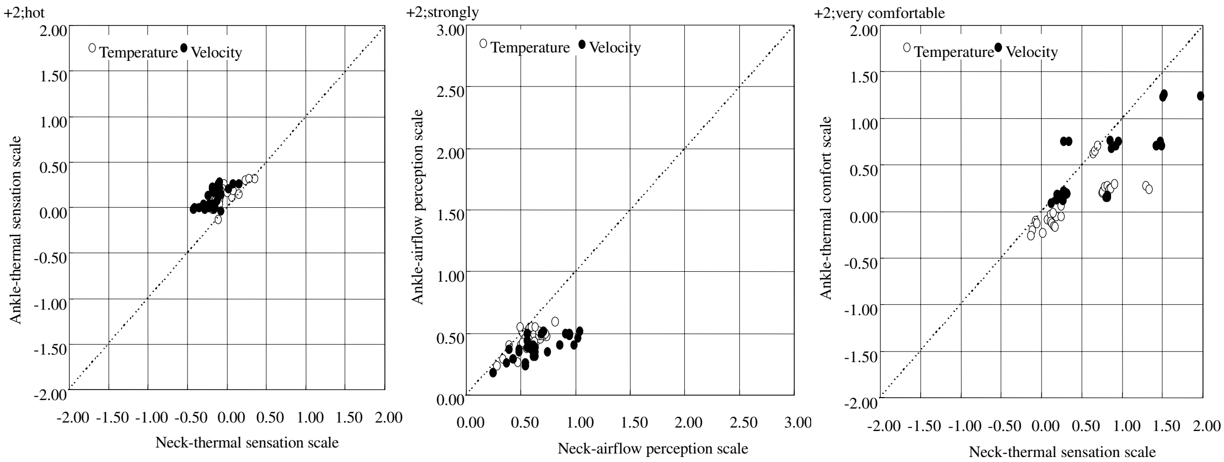


(a) Temperature (b) Velocity

Figure 6 Percentage of dissatisfied by the temperature and air velocity.

Comparison of Sensitivities of Necks and Ankles

The thermal sensation, velocity perception and thermal comfort at the two locations in the temperature and velocity change experiments are compared in Figure 7. Figure 7(a) shows that more marks were obtained in the second quadrant. This indicates that the back of neck perceived the airflow cooler than the ankles. The perceptions of airflow were stronger at the necks than at the ankles, as shown in Figure 7(b). This means that the necks were more sensitive than the ankle for the airflows. Figure 7(c) shows that many marks were obtained below the equal sensation line in the first quadrant. This indicates that the back of the neck felt the airflow more comfortably than the ankles.



(a) Thermal Sensation (b) Velocity Perception (c) Thermal Comfort

Figure 7 Comparison between neck and ankle in the temperature and velocity change.

DISCUSSION

The natural convection, which arises around a body by its metabolic heat, plays an important role in convection heat dissipation of the body in a room environment. The results of the present experiment showed the local airflow that, which penetrates through the natural convection boundary layer, caused the sensations of warmth or coolness and air motion. The thermal sensation, perception of airflow and thermal comfort were disturbed by the draft that had different temperatures and velocities. In the study of the convective heat transfer of a thermal manikin disturbed by local airflows by Homma (2001), it was indicated that the ankle was more strongly stimulated by the local airflows than the back of neck. Even if the physical result indicated so, the present experiment found that the psychological and physiological responses of a human body were different from it.

CONCLUSION AND IMPLICATIONS

The results of the present experiment showed that the thermal sensations and the airflow perceptions at the ankles were less sensitive than the necks for the stimulation of the temperature and the air velocity. This is clearly different from the several researches conducted in temperate or cold regions that indicate the neck perceives draft more tolerantly than the ankle (Gonzales and Nishi, 1976; Homma, 1988). The rise in temperature and air velocity increased thermal comfort at the necks and ankles. The necks felt the slow airflows more comfortably, while the ankles were more comfortable with the fast airflows. These may indicate that cool airflows should be limited to be directed to the back of the necks and the ankles. Also to keep the necks comfortable, airflow of high air velocity should be limited to deliver to the back of necks, but it should be blown to the ankles. The percentages of dissatisfied at the ankles were higher than the necks. The differences between the two locations may be caused partly by the natural convection and by the local difference in temperature and velocity perception.

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