The effects of direct and indirect airflow on thermal comfort

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ABSTRACT

A spot cooling system using the convective cooling effect of an air stream is known to be effective by its smothering intensive hot environment, supplying comfort sense and utilizing energy efficiently. However, its study on the interaction with human body or product itself is uncommon, showing that the spot cooling system intrinsically contains the possibility of draught because of its short emitting distance from the object, low air temperature, high air stream velocity and its direct local contact to human body. Therefore, the object of this study is to clarify the effects of the spot cooling system on the human body with detailed parts according to the room temperature, emitting air temperature to supply a more successful personal air conditioning system. The experiment was conducted in winter. The subjects (four young females) were exposed to the following conditions: combinations of air temperatures (T_a = 27, 30°C), discharge temperature (T_{dc} = 13°C) and relative humidity (RH = 50%).

INDEX TERMS

Localized airflow; Skin temperature; Thermal comfort vote; Thermal sensation vote; Airflow temperature

INTRODUCTION

A spot cooling system using the convective cooling effect of an air stream is known to be effective by its smothering intensive hot environment, supplying comfort sense and utilizing energy efficiently. However, its study on the interaction with human body or product itself is uncommon, showing that the spot cooling system intrinsically contains the possibility of draught because of its short emitting distance from the object, low air temperature, high air stream velocity and its direct local contact to human body. Moreover, most of the previous studies dealing with the problems of drought are confined to the case of low environmental temperature of 25°C, below which there is some deviation from the high emitting air temperature of the real air conditioners. Therefore, the object of this study is to clarify the effects of the spot cooling system on the human body with detailed parts according to the room temperature, emitting air temperature and humidity to supply a more successful personal air conditioning system.

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METHOD

The experiment was carried out using a climate chamber (W 6.9 m × 4.3 m) at LG Electronics. Figure 1 shows the plan of the climate chamber. We installed the window-type air-conditioner (WRAC: Modified Window Type Room Air-Conditioner) cooling system as the spot cooler. Figure 2 shows the landscape of the experiment. The subjects (four young women) were exposed to the following conditions: combinations of air temperature (T_a = 27, 30°C), discharge temperature (T_{dc} = 13°C) and relative humidity (RH = 50%) in still air with the air velocity less than 0.2 m/s. Table 1 shows the conditions of the experiment. Air temperature was measured at 315 points in the experimental room at four different levels (H = 0.1, 0.6, 1.1, 1.7 m), and the globe temperature was measured at the centre of the room (H = 0.6 m) by a globe thermometer of 15 cm diameter. Relative humidity was measured at five points by an electric motion assmann hygrometer. We also measured the inside wall and outside wall temperatures. To determine the physiological effects, the skin temperatures of the subjects were measured every 10 s at 12 points by cc thermocouples (Φ 0.1 mm). The mean skin

Table 1 Conditions of experiment

Environmental conditions	Ambient Temp.[•]	Discharge Temp.[•]	Air stream Direction	Globe Temp.[•]	Relative Humidity[%]	Air Velocity[•]
Pretest room Ta=30• , RH=50%	27	13	Head	26	50	2.0
	27	13	Over Head	28	50	

Table 2 Physical condition and characteristics of subjects

Subject	Age [yr.]	Height [cm]	Weight [kg]	As [m²]	BMI [kg/m²]
AVG.	22.75	163.38	56.25	1.69	19.9
STD.	± 1.89	± 7.82	± 6.29	± 0.09	± 1.60

Table 3 Time schedule of the experiment

Time [min.]	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60
Situation	Pretest room							Test room					
	Recess							Exposure (sitting on a chair)					
Votes	0	1	2	3	4	5	6,7	8	9	10	11	12	13
Skin temp.	(interval10 seconds, 7 points)												
Environmental temp.	(interval10 seconds, 315 points)												

Figure 1 Plan of the climate chamber.

temperature was calculated by the weighted mean formula at 12-points surface area by Hardy and DuBois (Hardy and DuBois, 1938). From 60 min before the experiment to 60 min after, the subjective psychological evaluation of the whole body and local body of subjects were described at 10-min intervals based on the traditional nine-point scale of thermal sensation votes (–4: very cold through +4: very hot), and the seven-point scale of thermal comfort votes (–3: very uncomfortable through +3: very comfortable). And we were evaluated the image scale of the airflow. Table 3 shows the time schedule of the experiment. The subjects were exposed to set conditions while sitting on a chair. The subjects, who were all females, were clothed in summer attire which we decided: T-shirts, short trousers, and their own panties and brassieres. The clothing insulation value was estimated about 0.5 clo. (Hanada *et al.*, 1981) The airflow apparatus was located 60 cm from the subject. Table 2 shows the physical condition and characteristics of the subjects. All subjects were paid for participating. The experiment was done December 2001.

RESULTS AND DISCUSSION

The following results were obtained:

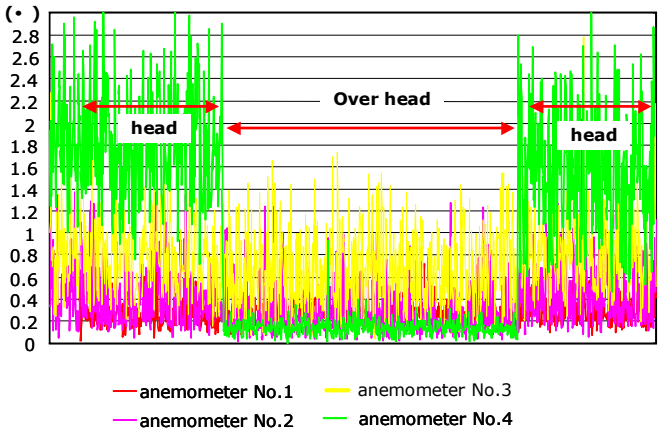

Figure 2 Air velocity.

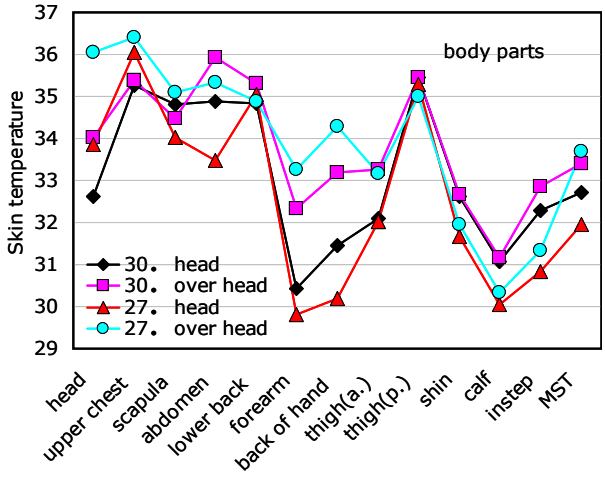

Figure 4 Changes in skin temperature with each condition.

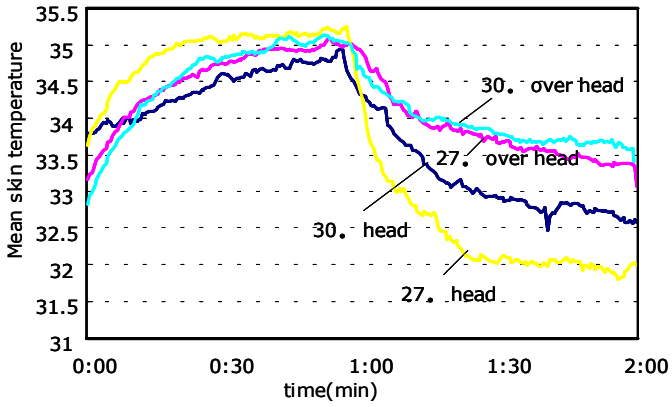

Figure 3 Changes in mean skin temperature.

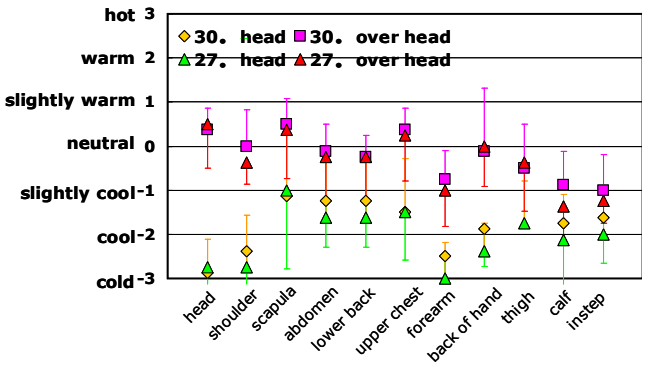

Figure 5 Changes in thermal sensation vote with each condition.

Figure 3 shows the changes in mean skin temperature with each condition. Generally, the mean skin temperature ranged from 33 to 34°C at overhead conditions. In the case of discharge temperature of 13°C the mean skin temperature of the head exposed to the air stream shows an abrupt drop to 32°C at T_a = 27°C.

Figure 3 shows the time dependency of the mean skin temperature for every given condition. In the case of indirect discharge for the direction of above-head, the mean skin temperature becomes stabilized to about 33–34°C and to the range of comfort. But in the case of direct discharge to the direction of the face, it does not become stabilized and reduces to 32°C. Under the circumstance temperature of 30°C, direct discharge shows the stabilization of MST contrary to the case of the circumstance temperature 27°C in which the MST continues to be lowered. But in the case of applying indirect discharge, the initial MST of 35°C is lowered to 33.5°C and to the range of comfort.

Figure 4 shows the skin temperatures of each part according to the applied conditions. There appears to be low temperature in the parts of abdomen, forearm, hand and calf due to the downward stream of cold air.

Figure 5 shows the thermal sensation vote of each part according to the applied conditions. The case of applying direct discharge was evaluated as cool or cold. It is also noticeable that the parts of shoulder, forearm and hand were evaluated as cold due to the downward stream of cold air. Applying the indirect upward discharge shows the evaluation range of: –1, slightly cool to +1, slightly warm. But it shows the same evaluation trend in each part regardless of its direction, which come from the greater psychological effect of head-part cooling.

Figure 6 shows the time dependency of whole body sensation vote. It is evaluated as ‘slightly warm’ in the pre-conditioned room of 30°C before entering the main chamber where it is evaluated as generally ‘cool’. With room temperature of 30°C, it is as ‘slightly cool’ and stabilized after 30 min when applying the above-head air stream. But, with the same room temperature, it is as ‘cold’ when applying the direct air stream to the face.

Figure 7 shows the time dependency of thermal comfort vote. It is evaluated as ‘+1, slightly comfortable’ to ‘+2, comfortable’, in the pre-conditioned room. But it becomes ‘comfortable’ with the indirect above-head discharge or ‘uncomfortable’ with the direct discharge to the face. Especially the direct discharge continues to increase the evaluation of ‘uncomfortable’.

Figure 8 shows the sensation of airflow. The sensation effect according to each part is quite clear in showing whether the airflow is direct or indirect. But the trend due to airflow is almost the same regardless of its direction. In the case of direct airflow, the sensation is in the order of head > hand > trunk > foot, and in the evaluation range of: ‘3, sensible to 5,very much sensible’, except at the part of foot.

In the case of indirect airflow, it is: 0, insensible to 1, very slightly sensible, which means that the airflow cannot reach.

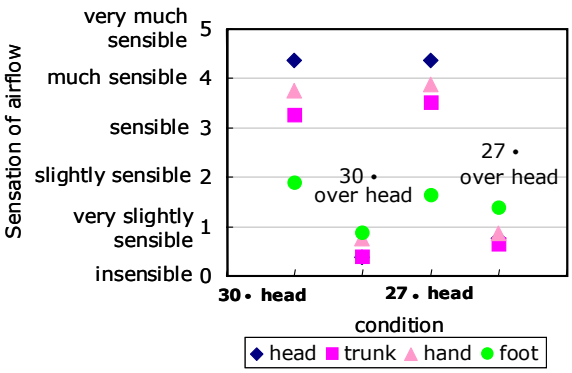

Figure 8 Sensation of airflow.

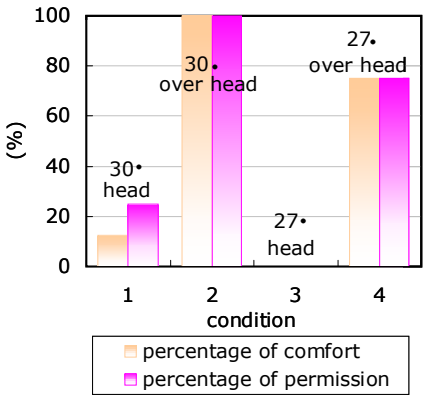

Figure 9 Percentage of comfort and permission.

Figure 9 shows the degree of comfort and permission to the environment. Generally they show the same degree of comfort. Under the circumstance temperature of 30°C, indirect airflow shows high degree of comfort contrary to the extremely low degree coming from direct airflow. It is evaluated as rather comfort to avoid direct contact of airflow than to make it.

CONCLUSION

These results lead to following conclusions:

1. Physiologically the indirect above-head airflow made the MST comfort range of 33–34°C stabilized, which is contrary to the case of bringing the MST down to 32°C with direct airflow to the face.
2. The thermal sensation vote shows as ‘cold’ when applying direct airflow to the face, but it shows as ‘slightly cool’ with the indirect airflow of above-head direction, which shows that the indirect airflow is less sensitive than the direct one.
3. The thermal comfort vote shows as ‘comfort’ in the case of indirect airflow contrary to the case of direct airflow.
4. The thermal sensation vote shows as ‘cold’ at the parts of shoulder, forearm and hand due to the downward stream of cold air. But it shows the same evaluation trend in each part regardless of its direction, which come from the greater psychological effect of head-part cooling.
5. With room temperature of 30°C, it is as ‘slightly cool’ and stabilized after 30 min when applying the indirect above-head air stream. But, with the same room temperature, it is as ‘cold’ when applying the direct air stream to the face.
6. In the case of direct airflow, the sensation is in the order of head > hand > trunk > foot, and a noticeable effect is found even to the part of trunk due to airflow.

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