Impact of non-isothermal task conditioning system on thermal comfort

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ABSTRACT
Subjective tests with a desktop-based task conditioning system were conducted. Previous to the subjective tests, detailed measurements of air velocities influenced by the system were performed. For subjective experiments, three ambient air temperature and relative humidity combinations, (1) 27°C/40%RH, (2) 30°C/40%RH and (3) 30°C/70%RH, were applied. Each of 16 college age subjects was exposed to the three different experimental room air conditions. There were six supply airflow patterns for task air conditioning, and the parameters included were isothermal airflow and non-isothermal airflow with three different air velocities. An experiment involving subjects using the task conditioning system suggested the possibility of employing hot space. Questionnaire responses under the 'preferred air' condition revealed the importance of adjustment of task conditioning.

INDEX TERMS
Task/ambient conditioning; Non-isothermal airflow; Subjective test; Thermal comfort

INTRODUCTION
Task/ambient air conditioning systems aim at moderating air conditioning in the ambient zone and reducing total energy load by intensive air conditioning of the task zone. The system enables office workers to adjust the level of air conditioning by themselves. Its advantages include considering varying personal preferences for thermal environment and making workers psychologically satisfied because of the awareness that they control the thermal environment by themselves. This paper refers to the serviceability of a desktop-based task conditioning system, using non-isothermal airflows.

Assessing the serviceability of task conditioning requires data collection under systematic experiment conditions. An experiment was therefore conducted in a climate chamber where conditions were controllable. Tanabe *et al.* (2001) verified that isothermal airflow-based personal air conditioning systems were highly effective at an airflow temperature of 26 or 28°C but not so effective at 30°C. In this research, experiments were conducted at air temperatures of 27 and 30°C in the ambient zone to investigate the effectiveness of a task conditioning system using non-isothermal airflows. First, the distribution of velocities of airflows from desktop diffusers of a task conditioning system unit was investigated to identify the characteristics of diffusion of airflows. Then, thermal conditions at different parts of a human body were estimated using a thermal manikin under high temperature ambient conditions. Humidity has a great impact on thermal sensation at high temperatures. Subjects were therefore used to examine the effect of the task conditioning system in ambient space of high temperature and high humidity. All of the experiments were conducted in the climate chamber (9.60 m (L) × 3.65 m (W) × 2.35 m (H)) of Kanto-Gakuin University, Yokohama (Akimoto *et al.*, 2001). The plan of the climate chamber is shown in Figure 1.

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DESKTOP DIFFUSER PERFORMANCE EVALUATION

Desktop-based Task Conditioning System

Figure 2 shows a desktop-based task conditioning system. The task conditioning system is installed on a desk and composed of diffusers and a mixing box. The temperature of airflow is controlled by mixing the primary airflow with room air in the mixing box. The temperature and velocity of airflow, foot thermal radiation from the panel, task lighting and white noise can be controlled by a manual controller. The controller has a built-in occupant sensor sensitive to human actions, and the task conditioning system ceases functioning in about 15 min after the occupant leaves the desk.

Measurement of Velocity of Airflow from Desktop Diffusers Methods

The characteristics of airflow from the desktop diffusers of a task conditioning system unit to be used in an experiment using a thermal manikin and in another involving subjective test were identified by measuring distributions of velocities of diffused airflow. Measurements were taken in a workstation booth in the climate chamber. Airflow distribution measurement points are shown in Figure 3. Velocities of airflow were measured at five levels up to a level 0.5 m above the desktop at intervals of 0.1 m. In the horizontal direction, measurements were taken at intervals of 0.1 m in a grid formed by columns 0–15 and rows A–O. Velocities were measured every second for 3 min at each measurement point. The mean value was regarded as the airflow velocity at the point. A multi-point anemometer (KANOMAX Model 1500) was used for measurement. The climate chamber was closed off and the ambient zone was not air-conditioned during the measurement. The chair and office automation equipment were all removed from the booth. The desktop diffusers were set to blow out air horizontally towards the centre of the booth. The amount of air supply was adjusted by a manual controller. The mean amounts of air obtained from the velocities of airflows from both desktop diffusers were 1.0, 1.6, 45 and 78 m^3/h at levels 1, 2, 3, and 4, respectively.

RESULTS

The distributions of horizontal and vertical airflow velocities at levels 1–4 are shown in Figure 4. It was confirmed that airflows reached the partition behind the worker regardless of the height of measurement point or the amount of air supply, and spread along the partition.

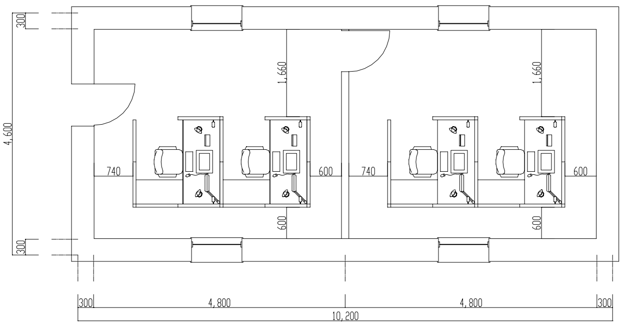

Figure 1 Climate chamber of Kanto-Gakuin University.

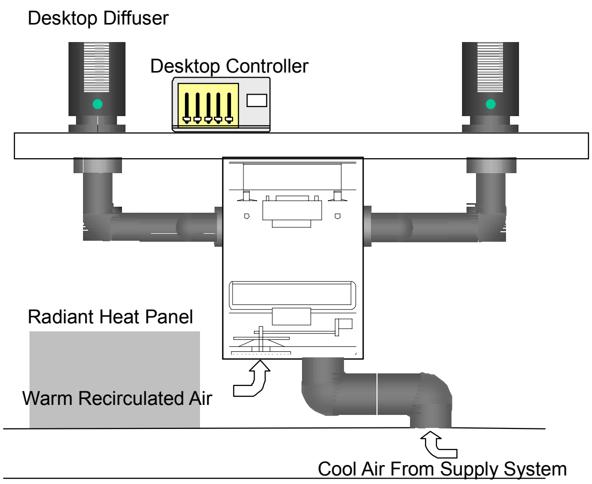

Figure 2 Desktop-based task conditioning system.

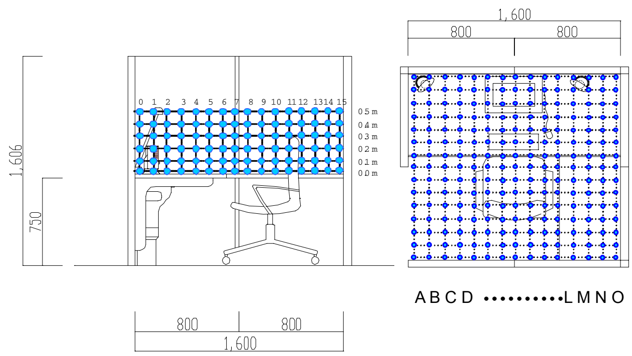

Figure 3 Airflow distribution measurement points.

Subjective Test Methods

The experiment was conducted during 20 August to 16 September 2001. The chamber was designed to simulate an office with four workstation booths separated from one another by partitions. Each booth was furnished with an office desk, a personal computer and a task conditioning system unit. A total of 16 healthy people, eight males and eight females, of college-student age were recruited as subjects. Each subject participated in three different condition tests twice. No information was provided to the subjects about the objective of the experiment and details of airflows. The amounts of clothing were 0.71 clo for males and 0.41 clo for females. In the ambient zone, air was supplied from the ceiling and sucked under the floor to minimize thermal stratification. During the tests, skin temperature, temperature and humidity in cloth of subjects were measured. The subjects clad in an outfit were led into the chamber and their weights measured. The subjects were instructed to keep still for 40 min and then to type text for 5 min before sensation voting. After the elapse of 60 min after entry into the room, the subjects were exposed to airflow conditions set by us. They underwent a 40-min test three times with 10-min intermissions in between times. Different task airflows were set in random order to prevent subjects from being biased. For the last 80 min of the experiment, the subjects adjusted airflow and thermal radiation from the foot panel to meet their personal preferences. Answers to a questionnaire were provided totally via the personal computer. The directions and angles of desktop diffusers and the position of the foot thermal radiation panel were kept fixed during the experiment. The subjects were allowed to adjust airflow temperature, airflow velocity and the level of thermal radiation from the panel only even under the ‘preferred air’ condition. The experiment conditions and procedure are shown in Table 1 and Figure 5, respectively. The measured supply task airflow temperature and velocity at the last 10 min in each case are shown in Table 2. The measured ambient temperature and humidity are shown in Table 3. The task air temperature was almost as designated under isothermal airflow conditions. When non-isothermal airflows were diffused,

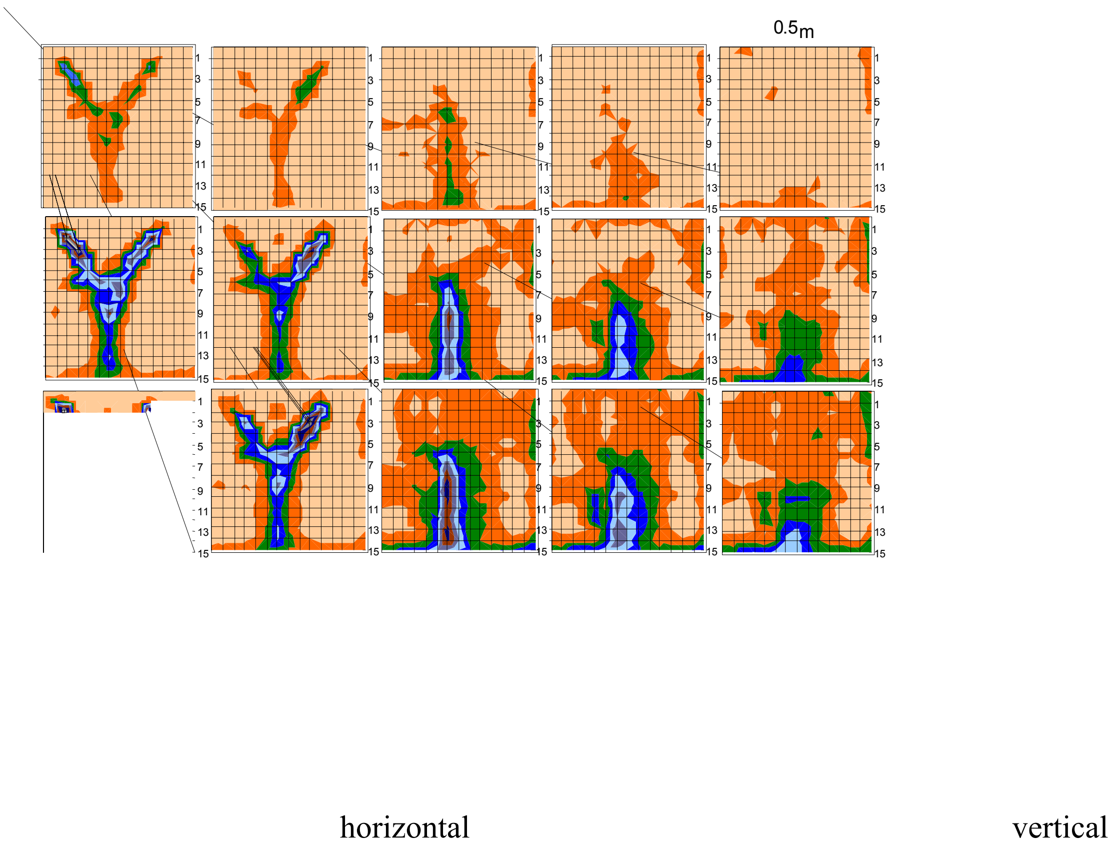

Figure 4 Distributions of airflow velocities (m/s).

there was a variance of about one degree Celsius in some cases. In the 27°C/40%RH condition for males, room air temperature was lower than designated as an experiment condition.

In the experiment, subjects were asked to complete a questionnaire to report their thermal sensation and comfort sensation (The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, 1979; Umemiya *et al.*, 1999). To investigate white-collar productivity, subjects were instructed to type in eight-digit figures. Subjects answered the thermal environment questionnaire and typed in eight-digit figures through a personal computer. The subjects were supposed to respond to the questionnaire by checking marks on scales and choosing appropriate answers from the lists of alternatives for local thermal sensation. The voting scales are shown in Figure 6.

Table 1 Measurement conditions of subjective test

Test date		20 August to 16 September 201		
Subjects	Number	Male: 8, female: 8		
	Clothing (clo)	Male: 0.71, female: 0.41		
Ambient	Air temperature T_0 (°C)	27	30	30
	Relative humidity (%RH)	40	40	70
	Air velocity	Still air		
	HVAC system	Ceiling supply, floor return		
Desktop diffuser	Air temperature (°C)	Isothermal T_0, non-isothermal $T_0 - 4$	–	Preferred
	Air velocity (m/s)	1.0, 2.0, 3.0	Still air	Preferred

Table 2 Task airflow temperature and velocity

case			To_1	To_2	To_3	To-4_1	To-4_2	To-4_3
air vel. [m/s]	female	27 40%	1.09	2.02	3.03	0.91	2.01	3.05
		30 40%	1.02	1.99	2.92	1.00	2.10	3.05
		30 70%	0.98	2.02	2.58	1.03	2.15	2.59
	male	27 40%	1.17	1.86	2.99	0.87	2.06	2.70
		30 40%	0.79	2.09	2.79	0.89	2.08	2.81
		30 70%	1.09	2.01	2.74	1.12	1.93	2.98
air temp. [°C]	female	27 40%	26.8	27.4	26.4	21.9	22.7	23.6
		30 40%	30.3	30.1	30.5	25.7	26.2	26.4
		30 70%	30.2	30.0	30.1	26.0	26.3	27.4
	male	27 40%	27.2	27.4	27.0	22.5	23.0	23.7
		30 40%	29.9	29.6	30.3	24.6	25.7	25.9
		30 70%	30.0	30.8	30.3	26.6	26.6	27.3

Table 3 Ambient temperature and humidity

case		temperature( )	humidity(%)
female	27 40%	27.1 ± 0.3	39 ± 2.0
	30 40%	29.1 ± 0.1	40 ± 0.7
	30 70%	29.7 ± 0.1	73 ± 0.4
male	27 40%	25.4 ± 0.1	41 ± 1.2
	30 40%	29.7 ± 0.1	41 ± 0.5
	30 70%	29.0 ± 0.1	75 ± 0.3

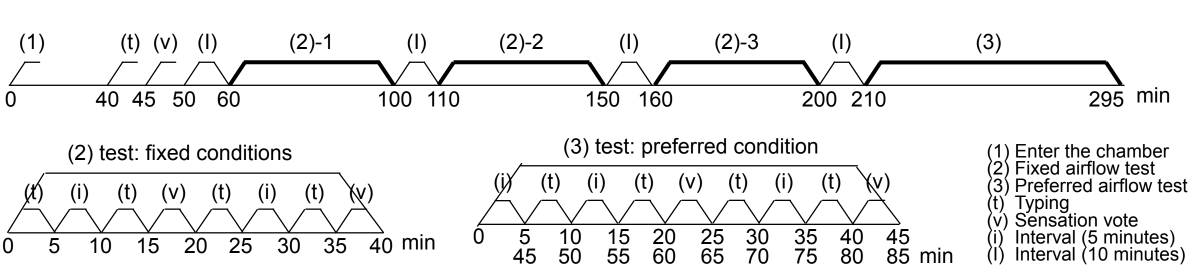

Figure 5 Experimental procedure.

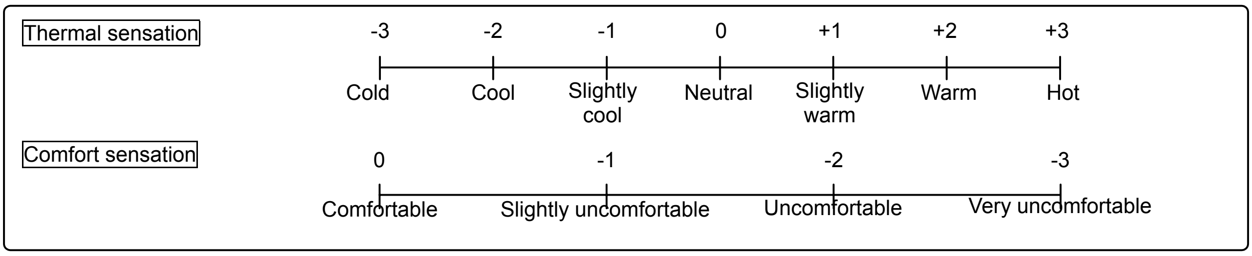

Figure 6 Voting scale.

Thermal Sensation Votes

Figure 7 shows thermal sensation vote reported by subjects.

27°C/40%RH condition

Female subjects reported that they felt cold under the ‘still air’ condition 35 min after they entered the room. They were in a nearly neutral state under the ‘preferred air’ condition. Males were exposed to room air of a temperature lower than designated as an experiment condition, so they reported that they felt cold when they used a task conditioning system. Under the ‘preferred air’ condition, their thermal sensation was also on the cold side, at –1.1.

30°C/40%RH condition

Both male and female subjects answered they felt hot under the ‘still air’ condition. They cooled themselves by exposing themselves to task airflows. The variance in thermal sensation when exposed to isothermal and non-isothermal airflows was greater for males than for females. The score for thermal sensation reported under the ‘preferred air’ condition was –0.7 for females and –1.1 for males. No subjects provided a response on the hot side.

30°C/70%RH condition

Exposure to task airflows resulted in lower thermal sensation either for male or female subjects on the average. Variation in sensation was great among males. Some obtained no cooling sensation. Thermal sensation was –0.5 for females and –0.1 for males under the ‘preferred air’ condition.

Comfort Sensation Votes

Figure 8 shows comfort sensation vote reported by subjects.

27°C/40%RH condition

Females felt cool without airflows. With the increase of airflow velocity, comfort sensation fell. Males were affected less by the increase in airflow velocity.

30°C/40%RH condition

There was no variation in comfort sensation among females according to the velocity of non-isothermal airflow. Under other conditions of task airflow, the increase of airflow

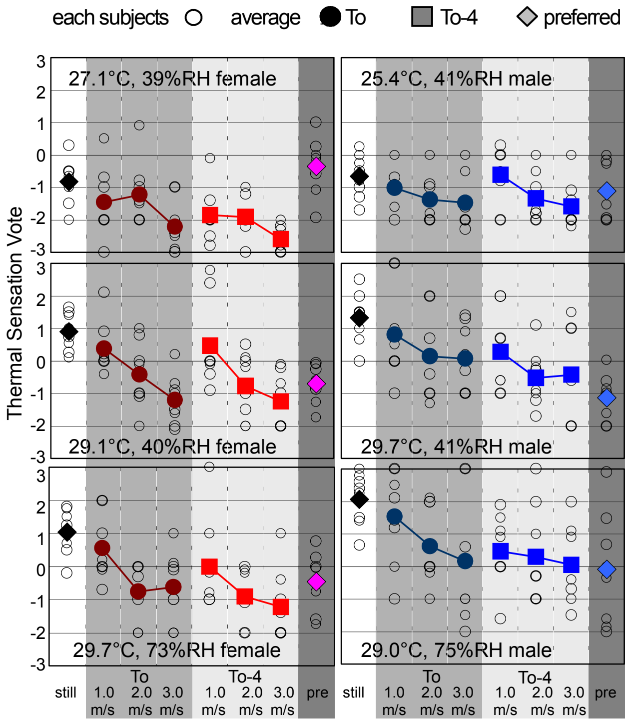

Figure 7 Thermal sensation vote.

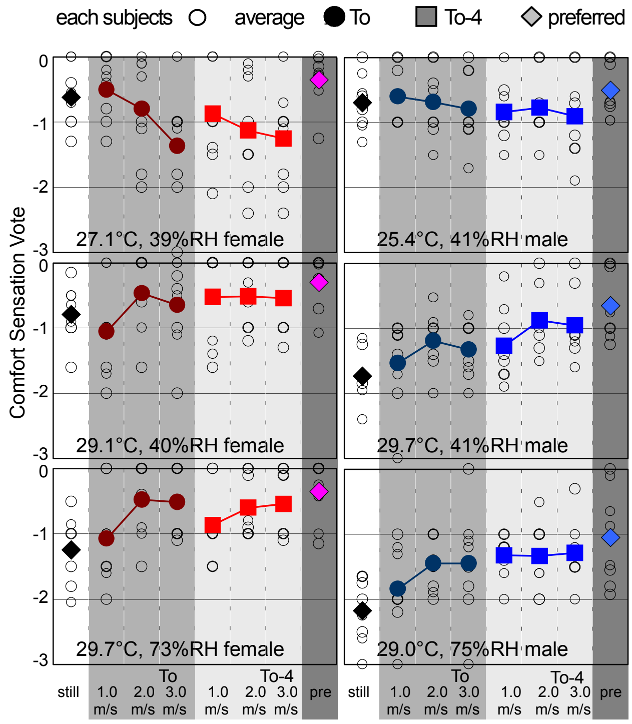

Figure 8 Comfort sensation vote.

velocity led to higher comfort sensation. Comfort sensation increased considerably when airflow velocity increased from 1.0 to 2.0 m/s.

30°C/70%RH condition

Females obtained greater comfort under either isothermal or non-isothermal airflow condition. Comfortable sensation also increased among males. Some, however, reported that they were ‘uncomfortable’ or ‘very uncomfortable’. Under the ‘preferred air’ condition, comfort sensation was below –1 among males at 30°C and a relative humidity of 70% while comfort sensation was –1 or higher on the average under other conditions regardless of sex.

CONCLUSIONS

Subjective tests with a desktop-based task conditioning system were conducted. The task conditioning system was composed of a desktop controller, two desktop diffusers, a mixing box set beneath a desk, and a radiant heat panel. Previous to the subjective tests, detailed measurements of air velocities influenced by the system were conducted. In 27°C/40%RH condition, female subjects' thermal sensation votes and comfort sensation votes were low according to the air velocity increase. In 30°C conditions, their comfort sensation votes increased while thermal sensation votes were still low. Male subjects also voted in the same way in 30°C conditions. When allow them to set preferred air velocities, most of subjects felt much more comfortable.

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