# Thermal preference of task environment and its influence on productivity

Junko Hayashi[a*], Takashi Akimoto[b], Sueng-jae Lee[c], Naoto Iesaki[a], Takashi Yokota[b], Shin-ichi Tanabe[a]

[a]*Depatment of Architecture, Waseda University, Japan;* [b]*Depatment of Architectural Environmental Engineering, Kanto-Gakuin University, Japan;* [c]*Advanced Research Institute for Science and Engineering, Waseda University, Japan*

## ABSTRACT
Thermal manikin test and subjective experiments with a desktop based task conditioning system were carried out in a climate chamber of Kanto-Gakuin University, Japan. The experiments were conducted under three different combinations of ambient air temperature and relative humidity. It was found that skin temperatures at the upper half of the manikin's body exposed to the supply air were decreased. Setting of task condition was fixed at first, and then the subjects were allowed to control the environment freely after a certain period in the subjective experiments. Thermal sensation vote, airflow sensation and other variable were investigated. The way the subjects controlled the task system was also monitored. In this study, the results for sensation vote and preference for task condition environment and productivity in task- conditioned were described. It was considered that the task conditioning system could keep people thermally comfortable with their ambient temperature higher than the condition without it. The learning effect influenced the experimental results and minor task conditioned environment effected on productivity.

## INDEX TERMS
Task/ambient conditioning; Thermal comfort; Productivity

## INTRODUCTION
Task conditioning system has been investigated because it is expected to reduce energy consumption on the whole building by controlling task zone intensively and improve thermal comfort by providing individual control (Bauman *et al.,* 1999). It has several advantages over a traditional ceiling-based air distribution system (Akimoto *et al.,* 1996). It deals with individuality on thermal comfort and improves psychological satisfaction of worker, control by oneself and productivity (Tanabe *et al.,* 2001). The purpose of this study is to clarify the influence of individually controlled task environment on thermal comfort and productivity. Thermal manikin tests and subjective experiments were conducted in a climate chamber equipped with a desktop based task conditioning system. The task conditioning system is shown in Figure 1.

Air temperature and air velocity from the desktop diffusers and radiant heat panel can be controlled with a desktop controller. The tests and the experiments were conducted in a simulated summer office environment. Thermal manikin was used to examine the influence of task environment on human heat loss. Eight males and eight females, healthy university students, participated in the subjective experiments. They were asked to

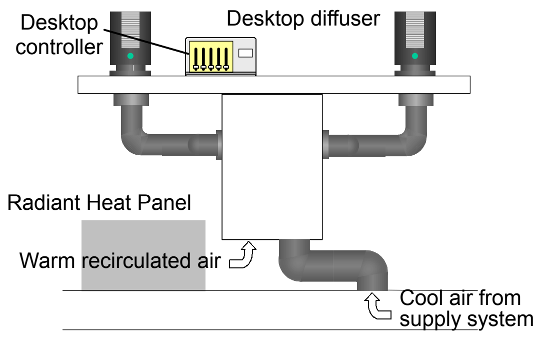


**Figure 1** Desktop-based task-conditioning system.

* Corresponding author. E-mail: hayashi@tanabe.arch.waseda.ac.jp

stay at work station equipped with the desktop task conditioning system under six fixed environmental conditions and a preferred condition where they were allowed to control the environment freely. Each subject voted on their thermal sensation of each body part, airflow sensation, airflow comfortable sensation and its acceptability. They also participated in text typing intended to investigate the effect of individual controlled environment on productivity.

## THERMAL MANIKIN TEST

### Methods

Thermal manikin tests were conducted in a climate chamber of Kanto-Gakuin University, Japan to investigate the effect of task airflow, isothermal and non-isothermal condition, on human body. The chamber was designed to simulate typical office environment. The chamber has four partitioned spaces. Each space is equipped with a desk, a personal computer and a desktop based task-conditioning system. The ambient zone was controlled by ceiling supply-floor return HVAC system in order to minimize thermal stratification. Skin temperature of manikin was measured under different thermal conditions. Measurement conditions, given in Table 1, were identical to the subjective experiment described later. Thermal manikin dressed in the experimental uniform was installed in a partition space in a seated position. After skin temperature of manikin was confirmed to be constant under still air condition, the manikin was exposed to airflow from the desktop diffuser. Airflow conditions were: six different combinations of air temperature and air velocity, shown in Table 2. Air temperature was isothermal, same as ambient air temperature, and non-isothermal, 4°C lower than ambient air temperature, and air velocity was 1.0, 2.0, and 3.0m/s. Skin temperature and heat loss were measured for each body part. Air velocity and air temperature around manikin's body parts were also measured. Maximum scale of the desktop controller, 3.4m/s was added to the air velocity measurement conditions.

**Table 1** Measurement conditions of thermal manikin test

| | | |
|---|---|---|
| Ambient | Air temperature | 27, 30°C |
| | Air velocity | Still air |
| | HVAC system | Ceiling supply, Floor return |
| Task | Air temperature | 27, 30°C, (27-4), (30-4)°C |
| | Air velocity | 1.0, 2.0, 3.0m/s |
| | Radiant heat panel | - |
| Manikin | Clothing | 0.41clo |
| | Posture | Sitting |

**Table 2** Airflow conditions from desktop diffuser

| Test no. | Air temperature | Air velocity |
|---|---|---|
| Still Air | - | - |
| To_1 | Isothermal airflow To | 1.0 m/s |
| To_2 | 27, 30°C | 2.0 m/s |
| To_3 | | 3.0 m/s |
| To-4_1 | Non-isothermal airflow To-4 | 1.0 m/s |
| To-4_2 | (27-4) , (30-4) °C | 2.0 m/s |
| To-4_3 | | 3.0 m/s |

### Results

Air velocity around manikin's body part is shown in Figure 2. When the manikin was exposed to 1 m/s supply air velocity, difference in airflow between body parts was small. Air velocity for the upper half of the manikin increased when the supply air velocity was increased. Especially, when supply air velocity increased from 1 to 3.4m/s, air velocity difference was 1.3 m/s in hands and 0.9 m/s in chest. Steady-state skin temperature of manikin is shown in Figure 3. Little skin temperature difference was observed in the lower half of the body and back even when the supply air velocity was increased. On the other hand, there was large temperature difference in upper half of the body when supply air condition changed. Especially under 27°C ambient air temperature condition, change in hand was the largest, maximum skin temperature decrease of 3°C was observed under To-4_3 airflow condition. It was considered that hand was near by diffuser and naked. It was found that desktop-based task conditioning system could decrease skin temperatures for upper half of the body by exposing its airflow.

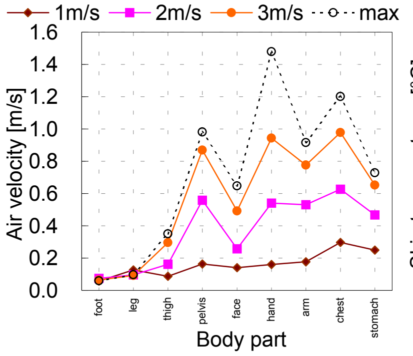


**Figure 2** Air velocity for manikin's body parts.

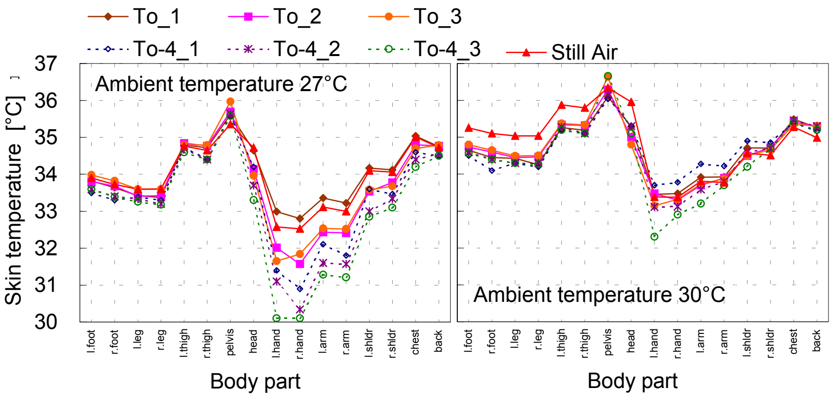


**Figure 3** Skin temperature.

## SUBJECTIVE EXPERIMENT

### Methods

Sixteen university students, eight males and eight females, participated in the subjective experiment from 20 August to 16 September 2001. Subjects were unaware of the purpose of this experiment or the airflow conditions. Subjects wore summer office workers' uniforms. Males' uniforms were long-sleeved shirt, slacks, necktie, underwear and shoes. Females' uniforms were short-sleeved shirt, skirt, underwear and sandals. Experimental conditions of the subjective experiment are shown in Table 3. Subjects were exposed to airflow from desktop diffuser and voted on their thermal sensation. The experimental procedure is shown in Figure 4 and voting scale is shown in Figure 5. Forty minutes after each subject entered the chamber, they typed an eight-digit number for 5 min and voted on thermal environment. Sixty minutes later, the fixed airflow test started for 40 min × three conditions, with 10-min intervals between each condition. In the last period of the test, subjects were allowed to control air velocity and temperature of the supply air and radiant heat panel by the desktop controller. Preferred airflow test (preferred condition) was conducted for 80 min. Five minutes of eight-digit number typing and sensation votes were repeated throughout the experiment.

**Table 3** Experimental conditions of subjective experiment

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Subjects | Number | Male: 8, Female: 8 | Ambient | Air temperature To [°C] | 27 | 30 | 30 |
| | Clothing [clo] | Male: 0.71, Female: 0.41 | | Relative humidity [%RH] | 40 | 40 | 70 |
| Task | Air temperature [°C] | Isothermal To, Non-isothermal To-4 | | | - | | Preferred |
| | Air velocity [m/s] | 1.0, 2.0, 3.0 | | | Still air | | Preferred |

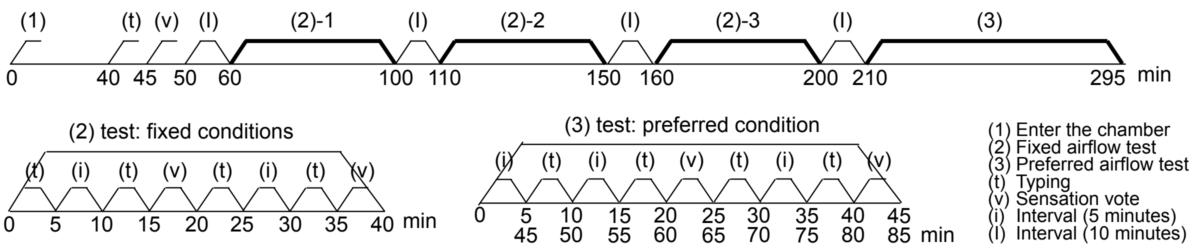


**Figure 4** Experimental procedure.

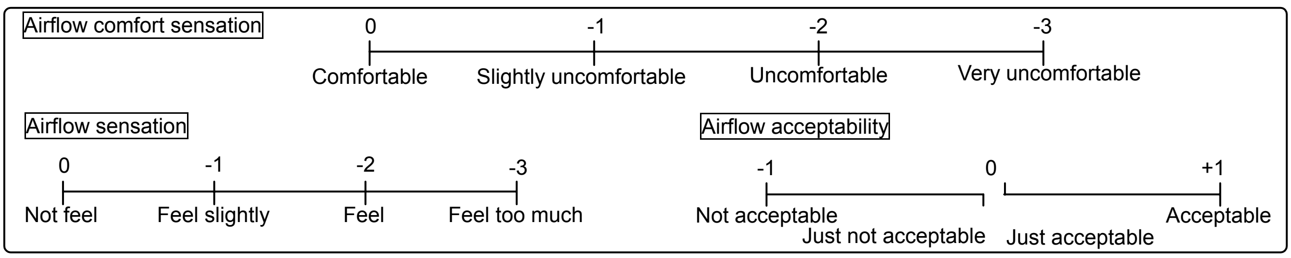


**Figure 5** Voting scale.

**Results**

Measured ambient condition is shown in Table 4. Ambient temperature of 27°C/40%RH condition for male was slightly lower than the target value of 27°C, and humidity of 30°C/70%RH condition for both male and female was slightly higher than 70%RH.

**Local thermal sensation votes**

Subjects were asked to vote if they felt either ‘hot’ or ‘cold’ for each of 18 body parts. The results were then grouped into seven sections (front, back, head, legs, foot, arms, hands) and voting rates (number of votes/total number of subjects) were derived. The voting rates, 35 min after subjects entered the chamber and the preferred condition, are shown in Figures 6 and 7 for ‘hot’ and ‘cold’ respectively. Under 27°C/40%RH condition, voting rate of ‘hot’ was low. Ambient temperature was low enough for them to feel cooler than neutral without task airflow. Female voting rate of ‘cold’ was higher in preferred airflow condition, especially for arms, 44%. This is considered that even if subjects minimized airflow volume, slight air blew from diffusers. Under 30°C conditions, voting rate of ‘cold’ was low because of higher ambient temperature. Voting rate of ‘hot’ for preferred condition decreased from the vote upon entrance, and a maximum decrease of 63% was observed for males’ head under 30°C/70%RH condition. Local thermal sensation was confirmed to be improved under preferred condition of 30°C ambient temperature.

**Table 4** Measured ambient conditions

| Case | Female | | Male | |
|---|---|---|---|---|
| | Air temperature | Relative humidity | Air temperature | Relative humidity |
| 27°C/40%RH | 27.1 °C | 39 %RH | 25.4 °C | 41 %RH |
| 30°C/40%RH | 29.1 °C | 40 %RH | 29.7 °C | 41 %RH |
| 30°C/70%RH | 29.7 °C | 73 %RH | 29.0 °C | 75 %RH |

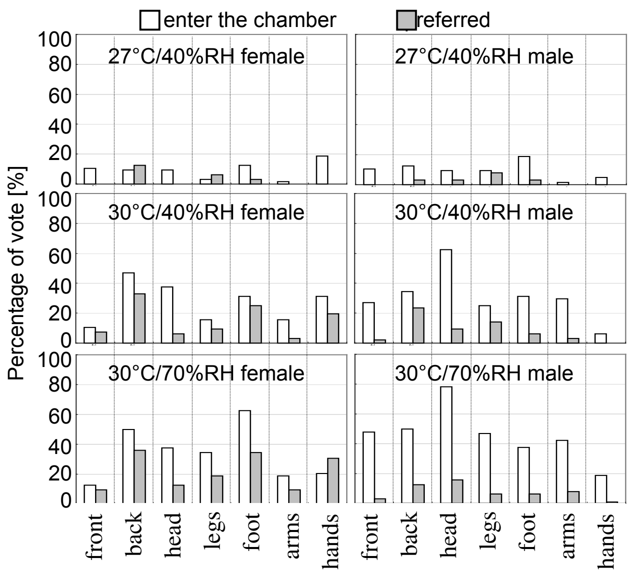


**Figure 6** Body parts feeling hot.

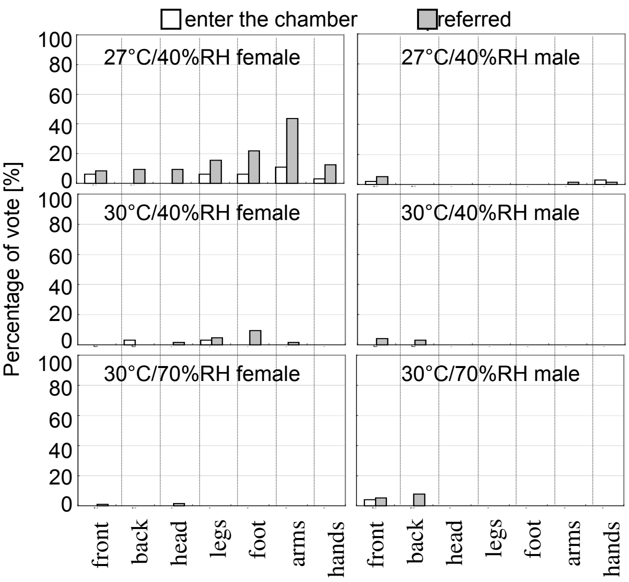


**Figure 7** Body parts feeling cold.

**Sensation vote for airflow**

Airflow sensation vote, airflow comfort sensation vote and airflow acceptability were investigated. The relationship between average airflow sensation vote and average airflow comfort sensation vote is shown in Figure 8. Under 27°C conditions, increase in airflow sensation resulted in the decrease of airflow comfort sensation vote. On the other hand, under

30°C conditions, airflow comfort sensation remained constantly high while airflow sensation votes increased. Airflow comfort sensation vote was higher in preferred conditions than in fixed conditions. Airflow acceptability is shown in Figure 9. Under 27°C condition, female subjects' airflow acceptability decreased when the air velocity increased. Under 30°C conditions, their airflow acceptability was high for all task conditions. When they were allowed to select preferred airflow, difference was small between each subjective vote. When male subjects used isothermal airflow, they voted higher airflow acceptability under 27°C conditions than under 30°C conditions. When the airflow was 1.0 m/s, 30°C/40%RH and 30°C/70%RH isothermal air was supplied, male subjects voted that the airflow is not acceptable (average –0.23 and –0.31 respectively). Under 30°C conditions, difference between 2.0 and 3.0 m/s was little. Acceptability of non-isothermal airflow condition was higher than that of isothermal airflow. Most subjects voted larger than 0 when they were allowed to select preferred airflow conditions.

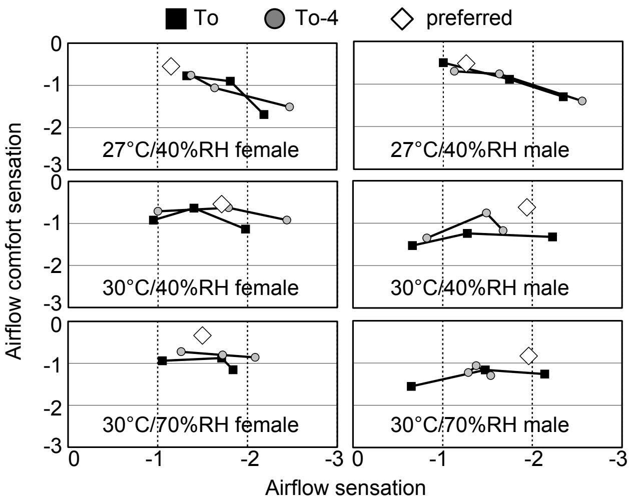


**Figure 8** Airflow sensation and comfort

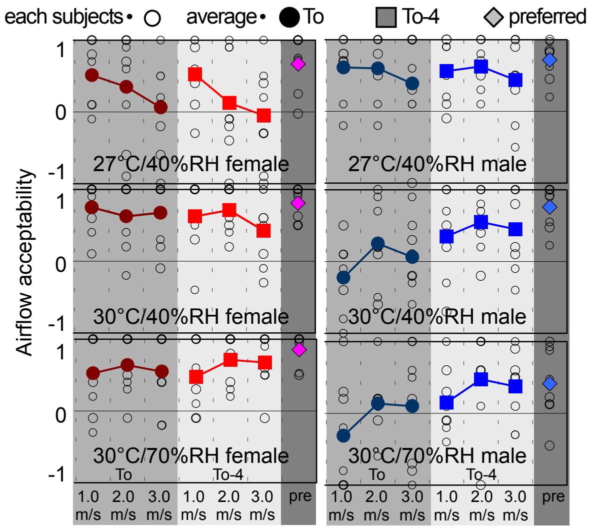


**Figure 9** Airflow acceptability.

## Thermal preference of task environment

In preferred condition, the output of individual control was monitored to investigate how subjects controlled the task system. They were able to control the degree and temperature of air velocity and radiation heat panel under the desk. Average of the individual control output of all the subjects are shown in Table 5. It was considered that females preferred lower air velocity than males, and females preferred higher airflow temperature under 27°C condition but they preferred lower air temperature in 30°C conditions than males. Standard deviations were larger than 0.50, and it was considered that each subject preferred various task conditions. Individual profiles of four males and four females for preferred condition in 30°C/40%RH are shown in Figure 10. Average thermal sensation vote throughout preferred condition are shown in the left corner of each figure. Large individual difference in subject's control condition of air velocity and temperature was observed. Thermal sensation vote was also various. Male 1, female 1 and female 2 used a radiant heat panel even when the ambient temperature was 30°C. It was considered that thermal preferences of task environment had a huge variety and individual control system was useful to meet their requirements.

## Productivity

In order to investigate productivity in the task-conditioned environment, subjects were asked to perform the 'eight-digit number typing' task on desktop computer. An eight-digit number was presented on the display, and subjects were asked to type the same number with a numeric keypad. Even if they typed incorrectly, the next eight-digit number was presented automatically. Subjects conducted this task for 5 min × 21 times a day. Their relationships between preferred and fixed conditions are shown in Table 6. The average of correct inputs of preferred condition tended to be larger than that of fixed conditions. Increase of correct inputs was 2.9% at maximum (female, 27°C/40%RH). More than half of subjects' correct inputs improved when subjects were allowed to control their preferred task conditioned environment. The averages of the correct inputs per day are shown in Figure 11. The correct inputs improved as they repeated the task, except for sixth day. Influence of ambient conditions was considered to be small, experimental conditions were arranged randomly. The typing experience influenced the results, and task-conditioned environment had a minor effect on productivity in this experiment.

**Table 5** Average conditions in preferred conditions.

| Case | Female Air velocity [m/s] | Female Air temperature [°C] | Male Air velocity [m/s] | Male Air temperature [°C] |
|---|---|---|---|---|
| 27°C/40%RH | 1.2 (±0.55) | 24.4 (±0.82) | 1.5 (±0.89) | 22.9 (±1.10) |
| 30°C/40%RH | 2.1 (±0.67) | 26.3 (±0.62) | 3.2 (±0.89) | 27.2 (±0.98) |
| 30°C/70%RH | 1.9 (±0.91) | 26.3 (±0.88) | 3.0 (±0.89) | 27.8 (±1.23) |

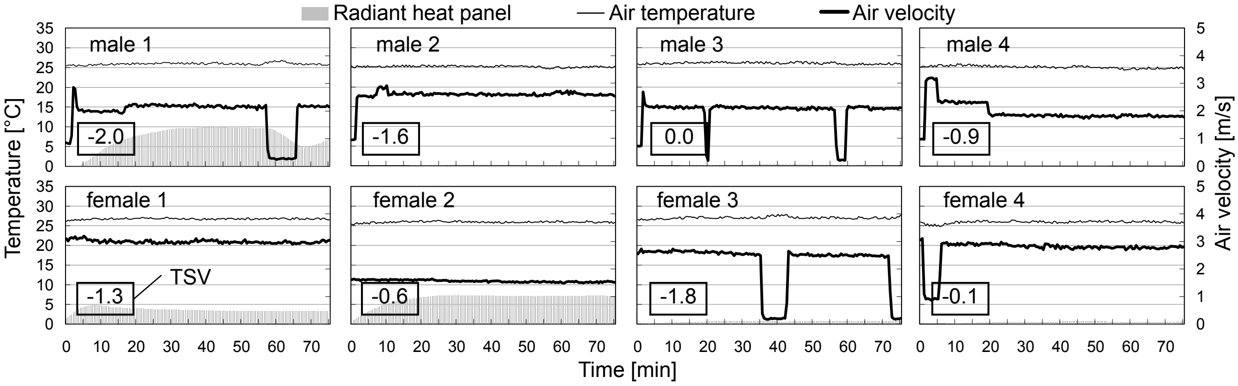


**Figure 10** Control condition in 30°C/40%RH.

**Table 6** Correct inputs per 5 min

| | Ambient condition | Controlled conditions [/5 min.] | Preferred conditions [/5 min.] | Number of improved subjects |
|---|---|---|---|---|
| Female | 27°C/40%RH | 75.1 | 77.3 | 6/8 |
| | 30°C/40%RH | 78.1 | 78.4 | 5/8 |
| | 30°C/70%RH | 78.9 | 80.4 | 4/8 |
| Male | 27°C/40%RH | 61.8 | 62.7 | 5/7 |
| | 30°C/40%RH | 68.4 | 68.4 | 4/7 |
| | 30°C/70%RH | 66.2 | 67.8 | 6/7 |

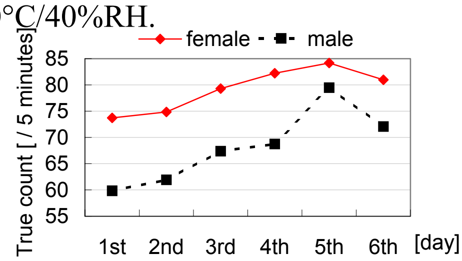


**Figure 11** Ave. true count a day.

## CONCLUSIONS

Thermal manikin tests and subjective experiments with a desktop-based task-conditioning system were conducted in a climate chamber of Kanto-Gakuin University, Japan. It was found that skin temperatures of the upper half of the manikin's body were decreased when exposed to the airflow from the desktop diffuser. Under 30°C ambient temperature and preferred condition, local thermal sensations were improved. Most subjects voted the airflow acceptability larger than 0 when they were allowed to select preferred airflow conditions. Thermal preference of task environment was various, and individual control system was useful to fulfil their needs. It was considered that the ambient temperature could be greater than usual with the task conditioning system to keep people comfortable. Productivity was influenced by the learning effect, not the task environment, in this experiment.

## ACKNOWLEDGEMENTS

A part of this study was financially supported by 'Grant-in Aid for Scientific Research (13750560, 2001) of Japan Society for the Promotion of Science (JSPS).

## REFERENCES

Akimoto, T., Bauman, F., Benton, C. *et al.* (1996). Field study of a desktop-based task conditioning system. *Journal of Architure Planning and Environmental Engineering, AIJ* **490**, 35-46.

Bauman, F., Tsuzuki, K., Hui, Z. *et al.* (1999). Experimental Comparison of Three Individual Control Devices: Thermal Manikin Tests: Johnson Controls, Inc.

Tanabe, S., Nobe, T., Lee, S. *et al.* (2001). Study on task and ambient conditioning system (Parts1 and 2), *Technical Papers of Annual Meeting the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan,* pp741-748, (in Japanese)