Workers' Behavior and Thermal Sensation in Task-conditioned Office

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SUMMARY

Field survey in the M-Office which installed Task/ambient conditioning systems (hereinafter referred to as the "TAC") was conducted in 2005 and 2006. It was intended to investigate the influence of the worker's behavior and task-conditioning to worker's comfort sensation. In this survey, immediately thermal environment and worker's behavior were measured, and questionnaire to occupants who worked as usual were conducted. We found that both activity level of occupant and exposed thermal environment is greatly different one by one. It was suggested that an increase in metabolic rate according to worker's behavior influence on thermal and comfort sensation certainly. It is necessary to recognize the metabolic rate to estimate the occupant's declaration in a field survey. In an actual office where occupants stay long terms, the tendency that occupant prefer isothermal airflow was seen. It was thought that adjustment performance with wide amount of task air-conditioning airflow and operationality was desirable to cover occupant's sense integrally or to connect with occupant's comfort and satisfaction. Based on the knowledge obtained from this investigation, needs for TAC were discussed.

INTRODUCTION

To stop the environmental destruction that progresses globally, the energy reduction is demanded in an architectural industry. In Japan, it is recommended by the Government to set the air temperature in an office building to be 28 °C in summer. TAC is assumed to be one of the solutions to it. By installing TAC, total energy can be lowered by moderating the amount of energy to ambient zone and giving intensive to the task zone. Moreover, the improvement of the comfort and satisfaction is expected by individual adjustment to create the desirable environment and by direct supply of a fresh air to the breath region. In this survey, it was intended to investigate the influence of worker's behavior and task air-conditioning to worker's comfort sensation. For that purpose, immediately thermal environment and worker's behavior, like a sit-down state, walking distance, and metabolic rates, were measured, and questionnaire to occupants who worked as usual for thermal sensation, comfort sensation, and so on were conducted.

METHODS

Outline of the M-Office and TAC

Figure 1 shows perspective of the M-Office, both interior view and exterior view [1]. It has a site area of $4,782 \text{ m}^2$ and a gross area of $19,169 \text{ m}^2$, and four floors above ground and one below ground. Structure of the M office is SRC.

Figure 2 shows the outline and layout of TAC in the M-Office. There is a unit of under floor air-conditioning (100 CMH) per two occupants, and a unit of task air-conditioning (25 CMH) per one occupant. The partition connects under floor, so air for floor-supply is used as for it from task unit. All occupants can handle the task unit for adjusting air volume between 0% and 100%, and air direction between 0° and 45° of the task air-conditioning by an individual.



Figure 1. Perspective.

Figure 2. Walking distance and Metabolic rate.

Measuring methods

Field survey was conducted for five days in summer, between period, winter of fiscal year 2005, and summer of 2006. Twenty people who work at the M-Office, namely twelve males and eight females, participated in this survey. It was investigated that the influence of the worker's behavior and task air-conditioning to worker's comfort sensation. Table 1 shows measuring items in this investigation. In the investigation in 2006, immediately thermal environment, temperature of airflow from task-conditioning, sit-down state, number of steps, and metabolic rate were measured at any time in work hours to understand the worker's activity state and the thermal environment workers were exposed. Only the investigation of sit-down state was also measured in fiscal year 2005. Questionnaire to occupants who worked as usual for thermal sensation, comfort sensation, and so on were conducted once in the morning and once in the afternoon. At that timing, air temperature, relative humidity, radiant temperature, and airflow velocity at the position of subject were measured. Questionnaire was done only for three days, and it was made conditions in the use of task air-conditioning. Occupants cannot use task air-conditioning in the 1st day (TASK-OFF), must open fully the shutter of task air-conditioning in the 2nd day (TASK-ON), and can use task air-conditioning freely in the 3rd day (TASK-FREE).

Measuring items	Measuring equipment	Subject number	Interval	Timing				
Air temperature	C-C Thermocouples	8 people	1 sec	declaring				
Relative humidity	RH sensor	8 people	1 sec	declaring				
Radiant temperature	Directional Radiometer	ometer 8 people		declaring				
Airflow velocity	Heated Anemometer	8 people	1 sec	declaring				
Immediate air temperature	Thermohygrometer	20 people	1 min	any time				
Airflow temperature	Thermohygrometer	20 people	1 min	any time				
Opening level of task- conditioning shutter	Eye Observation	20 people	1 hour	-				
Number of steps	Pedometer	20 people	1 hour	any time				
Metabolic rate	Accelerometer	8 people	1 min	any time				
State of seating	Thermometer	20 people	1 min	any time				
Sensation vote	on vote Questionnaire sheet		1 min	declaring				

Table 1. Measuring items.

RESULTS

Worker's behavior

Working hours in M-Office is 9:00-18:00. The clerical worker was targeted in the measurement of 2006, and worker whose type of job in the measurement of 2005 is coexistence of the business employment, the research employment, and the clerical work. All data that will be shown are the average of five days on the weekday. But, absentee and occupant who sat only by ten minutes or less weren't included in the average.

1) Seating rate, Seat occupancy rate

Whether occupant seated or not was judged by the change of the surface temperature of the seats in one minute [2]. So there is a possibility that too short sitting down is not counted. The definition of seating rate and seat occupancy rate are as follows.

seat occupancy rate = (the number of the occupants seated) ×(total number of the attendance) seating rate = (hour while the occupants seated) ×(Work hours)

Figure 3 shows temporal change of seat occupancy rate, and Figure 4 shows seating rate that was the average of twenty occupants. The same tendency was seen at three terms of fiscal year 2005. Excluding the break in daytime, seat occupancy rate, that shows the rate of person exposed to the task air-conditioning at given times, in 2005 hover nearly 40%, that in 2006 hover at 60-80%. In other measurement, seat occupancy rate hovers at 30-50% [3]. It becomes 0-20% at lunchtime, but 80% immediately after lunchtime. Seating rate in summer is 37%, that in between period was 35%, that in winter was 39%, that of yearly average is 37%. But that in summer 2006 is high, 63%. It is found that the rate of hours occupants stay in task-zone during work hours baries by occupational category and the content of work.



2) Sitting down, Getting out of the seat

Figure 5 shows the penchant for sit-down. The rate of the number of 1-5 minute sitting down is the highest, nearly 50%. In the mean while, the rate of the number of 1-5 minute getting out of the seat is the highest, nearly 70% in 2005, 86% in 2006. Number of times shows occupant doesn't leave one's desk easily when occupant sits down once. It is found that workers are not frequently repeating sit-down and leaving-out, so it is thought that metabolic rate while occupants are sitting down is sort of steady.



Figure 5. Penchant for sit-down.

3) Worker's behavior and thermal environment

Figure 6 shows worker's behavior and exposed air temperature of M2, one of the male subject, at TASK-OFF condition, that task conditioning system was not allowed to use. It also shows the declared time zone and timing he declared. Metabolic rate in this paper indicates the instant mean value per minute measured by omnidirectional accelerometer, that is a physical activity logging system. When a strong movement is momentarily done, a high value is measured, like 3.0 met or more. Almost activity level of occupant can be recognized. It was found that both activity level of occupant and exposed thermal environment is greatly different one by one.



Figure 6. Worker's behavior and Exposed air temperature.

Figure 7 shows number of steps and metabolic rate that is mean value of all occupants. Table 2 shows five days average of metabolic rate while seating and that while leaving from the seat of each occupant. It is found that the number of steps in an hour was about 300 steps or more in work hours. Average of metabolic rate through work hours is 1.4 met, that while seating is 1.3 met, and that while leaving from the seat is 1.7met. Average of metabolic rate, which shows activity level, while seating is to each occupant. Metabolic rate measured in this survey could be one of the useful basic design value.



Figure 7. Number of steps and Metabolic rate.

Table 2. Metabolic rate [met] while seating and while leaving from the seat.

	M1	M2	M3	M4	F1	F2	F3	F4	Ave.
Work hours	1.4	1.7	1.3	1.4	1.3	1.4	1.3	1.7	1.4
While seating	1.3	1.5	1.2	1.2	1.2	1.2	1.2	1.4	1.3
While leaving	1.5	2.3	1.5	1.8	1.6	1.5	1.4	2.2	1.7

Occupant's sensation vote and metabolic rate

Figure 8 shows relation between declaration and metabolic rate. Standard new effective temperature (hereinafter referred to as the "SET*") was derived from questionnaire about amount of clothes in the morning and environmental measurement at declaration timing, namely air temperature, relative humidity, radiant temperature, and airflow velocity at the position of subject. But difference was not found by the classification by SET* between conditions. So the declaration was classified from the viewpoint of metabolic rate that was 30 minutes average before occupant declared, metabolic rate is less 1.2 met and is 1.2 met or more, so declarations in this figure are mixed with TASK-OFF, TASK-ON, TASK-FREE condition.

In case metabolic rate is 1.2 met or more, the declaration of thermal sensation votes (TSV) increased that on the hot side, and that of thermal comfort sensation votes (TCSV) increased that on the uncomfortable side. It was suggested that an increase in metabolic rate according to worker's behavior influence on thermal and comfort sensation certainly.



Figure 8. Relation between Metabolic rate and Declaration.

Occupant's sensation vote and temperature of airflow from task air-conditioning

Figure 9 shows relation between Δt and declaration of twenty occupants (Δt -TSV, Δt -TCSV, Δt -ECSV, Δt -EAV). Table 3 shows voting scales. The definition of Δt in this paper is as follows, and Δt as isothermal is between -1 °C to 1 °C, Δt as non-isothermal is more or less than 1°C.

$\Delta t = (temperature in task-zone) - (temperature of airflow from task air-conditioning)$

Temperature in task-zone and temperature of airflow from task-conditioning was averaged in time zone occupants declared, 11:00-11:30 and 15:00-15:30. The declaration in TASK-FREE condition, that occupants could operate task-conditioning systems freely, targeted only the occupants whose opening rate of the task air-conditioning shutter was 50% or more because of searching the influence that the task air-conditioning gives to sense of occupant. For TASK-ON condition, task-conditioning systems were forced to use without any occupants' control.

When airflow was isothermal, thermal sensation votes (TSV) were almost installed between from -1 to 1. Thermally or environmental comfort sensation votes (TCSV, ECSV) were positioned on the comfort side, and environmentally acceptable votes (EAV) were on the acceptable side. Meanwhile airflow is non-isothermal, both the hot side and the cold side declarations were seen with TSV. The declarations of the uncomfortable side were seen with TCSV, ECSV, and the declarations of the unacceptable side were seen with EAV. In an actual office where occupants stay long terms, the tendency that occupant prefer isothermal airflow was seen.



Figure 9. relation between Δt and declaration.

Declaration items	3	2	1	0	-1	-2	-3
Thermal sensation	hot	Sl. Warm	Warm	Neutral	Sl. Cool	Cool	Cold
Thermal and Environmental comfort sensation	-	-	-	Comfortable	Sl. Uncomfortable	Uncomfortable	Very Uncomfortable
Environmental acceptable sensation	-	-	Acceptable	-	Unacceptable	-	-

DISCUSSION

We found that the rate of hours occupants stay in task-zone during work hours is few by the type of job, and workers are not frequently repeating sit-down and leaving-out, so it is thought that metabolic rate while occupants are sitting down is sort of steady. But while leaving from the seat, both activity level of occupant and exposed thermal environment is greatly different one by one. It was confirmed that an increase in metabolic rate according to worker's behavior influence on thermal and comfort sensation certainly. It is necessary to recognize the

occupant's situation, especially like metabolic rate and exposed air temperature, to estimate the occupant's declaration in a field survey.

In an actual office where occupants stay long terms, the tendency that occupant prefer isothermal airflow was seen. It was thought that adjustment performance with wide amount of task air-conditioning airflow and operationality was desirable to cover a lot of occupants of sense integrally or to gain occupant's comfort and satisfaction. There is a report which is research of causing the delay in changing the metabolic rate and the skin temperature [4]. It is thought that air-conditioning at space that occupant fit in is very important for gaining occupant's satisfaction. It is possible to decrease dissatisfaction by the task air-conditioning. TAC is an air-conditioning system considering energy balance of task-zone and ambient-zone totally. How to use the building and office changes depending on the occupational category and the content of work, so it is desirable to design HVAC system and to decide operation considering usage. Therefore it is needed to design the HVAC system which can change the operation balance of ambient air-conditioning supply and task air-conditioning supply on some level. Environmental load reduction may be realized without losing occupant's comfort.

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