

Effect of Moderately Hot Environment on Productivity and Fatigue Evaluated by Subjective Experiment of Long Time Exposure

Masanori Ueki¹, Shin-ichi Tanabe¹, Naoe Nishihara¹, Masaya Nishikawa², Masaoki Haneda¹, and Akihiro Kawamura¹

¹Waseda University, Japan

²The Tokyo Electric Power Company, Inc.

Corresponding email: ueki@tanabe.arch.waseda.ac.jp

SUMMARY

In this study, a subjective experiment was conducted in a climatic chamber to clarify the effect of moderately hot environment on productivity, especially on the relationship between performance and fatigue. The climatic chamber was conditioned at operative temperature of 25.0°C (insulation value of 0.93 clo), 28.0°C (insulation value of 0.93 clo), and 28.0°C (insulation value of 0.57 clo). Subjects were exposed in the environment for six hours. The performance at 28.0°C condition was lower than at 25.0°C condition. Performance decreased as the sessions proceeded, while the total rate of subjective symptoms of fatigue increased. Correlation between personal rates of complaints of fatigue and performance in Z-score was observed with correlation coefficient of -0.76. From the linear regression model, increase in 10% of fatigue corresponded to the decrement in standard number of correct answers by 1.7%. These results implied that thermal environment effected on performance and fatigue and subjects performed worse when they felt high level of fatigue.

INTRODUCTION

It was reported that subjects exposed to moderately hot environment condition worked as much as exposed to thermally neutral conditions for short time exposure [1], [2]. However, it was shown that the subjects felt more tired in hot environment conditions than in thermally neutral conditions, so it was suggested that the evaluation of fatigue feeling was useful to evaluate productivity in thermal environment from the assumption that performance would eventually decrease when workers were tired. But there was little clear scientific evidence for the relationship between the level of fatigue and performance. The objective of this study is to clarify the effect of moderately hot environment on productivity, especially on the relationship between performance and fatigue. Subjective experiment for six hours exposure was conducted in this study.

METHODS

Experimental Conditions

Subjective experiment was conducted in a climatic chamber to clarify the effect of moderately hot environment on productivity, especially on the relationship between performance and fatigue. This experiment was conducted from July 13 to August 10, 2005. As effort for energy conservation, Japanese government has recommended to modify the cooling temperature setting in offices and to also modify the dress code to keep the workers be comfortable in summer. From this perspective, the conditions were set by the combination of operative

temperature in the chamber and the amount of clothing insulations [3] as: 25.0°C with 0.93 clo, 28.0°C with 0.93 clo, and 28.0°C with 0.57 clo. A practice at 25.0°C with 0.93 clo was conducted prior to these experimental conditions, and these conditions were balanced for order. Experimental conditions are shown in Table 1. Air temperature was measured by Type T thermocouples, relative humidity was measured by Thermo Recorder RS-11(ESPEC), desktop illuminance was measured by digital illuminometer T-10 (MINOLTA), equivalent sound level was measured by sound level meter NL-31 (RION), and the concentration of CO₂ was measured by IAQ monitor MODEL2332 (KANOMAX). Air temperature, relative humidity, and the concentration of CO₂ were measured at 1.1 meters from the floor every one minute. Desktop illuminance was measured on each desk prior to the experiment. And sound level was measured at 1.1 meters from the floor every one second.

Table 1 Environmental conditions

Conditions	Operative Temperature [°C]	Relative Humidity [%RH]	CO ₂ Concentration [ppm]	Desktop Illuminance [lx]	Equivalent Sound Level [dBA]
Practice	25.0 (0.16)	47 (1.2)	841 (49)	730 (43)	59.5
25°C with 0.93 clo	25.0 (0.30)	48 (0.9)	843 (113)	679 (38)	57.9
28°C with 0.93 clo	28.3 (0.42)	48 (2.9)	880 (117)	710 (43)	57.6
28°C with 0.57 clo	28.1 (0.34)	48 (3.2)	910 (61)	682 (39)	58.0

() Standard Deviation

Subject

Fifteen collage-age male subjects participated in this experiment. For the analysis, data of fourteen subjects were available except for the data of one subject whose data was partially missing. The anthropometrical data of the fourteen subjects were age of 20.8 ± 1.6, height of 171.7 ± 7.0cm, and weight of 62.3 ± 10.9kg. To keep the motivation of the subjects at same level, they were informed to be paid a bonus depending on their performance. Every subject participated in this experiment on same day of the week and same time of the day in the successive weeks to avoid the day and/or time influence.

Experimental Procedure

The experimental procedure is shown in Figure 1. First, subjects changed into suit coat, long-sleeved shirt, T-shirt, necktie, socks, suit trousers and leather shoes (without suit coat and necktie at 0.57 clo conditions), and then answered questionnaire on paper in the anteroom. After that, subjects entered the chamber, and then reported first thermal sensation in the chamber and their feeling of fatigue on PC and took flicker test. Subjects rested for 30 minutes in sedentary position to adapt themselves to the environment. Then, subjects were assigned to work on nine sessions of one-digit addition tasks on PC. In each session, the subjects worked for 30 minutes on the task and they reported thermal sensation, their feeling of fatigue and their evaluation of the productivity on PC and took flicker test.

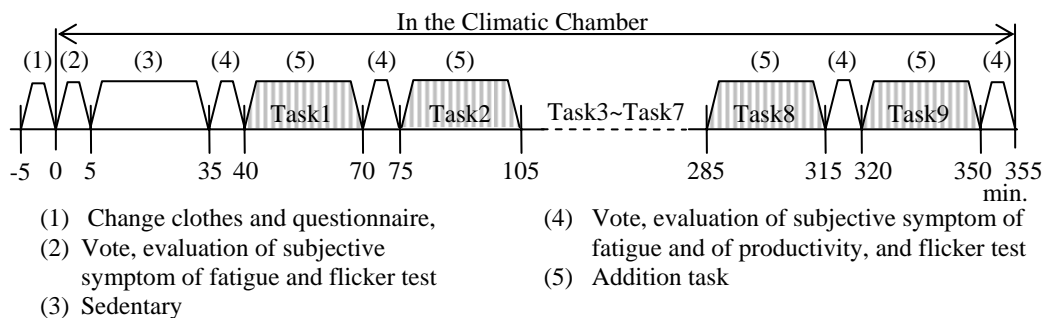


Figure 1 Experimental procedure

Measurement Items

Thermal sensation votes, thermal acceptance, and comfort sensation votes were asked to evaluate the perception of the thermal environment. Subjective votes on thermal environment are shown in Figure 2.

Satisfaction level, suitability for work, and effect of thermal environment on workability when subjects were exposed to the thermal environment were asked in order to evaluate the productivity which was evaluated by the subjects. Subjective votes on productivity are shown in Figure 3.

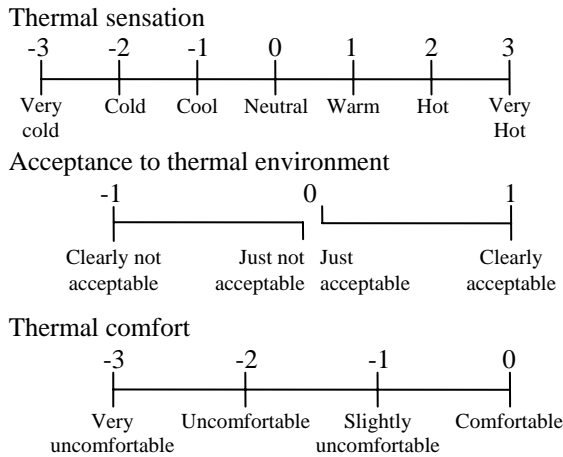


Figure 2 Subjective votes on thermal environment

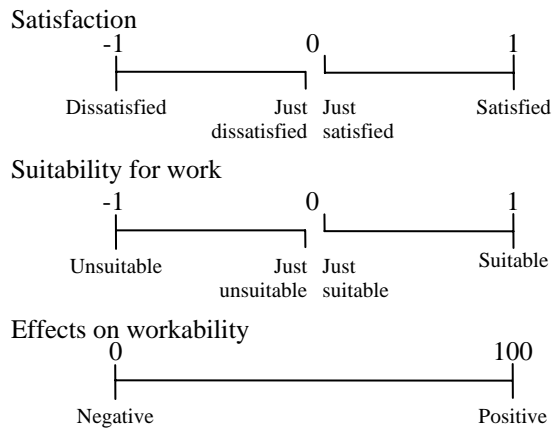


Figure 3 Subjective votes on productivity

To evaluate the feeling of fatigue, subjects filled in the questionnaire of “Evaluation of Subjective Symptoms of Fatigue [4]” on PC. It consists of three categories: group I consists of 10 terms on “drowsiness and dullness”, group II consists of 10 terms on “difficulty on concentration”, and group III consists of 10 terms on “projection of physical disintegration”. Based on Yoshitake’s method, the rate of complaints was calculated by the equation (1). By the order of rate of complaints among three categories, three types of fatigue feeling were suggested: “I>III>II” for general pattern of fatigue, “I>II>III” for typical pattern of mental work and overnight duty, and “III>I>II” for typical pattern of physical work. “General rate of complaints” is defined as the rate of complaints about all thirty symptoms.

$$\text{Rate of complaints} [\%] = \frac{\text{number of selected symptoms of all subjects}}{\text{number of terms concerned} \times \text{number of subjects}} \times 100 \dots(1)$$

Subjects were assigned to work on nine sessions of one-digit addition tasks which were programmed in computers. In each session, subjects worked on the task for 30 minutes. Performance was evaluated by the number of correct answers per session in terms of Z-score (standard score). Z-score was calculated from the equation (2)

$$\text{Z-score } S_{A,i} = \frac{x_{A,i} - \bar{x}_A}{s_A} \dots(2)$$

where, $x_{A,i}$ is the number of correct answers during the session i for subject A , \bar{x}_A is the average number of correct answers of the subject A among all sessions, and s_A is the standard deviation for the number of correct answers of the subject A among all sessions.

To evaluate fatigue from physiological responses, flicker tests were taken at the first vote, after the rest in sedentary, and after each task session. In each test, flicker values were measured for five times, and the average of three flicker values without the highest and the lowest values was calculated. Then, the flicker value was evaluated by the change rate from a value of flicker value measured after sedentary.

Statistical Analysis

The comparisons between the environmental conditions were analyzed by using one-way ANOVA with the level of significance of $p < 0.05$. When a significant difference of $p < 0.05$ was found, Fisher's protected LSD was used for further analysis. For analysis of correlation between fatigue level and corresponding Z-score of task performance, Pearson's product moment correlation coefficients weighted by number of subjects were calculated.

RESULTS

Perception of thermal environment

The results of thermal sensation, thermal acceptance and thermal comfort votes are shown in Figure 4, 5 and 6. From these results, subjects evaluated the conditions of 28.0°C with 0.93 clo and 28.0°C with 0.57 clo as hotter, less acceptable, and less comfortable than the condition of 25.0°C with 0.93 clo ($p < 0.01$, $p < 0.05$).

Productivity evaluated by the subjects

Satisfaction level of the thermal environment reported by the subjects is shown in Figure 7. Suitability of the thermal environment of the conditions for work reported by the subjects is shown in Figure 8. Effect of thermal environment of the conditions on workability reported by the subjects is shown in Figure 9. From the results, the environment of 28.0°C was evaluated as dissatisfied, unsuitable for work, and negative on workability, while that of 25.0°C was evaluated as satisfied, suitable for work, and positive on workability. Subjects evaluated the conditions of 28.0°C with 0.93 clo and 28.0°C with 0.53 clo as less satisfied, less suitable for work, and less positive than the condition of 25.0°C with 0.93 clo ($p < 0.01$, $p < 0.05$).

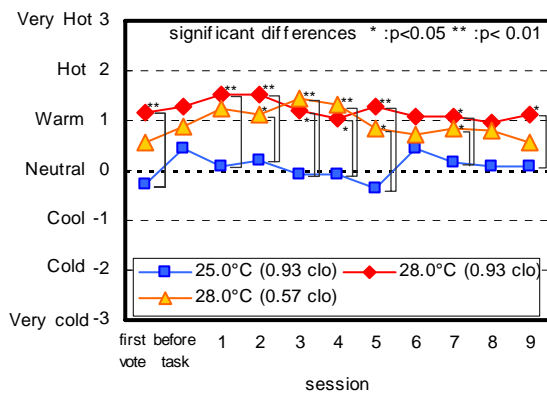


Figure 4 Thermal sensation

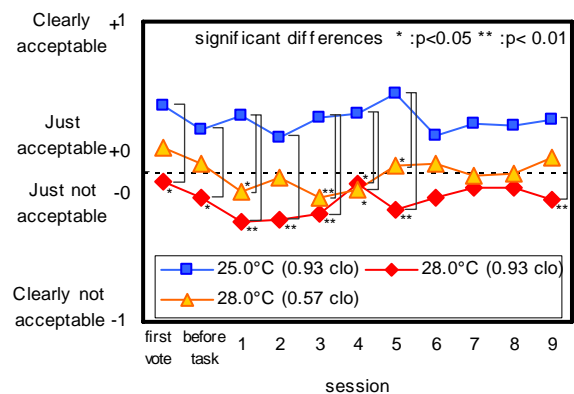


Figure 5 Thermal acceptance

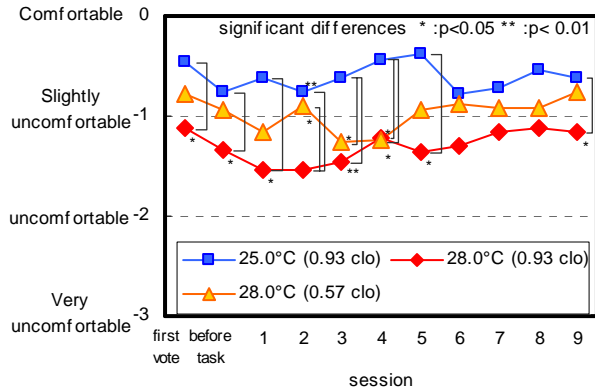


Figure 6 Thermal comfort

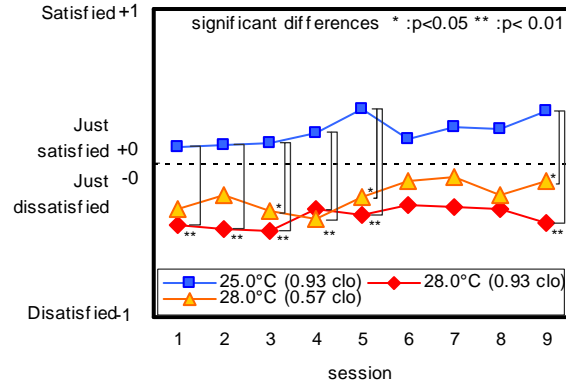


Figure 7 Satisfaction level of the thermal environment

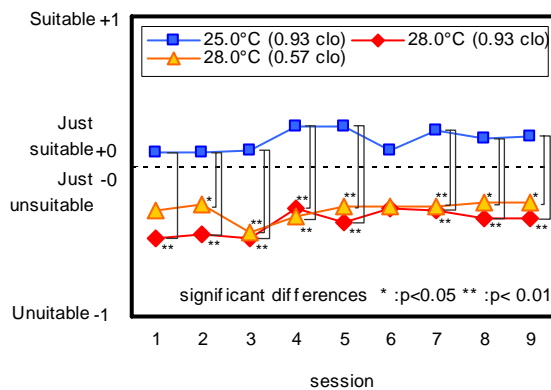


Figure 8 Suitability of the thermal environment

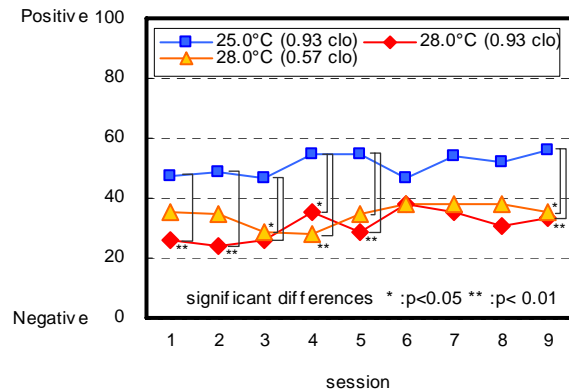


Figure 9 Effect of thermal environment on workability

Fatigue

The results of “Evaluation of Subjective Symptoms of Fatigue” are shown in Figure 10. The general rate of complaints tended to increase over the time in all conditions.

To evaluate fatigue after entire task sessions, the general rate of complaints of before and after tasks, i.e. the rates of complaints after sedentary and that after session 9, were calculated. The results are shown in Table 2. After the tasks, the general rate of complains increased, and the type of the fatigue feeling the subjects felt was the typical pattern of mental work and overnight duty (I>II>III) from the order of the categories in all conditions.

The change rate of flicker value is shown in Figure 11. The change rate of flicker value of after resting in sedentary, i.e. before task, was compared with the sessions after that. The increase rate of flicker value tended to decrease over the time in all conditions.

Table 2 The result of “Evaluation of Subjective Symptoms of Fatigue” before and after tasks

	Conditions	Rate of Complaints[%]				Category
		I	II	III	T	
Before task	25.0°C (0.93 clo)	17	11	9	12	I > II > III
	28.0°C (0.93 clo)	23	21	7	17	I > II > III
	28.0°C (0.57 clo)	20	4	12	12	I > III > II
After task	25.0°C (0.93 clo)	45	29	21	31	I > II > III
	28.0°C (0.93 clo)	45	43	22	37	I > II > III
	28.0°C (0.57 clo)	47	35	23	35	I > II > III

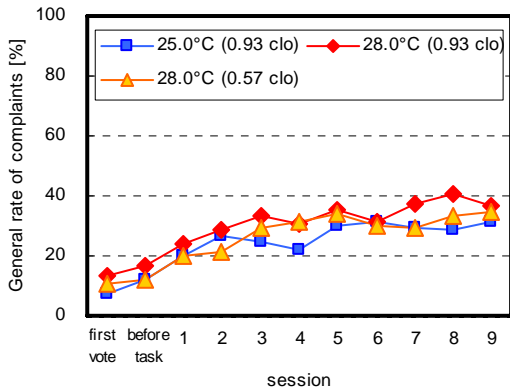


Figure 10 General rate of complaints

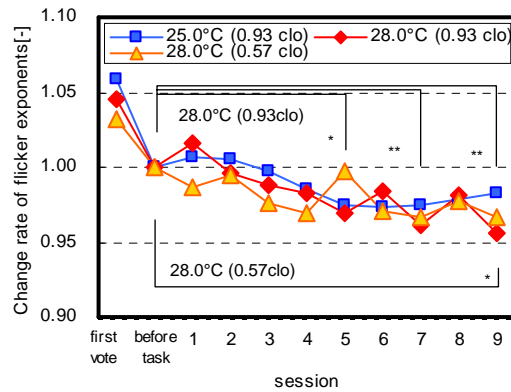


Figure 11 Change rate of flicker exponents

Performance

The result of Z-score is shown in Figure 12. The performance decreased as the sessions proceeded. The performance of the first session was compared with the sessions after that. Z-score did not change significantly at 25.0°C with 0.93 clo condition over the time. However, the performance was significantly lower after six sessions ($p < 0.01$, $p < 0.05$) at 28.0°C with 0.93 clo condition. Also, the performance was significantly lower after the third session ($p < 0.01$, $p < 0.05$) at 28.0°C with 0.57 clo condition. The performance at 28.0°C condition was not significantly lower than at 25.0°C condition.

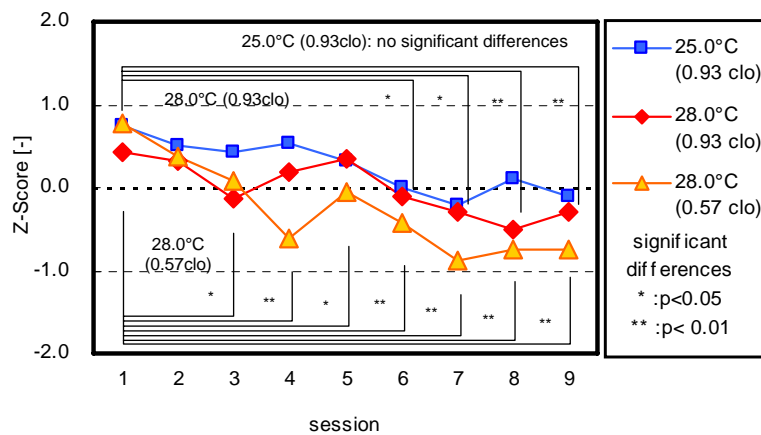


Figure 12 Task performance in Z-score

To determine the effects of thermal environment on fatigue, fatigue were analyzed in terms of the personal rates of complaints of fatigue, which are calculated by equation (1) whose number of subjects is 1. The relationship between the subjective votes on thermal environment and the personal rate of complaints of fatigue are shown in Figure 13. The data set of thermal sensation by the interval of 0.5 was averaged, and corresponding Z-score was averaged. Similarly, thermal acceptance the interval of 0.2 and thermal comfort by the interval of 0.2 were calculated. Circle shown in Figure 13 describes the number of corresponding subjects. The correlation coefficients of fatigue and thermal sensation was 0.44, thermal acceptance was -0.91 and thermal comfort was -0.93. From the result, fatigue increase when the subjects evaluated the thermal environment as hot, unacceptable, and uncomfortable.

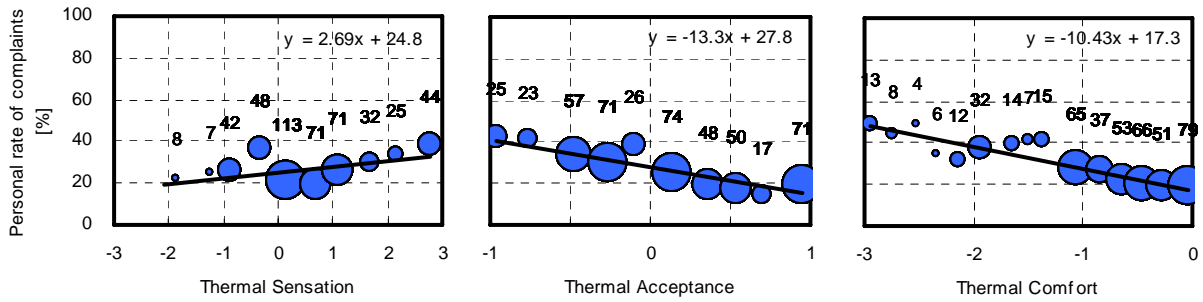


Figure 13 The correlation of the subjective vote on thermal environment and personal rate of complaints of fatigue

To determine the relationship between the level of fatigue and performance, personal rates of complaints of fatigue were analyzed. The relationship between personal rates of complaints of fatigue and task performance is shown in Figure 14. The data set of personal rates of complaints by the interval of 10% was averaged, and corresponding Z-score of task performance was calculated. The correlation between personal rates of complaints of fatigue and performance was observed ($r = -0.76$). In order to standardize the number of correct answers which included individual differences, standard number of correct answers was calculated by the equation (3).

$$\text{Standard number of correct answers } T = \frac{\sum_{i=1}^N (\bar{x}_A + S_{A,i} \times s_A)}{N} \quad \dots(3)$$

where, \bar{x}_A is the average number of correct answers of the subject A among all sessions, $S_{A,i}$ is the number of correct answers in Z-score, s_A is the standard deviation for the number of correct answers of the subject A among all sessions, and N is the total number of data.

From the linear regression model obtained from the results, increase in 10% of fatigue corresponds to the decrement in the standard number of correct answers by 1.7%.

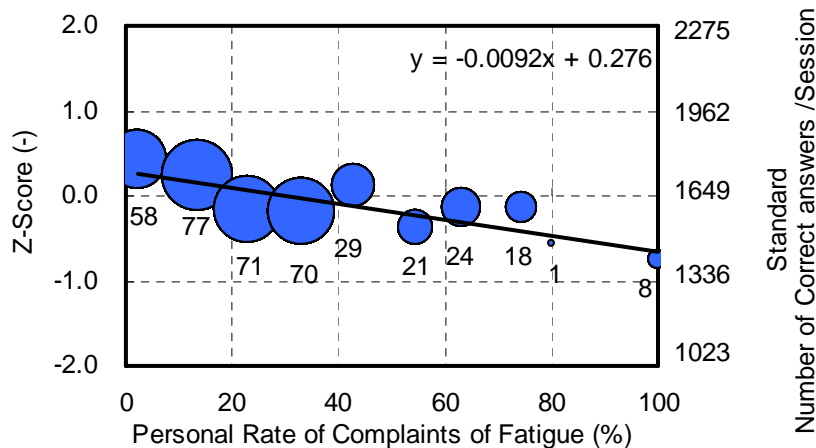


Figure 14 The correlation of the personal rates of complaints of fatigue and performance

DISCUSSION

It was suggested to evaluate productivity not only with task performance but also with human responses such as feeling of fatigue and cerebral blood oxygenation in the short exposure (2-3 hours) studies [1], [2]. There was an assumption that the high level of fatigue would lead the workers to perform worse. In this study, six hours experiment was conducted, and the results

showed that there was a relationship between the subjective votes on thermal environment and the level of fatigue. Also, a relationship between the level of fatigue and performance was observed. Increase in 10% of fatigue corresponds to the decrement in standard number of correct answers of one-digit addition by 1.7% in this experiment. The results, higher level of fatigue had negative effect on task performance, supported the earlier assumption and implied the possibility that to measure subjective votes, productivity would be evaluated with higher dimensional accuracy.

CONCLUSION

To examine the effect of thermal environment on performance and fatigue, and the relationship between performance and fatigue, subjective experiments were conducted and the following results were obtained.

1. The general rate of complaints of fatigue tended to increase over the time in all conditions.
2. The performance decreased as the sessions proceeded. The performance at 28.0°C condition was not significantly lower than at 25.0°C condition.
3. The personal rate of complaints of fatigue increased when subjects evaluated the environment as hot, unacceptable, and uncomfortable. From the results, there might be effects of thermal environment on fatigue.
4. The correlation between personal rates of complaints of fatigue and performance was observed ($r = -0.76$). From the linear regression model obtained from the results, increase in 10% of fatigue corresponds to the decrement in the standard number of correct answers by 1.7%

ACKNOWLEDGEMENT

The authors wish to express their appreciation to Ms. A. Tanaka, Ms. M. Hayakawa, Mr. S. Hyodo, and Mr. T. Kumata for their assistance during the experiment. This study was partially funded by the Project Research of Advanced Research Institute for Science and Engineering, Waseda University and by the Global Environment Research Fund (H-061) by the Ministry of Environment, Japan.

REFERENCES

1. Tanabe, S. and Nishihara, N. 2004. Productivity and fatigue, *Indoor Air*, No.14, pp.126-133
2. Tanabe, S. 2006. Indoor Temperature, Productivity and Fatigue in Office Tasks, *Healthy Buildings 2006, Proceedings Vol.1*, pp.49-56
3. 2005. ASHRAE HANDBOOK FUNDAMENTALS, SI Edition
4. Yoshitake, H. 1973. Occupational fatigue-Approach from subjective symptom, Tokyo, Japan: The institute for science of labor (in Japanese)