The Fifth International Conference on Human-Environment System
ICHES2016 Nagoya, October 29 - November 2, 2016

EFFECTS OF INDOOR TEMPERATURE CHANGES ON OCCUPANTS' AROUSAL STATE

Maiko Furukawa[1)], Tomonobu Goto[1)], Yuri Yanagida[2)], Ryosuke Kondo[1),]
Kunio Mizutani[3)] and Kenji Tsukamoto[4)]
1) Graduate School of Engineering, Tohoku University, Sendai, Miyagi, 980-8579, Japan
2) Taisei Corporation, Shinjuku-ku, Tokyo, 163-0606, Japan
3) Faculty of Engineering, Tokyo Polytechnic University, Atsugi, Kanagawa, 243-0297, Japan
4) Sato Kogyo Co., Ltd., Atsugi, Kanagawa, 243-0123, Japan
Contact person: t-goto@sabine.pln.archi.tohoku.ac.jp

ABSTRACT
Indoor environment affects occupants' physical and psychological condition, and such condition disturbs relationship between occupants' ability and their performance. Arousal is one of the representing factors of the physical and psychological condition. Our previous study (Goto et al., 2015) had shown that high energetic arousal (EA) causes high work performance but high tense arousal (TA) causes low task performance. In the present study, we investigated a new indoor temperature control method, which is more effective to improve arousal state and work performance than keeping a constant indoor temperature. We carried out two experiments. The first experiment was to observe effects of each rising and falling temperature on arousal state. Six experimental cases were tested in the experiment. Four cases contained a change of indoor temperature from 23°C to 29°C or the opposite, and the rate of the change was 0.15°C/min or 0.30°C/min. Other two cases were set as comparative cases and the temperature was constant at 23°C or 29°C. Eighteen subjects participated, and all six cases were assigned to each of them. The results showed that TA after the temperature rising or falling was lower than that in the case of the constant temperature of 23°C. Moreover, EA after the temperature rising with 0.30°C/min or falling with 0.15°C/min was higher than that in the case of 23°C. Based on the first experiment, we proposed two patterns of cyclic temperature change and tested in the second experiment. Both patterns consisted of 0.30°C/min rising and 0.15°C/min falling, but the temperature range and the cycle time were different. We also tested two constant temperature cases (23°C and 26°C) for comparison with the cyclic change cases. Thirty-one subjects participated, and all four cases were assigned to each subject. During the experiment, the subjects performed a number puzzle task (Sudoku) to evaluate their performance. As a result, it was found that the cyclic temperature pattern could improve occupants' arousal state and performance, if the occupants had spent a certain time without any strong stimuli except for the temperature change.

Keywords: Arousal state, Work performance, Productivity, Unsteady thermal environment

1. INTRODUCTION

Occupants' work performances are primarily related to their abilities for the works. However, indoor environment affects occupants' physiological and psychological responses, e.g. motivation, arousal and fatigue, and those responses disturb the relationships between the abilities and performances. We had done a series of studies on the causal relationship between indoor environment and occupants' performance mediated by their arousal state (Goto et al., 2015a, b). Those studies had shown that arousal state was a better indicator of subjects' task performance than thermal satisfaction. In addition, they had shown that 22°C of indoor temperature brought better arousal state than 28°C, and consequently task performance at 22°C was better than that at 28°C.

According to the previous studies, improving occupants' arousal state is one of the keys for improving their performance. On the other hand, some sort of indoor temperature changes may improve occupants' arousal state than keeping a constant indoor temperature. Therefore, we tried to find whether there are any effective indoor temperature change patterns for improving arousal state and consequently work performance.

The present study consisted of two stages. In the first stage, we carried out an experiment to observe the effects of temperature rising on arousal state and the effects of temperature falling on arousal state, respectively. In the second stage, we derived two cyclic temperature change patterns from the findings of the first stage, and carried out another experiment to confirm the availability for improving arousal state and task performance.

2. FIRST STAGE EXPERIMENT

2.1 Methods

In the first stage, a subjective experiment was done to observe the effects of temperature rising on arousal state and the effects of temperature falling on arousal state respectively. The subjects' arousal state was evaluated with a questionnaire: Japanese UIST Mood Adjective Checklist (JUMACL, Shirasawa et al., 1999), shown in Table 1. Each adjective was converted into the score as shown in Table 2, which was slightly modified by us from the original manner. With this questionnaire, arousal state can be evaluated in two dimensions, i.e. energetic arousal (EA) and tense arousal (TA). We had used it in our previous studies (Goto et al., 2015a, b), and found that high energetic arousal (EA) causes high task performance but high tense arousal (TA) causes low task performance.

Table 1. JUMACL (Questionnaire on arousal state)

Does the adjective define your present mood?

(1: Definitely, 2: Slightly, 3: Slightly not, 4: Definitely not)

Restful	1	2	3	4	Unenterprising	1	2	3	4
Bright	1	2	3	4	Placid	1	2	3	4
Energetic	1	2	3	4	Calm	1	2	3	4
Relaxed	1	2	3	4	Dull	1	2	3	4
Nervous	1	2	3	4	Anxious	1	2	3	4
Sleepy	1	2	3	4	Vigorous	1	2	3	4
Industrious	1	2	3	4	Idle	1	2	3	4
Composed	1	2	3	4	Stirred up	1	2	3	4
Tense	1	2	3	4	Active	1	2	3	4
Passive	1	2	3	4	Jittery	1	2	3	4

Table 2. Scores of JUMACL

Energetic Arousal (EA)	Bright, Energetic, Active, Vigorous, Industrious	Definitely (+3), Slightly (+2), Slightly not (+1), Definitely not (0)
	Sleepy, Passive, Idle, Dull, Unenterprising	Definitely (-3), Slightly (-2), Slightly not (-1), Definitely not (0)
Tense Arousal (TA)	Nervous, Tense, Anxious, Jittery, Stirred up	Definitely (+3), Slightly (+2), Slightly not (+1), Definitely not (0)
	Restful, Relaxed, Calm, Placid, Composed	Definitely (-3), Slightly (-2), Slightly not (-1), Definitely not (0)

This experiment was conducted in an experimental room at Tohoku University in October 2014. Figure 1 shows the layout of the experimental room. The experimental cases were shown in Table 3. Cases 1 and 2 were set as the reference cases, and the indoor operative temperature was kept at a constant of 23°C or 29°C. Cases 3 to 6 were the target cases. These cases contained a change of indoor operative temperature from 23°C to 29°C or the opposite, and the rate of the change was 0.15°C/min or 0.30°C/min. Figure 2 shows the time course of the temperature change. Outdoor air (OA) supply rate was set at 30m^3/h/person. Illumination intensity was set at 200 lx. Humidity was not controlled and varied between 0.004 to 0.009 kg/kg'.

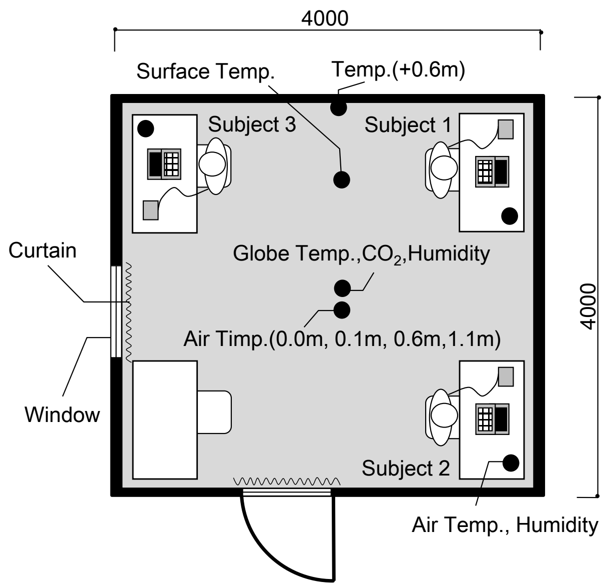

Figure 1. Experimental room

Table 3. Experimental cases (First stage)

	Indoor operative temperature
Case 1	23°C
Case 2	29°C
Case 3	From 23°C to 29°C (0.30°C/min)
Case 4	From 23°C to 29°C (0.15°C/min)
Case 5	From 29°C to 23°C (-0.30°C/min)
Case 6	From 29°C to 23°C (-0.15°C/min)

Figure 3 shows the schedule of an experimental session. Before entering the experimental room, subjects did light stepping exercise for 3 min to warm up their body. After the entering experimental room, subjects engaged in six sets of Sudoku task. The questionnaires on arousal state were answered before and after each task. Other questionnaires on physical condition, environmental satisfaction and fatigue were answered before the 1st task and/or after the 6th task. Each subjects participated in each of six experimental sessions of different experimental cases, and the experimental cases were assigned to the subject in a randomized order.

Eighteen subjects (17 male and 1 female) participated as volunteers. They were all university students or graduate students with an average age of 21.8 years. They were paid for their participation. To reduce the effects of circadian rhythm, all experimental sessions of each subject were done in the same time frame (10:00-12:40 or 15:00-17:40). All subjects were instructed to wear as 0.68 clo.

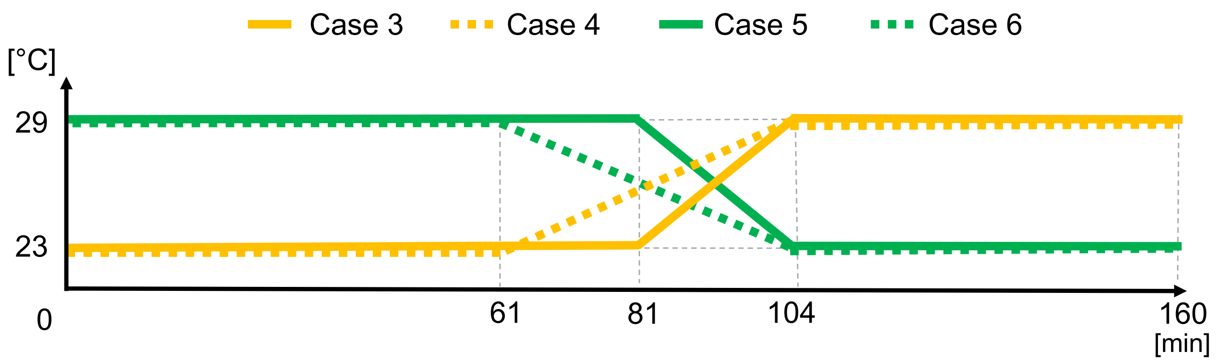

Figure 2. Time course of temperature change (First stage)

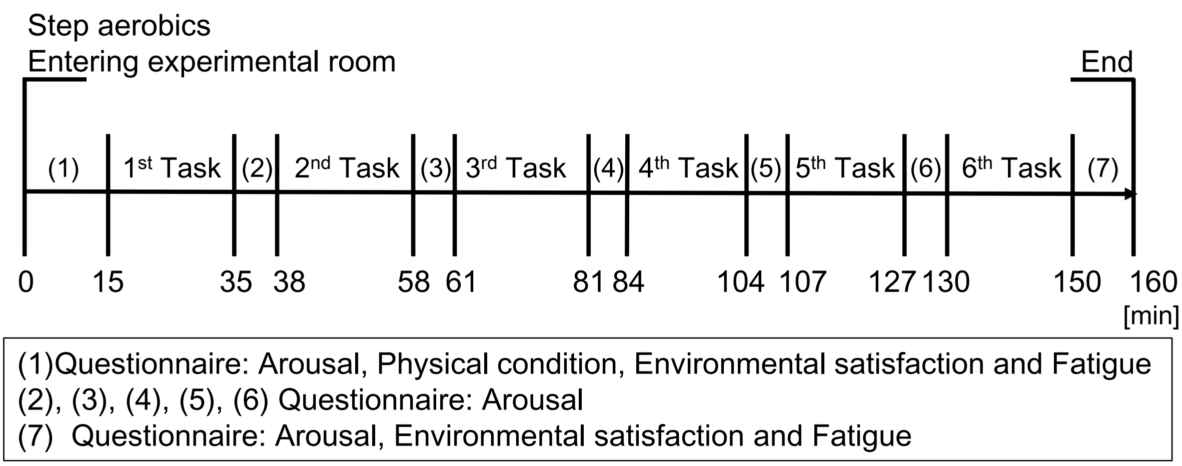

Figure 3. Schedule of experimental session (First stage)

2.2 Results and discussions

Figures 4 and 5 show the results of arousal state in temperature rising and falling cases, respectively. The marks in these figures indicate significance of differences between cases which were tested by Wilcoxon signed rank test. However, the marks between Case 1 and Case 2 were omitted from the figures although EA in Case 1 was significantly higher than Case 2 during the whole experimental period except for the first and last assessments.

As shown in Figure 4, EA in Case 3 increased just after the temperature rising. At this moment, EA in Case 3 was higher than that of Case 1 although the difference was not significant. In contrast, EA in Case 4 decreased after the temperature rising. On the other hand, TA after the temperature risings in Cases 3 and 4 were lower than that at the same period in Case 1, although the differences were not significant.

As shown in Figure 5, EA in both Cases 5 and 6 increased after the temperature falling. Especially, EA in Case 6 tended to become higher than that in Case 1, and the difference at 150 min, i.e. 40 min after the temperature falling, was found to be significant ($p<0.05$). TA after the temperature fallings in Cases 5 and 6 were lower than that of Case 1, although the differences were not significant except for Case 5 at 105 min.

The findings in this experiment suggested that temperature rising with 0.30°C/min and falling with 0.15°C/min had an effect to make occupants' EA higher. It was also suggested that temperature rising and falling had an effect to make occupants' TA lower.

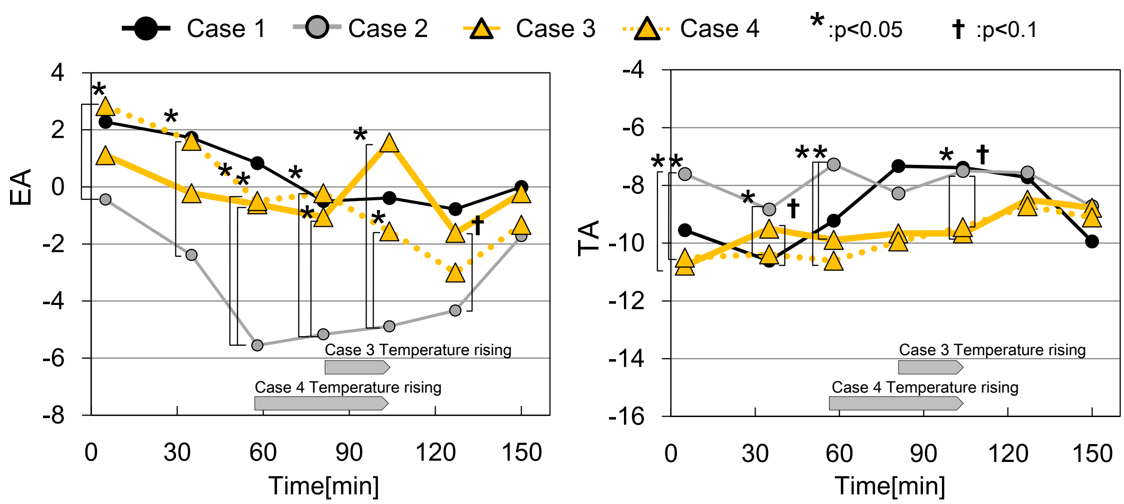

Figure 4. EA and TA (Case 1, 2, 3 and 4)

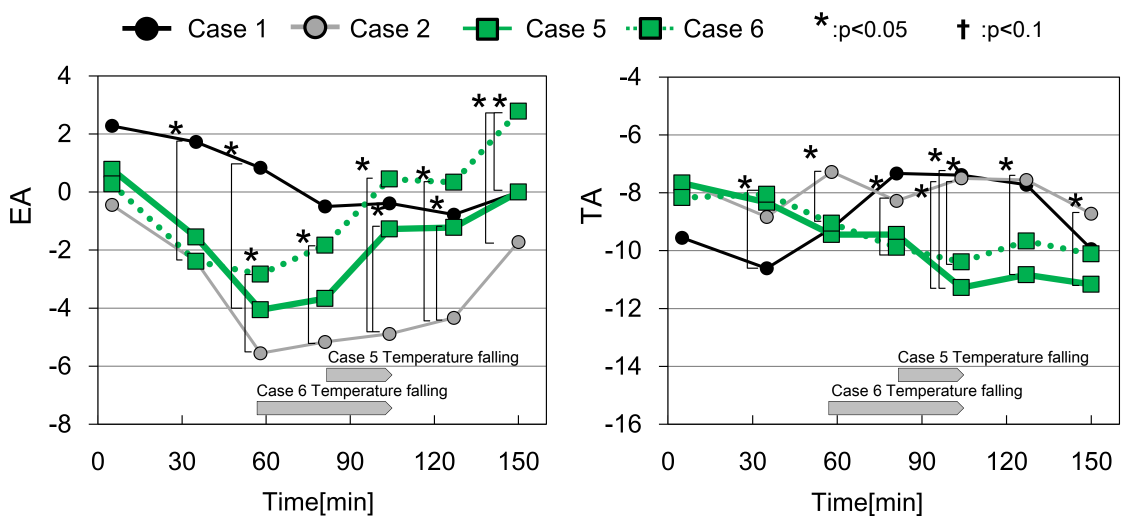

Figure 5. EA and TA (Case 1, 2, 5 and 6)

3. SECOND STAGE EXPERIMENT

3.1 Methods

Based on the first stage experiment, we proposed two cyclic temperature change patterns for improving arousal state and task performance. Both patterns consisted of 0.30°C/min rising and 0.15°C/min falling, but the temperature range and the cycle time were different. One was between 23°C to 29°C in 60 min cycle, and the other was between 24.5°C to 27.5°C in 30 min cycle. In order to confirm the effects of these patterns, another subjective experiment were carried out.

The experiment was conducted at the same experimental room as the first stage from July to August 2015. The experimental cases were shown in Table 4. Cases 1 and 2 were set as the reference cases, and the indoor operative temperature was kept at a constant of 23°C or 26°C. Cases 3 and 4 were the target cases with the proposed temperature change patterns. Figure 6 shows the time course of the operative temperature change, and there are two lines with each case. Half of the subjects were assigned to one of them, and the other half were assigned to the other. OA supply rate was set at 30m^3/h/person. Illumination intensity was set at 200 lx. Humidity was not controlled and varied between 0.008 and 0.011kg/kg'.

Figure 7 shows the schedule of an experimental session. During the first 30 min, subjects adapted to the environment while watching a video lecture about geoscience. Then, the subjects engaged in four sets of Sudoku task. Subjects' arousal state was evaluated before and after each task by using the same questionnaire as the first stage experiment. Subjects' performance was evaluated by the number of correct answers of Sudoku. Each subjects participated in each of four experimental sessions of different experimental cases, and the experimental cases were assigned to the subject in a randomized order.

Thirty-one subjects (16 male and 15 female) participated as volunteers. They were all university students or graduate students with an average age of 21.5 years. They were paid for their participation. To reduce the effects of circadian rhythm, all experimental sessions of each subject were done in the same time frame (10:00-12:45 or 15:00-17:45). All subjects were instructed to wear as 0.68 clo.

Table 4. Experimental cases (Second stage)

	Indoor operative temperature
Case 1	23°C
Case 2	26°C
Case 3	Between 23°C and 29°C (60 min cycle)
Case 4	Between 24.5°C and 27.5°C (30 min cycle)

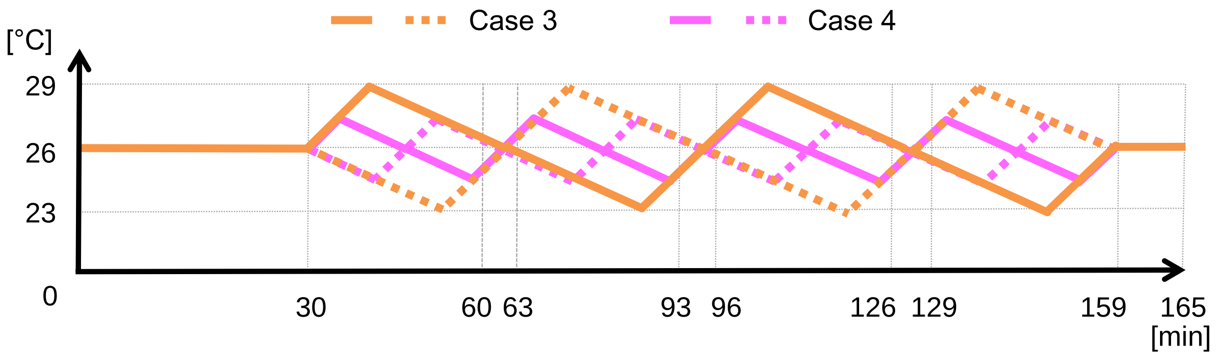

Figure 6. Time course of temperature change (Second stage)

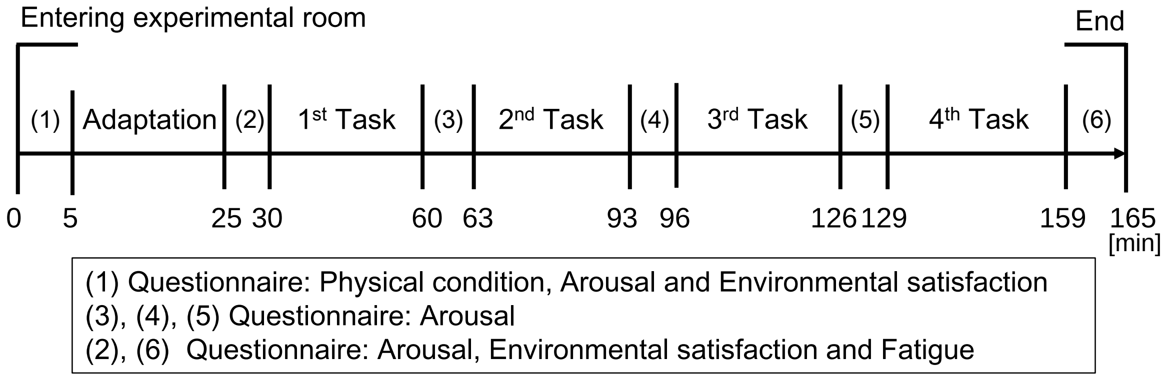

Figure 7. Schedule of experimental session (Second stage)

3.2 Results and discussions

Figure 8 shows the results of arousal state and performance. EA in Cases 1 and 2 had the peak at 60 min, i.e. just after the first task, and decreased continuously until the end of the experimental session. EA in Cases 3 and 4 also had similar trend in the early part of the session, but tended to increase again in the latter part of the session. On the other hand, TA in Cases 1 and 2 were almost constant during the whole session, while that in Case 3 tended to increase in the early part and decrease in the latter part. However, there were almost no significant differences between the cases both in EA and TA.

There were also almost no significant differences in subjects' performance. Thus, it was not confirmed that the proposed temperature change patterns had any positive effects on occupants' arousal and performance.

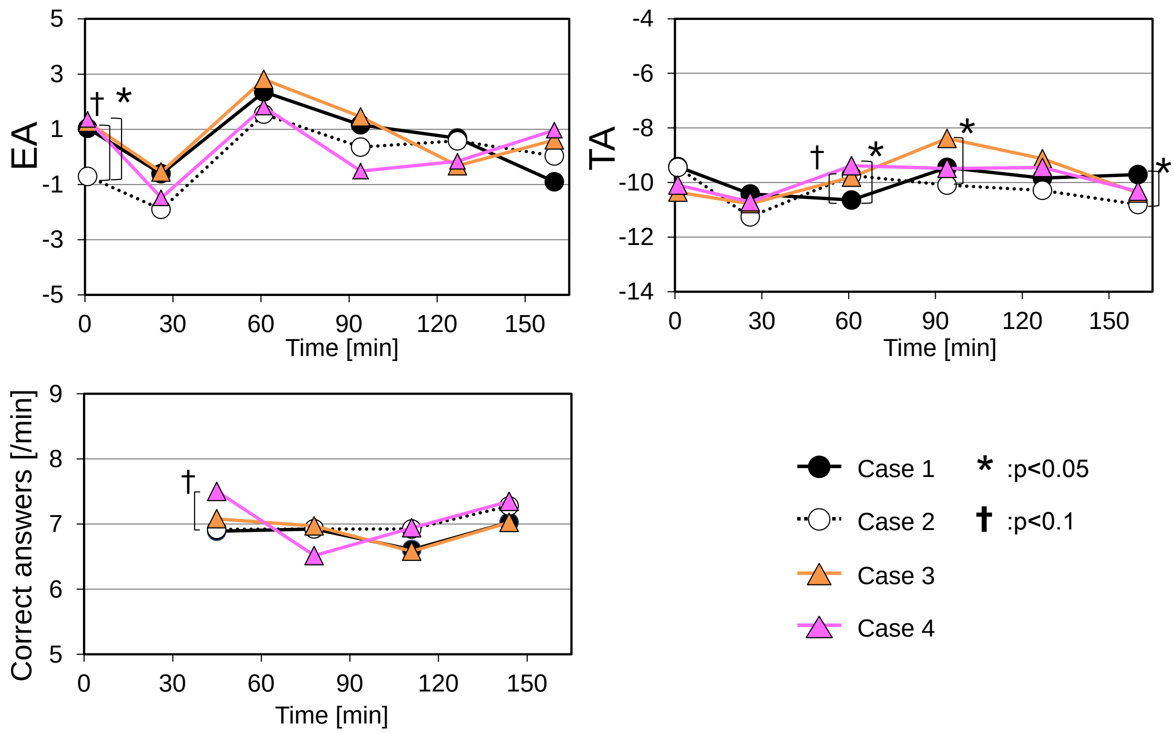

Figure 8. EA, TA and performance (All subjects)

Despite of the facts mentioned above, there were some possibilities that the results were disturbed by the outdoor temperature which subjects experienced before the experiment. Therefore, we divided the subjects into two groups and re-analyzed the results of each groups. The subjects who exposed to high outdoor temperature just before the experiments were distinguished into Group A. The average of the outdoor temperature was about 31°C. The subjects who exposed to low outdoor temperature just before the experiments were distinguished into Group B. The average of the outdoor temperature was about 26°C.

Figures 9 and 10 show EA, TA and performance of each group. It was found that the EA was clearly different between the groups, and the EA of Group B indicated the positive effects of the temperature change pattern of Case 4. The reason of this result can be inferred from the first stage experiment. The first stage experiment had shown that the temperature falling made EA higher and kept it for at least 40 min. Therefore, it was considered that the EA of Group A was made higher by the fall of the exposed temperature when entering the room in every case, and this effect must be remained for 40 min or longer. Thus, the temperature fallings given in Cases 3 and 4 did not effectively contribute to improve EA, unless the effects were simply accumulative. On the other hand, the first stage experiment had shown that the temperature rising made EA higher. However, this temperature rising was given to the subjects after spent the time for 80 min without any strong stimuli (staying the same room and doing the same task). This fact implies that the temperature risings given in Cases 3 and 4 contributed positively only in the latter part of the experiment, while those could affect negatively in the early part of the experiment. It must be the reason why EA of Group B became higher in Cases 3 and 4 than that in Case 1 only in the latter part of the experiment. Moreover, such effects of temperature rising must cause that EA of Group A was lower in Case 4 than that in Case 1.

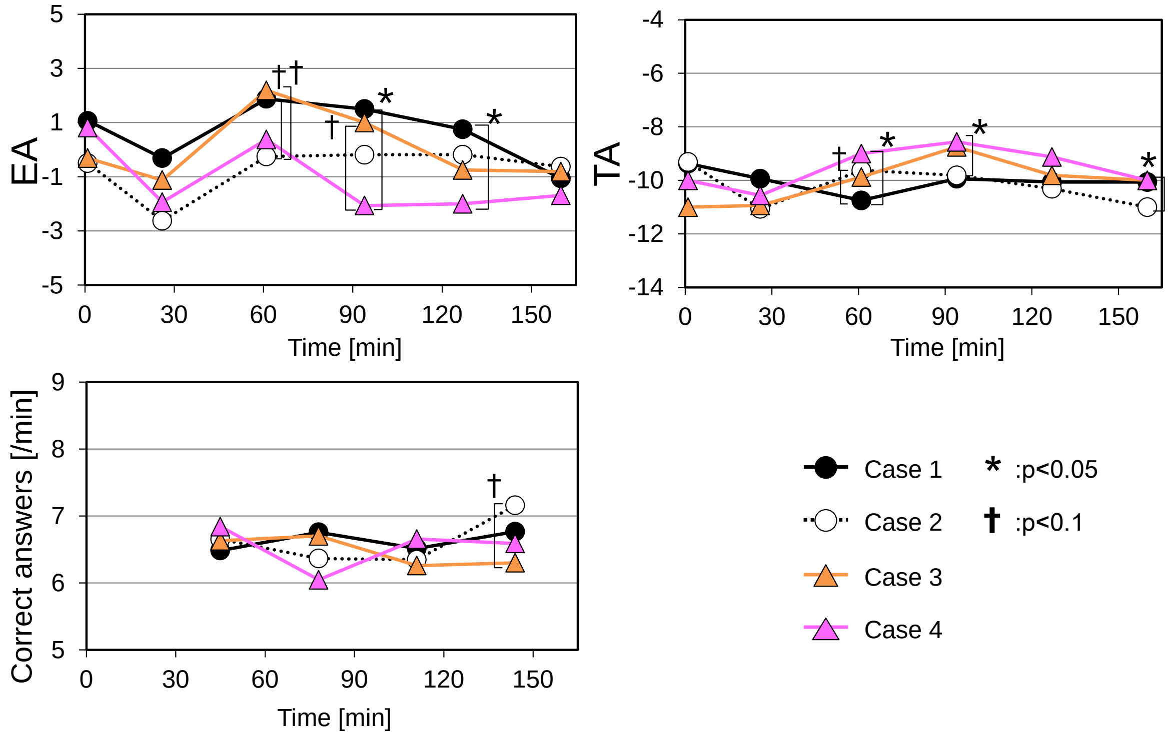

Figure 9. EA, TA and performance (Group A)

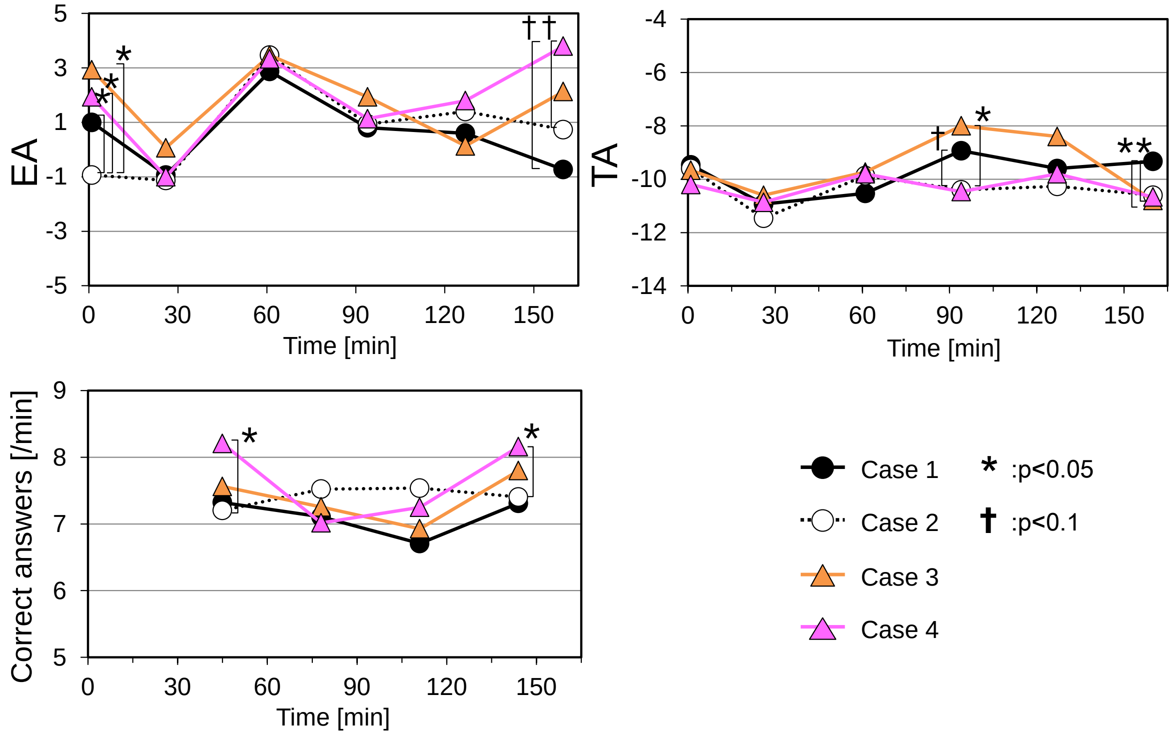

Figure 10. EA, TA and performance (Group B)

As shown in Figures 9 and 10, TA of both groups tended to increase in early part but decrease in latter part. It can also be explained by the effects of temperature rising. On the other hand, subjects' performance in Cases 3 and 4 of Group B tended to increase in the latter part of the experiment. It corresponded to the fact that EA increased toward the end of the experiment.

4. CONCLUSIONS

We conducted two subjective experiments to find whether there are any effective patterns of indoor temperature change for improving arousal state and performance. In the first stage experiment, it was suggested that temperature rising with 0.30°C/min and falling with 0.15°C/min had some potential to improve occupants' arousal state. In the second stage experiment, we tried to confirm the effects of cyclic temperature change pattern which consisted of 0.30°C/min rising and 0.15°C/min falling. From this experiment, it was found that the cyclic temperature pattern could improve occupants' arousal state and performance, if the occupants had spent a certain time without any strong stimuli except for the temperature change.

5. ACKNOWLEDGMENTS

This study was supported in part by Grant for Environmental Research Projects from the Sumitomo Foundation, and by the Joint Usage/Research Program of the Wind Engineering Research Center, Tokyo Polytechnic University.

6. REFERENCES

Shirasawa, S., et al. 1999. The effects of energetic arousal on memory search, The Japanese Journal of Psychonomic Science, 17, pp.93-99.

Goto, T., Koganei, M., Hiramatsu, M. 2015a. Subjective experiments on relationships between indoor environment and arousal state and between arousal state and work performance, Healthy Buildings Europe 2015, Paper ID 575

Goto, T., Koganei, M., Hiramatsu, M. 2015b. Subjective experiment on causal relationship between indoor temperature and occupants' performance mediated by arousal state, Healthy Buildings Europe 2015, Paper ID 576