Effect of Overcooling on Productivity Evaluated by the Long Term Field Study

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SUMMARY

A long-term field study was conducted in an office for seven months to clarify the effect of thermal environment on productivity. Seven male software programmers participated as subjects. They answered the questionnaires on their personal computer including thermal sensation votes, complaints about their working environment, fatigue, vitality, mental workload and self estimated productivity every workday. The numbers of keystrokes were automatically recorded during the operation of their computers. Advanced Trail Marking Test (ATMT) was also conducted as the estimation of performance. Under lower temperature, the percentage of dissatisfied about “Low temperature” and “Draft” were higher and the vitality level was lower. The decrement in the total number of keystrokes of one day was 7.8% and that in the numbers of reaction per second of ATMT was 2.6% as temperatures dropped by 1.0°C below thermally neutral temperature. The result showed that overcooling brought the decrement of performance in the office.

INTRODUCTION

The objective of this study was to clarify the effect of thermal environment on productivity in the actual office. Especially, the effect of overcooling on office workers’ productivity was discussed in this study. A field study was conducted in a programmers’ office for seven months. The air temperatures were measured near the subjects’ desks. The relationships of air temperature, subjective vote and their performance were analyzed.

It is not simple to quantify the effects of thermal environment on performance of actual office works objectively. In this study, the numbers of keystrokes of the programmers were automatically recorded during their work time as their performance. Advanced Trail Marking Test (ATMT) [1] which was the standardized performance test that requires searching and clicking on the target character from twenty-five randomly appeared alphabets on their computers’ screen, was also asked to subjects.

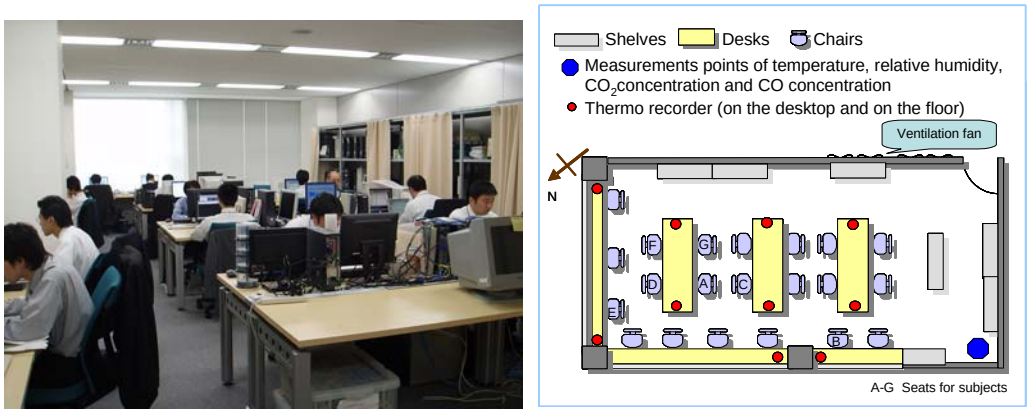
METHODS

The field study was conducted from July 2005 to January 2006 in the programmers’ room. During the field study, the office was cooled by air-conditioner. The setting temperature of air-conditioning unit during the survey is shown in Table 1. The scene of the programmer’s room and the floor plan of the programmers’ room are shown in Figure 1.

Air temperature, relative humidity, the concentrations of CO_2 and CO were measured 10-minute intervals by IAQ -Calc Model 8762 (TSI) during the survey. The concentration of CO_2 was 577±135ppm and that of CO was 2.6±0.4ppm. Air temperature and relative humidity near the subjects' seats were measured. At each with measurement point, the environmental factors at the height of desktop and floor were measured 10-minute intervals by thermo recorder TR-72U（T and D）. The measurement points are shown in Figure 1.

Table 1. The setting temperature of air-conditioning unit

Setting temp. (°C)	4-8 Jul.	11-15 Jul.	19-22 Jul.	25-29 Jul.	1-5 Aug.	8-12 Aug.	22-26 Aug.	29 Aug. -2 Sep.	5-6 Sep.	7-9 Sep.	12-30 Sep.	3 Oct. -18 Jan.
Working hour 10:00-17:00	21	23	24	22	24	24	26	26	25 -28	25	Un-known	24
Others	19	21	22	19	22	21	24	25		24		23



(a) (b)

Figure 1. (a) Scene and (b) the floor plan of the programmers' room

In the room, ten to twenty programmers were working depending on the type and scale of their projects. In this study, seven male software programmers, with their age of 28.4±2.9, height of 168.1±3.5cm, and weight of 57.6±6.6kg, participated as the subjects. They were in their suits as usual and they were allowed to adjust their clothing.

They answered the questionnaires on their computer including thermal sensation votes, complaints about office environmental quality, fatigue and vitality at the beginning and the end of their office hours. They also answered mental workload and self estimated productivity at the end of their office hours every workday.

The voting items are shown in Table 3. Thermal sensation was voted on scales. Complaints on other indoor environmental elements were reported by checking the applicable items listed in "Complaints about indoor environment".

As the scale for subjective evaluation on mental workload, National Aeronautics and Space Administration Task Load Index (NASA-TLX) was proposed by Hart and Staveland [2]. The Japanese version of NASA-TLX [3] was used. NASA-TLX consists of six components: 'mental demand', 'physical demand', 'temporal demand', 'performance', 'effort' and 'frustration level'. The subjects indicated these components by a mark on each scale. The leftmost end was 'good (0)', and the rightmost end was 'poor (100)' for 'performance' scale. The leftmost ends were 'low (0)', and the rightmost ends were 'high (100)' for the other

scales. For a comprehensive evaluation of the mental workload, Raw TLX (RTLX) proposed by Miyake was used. RTLX were calculated by averaging ratings of six components.

To evaluate the feeling of fatigue, 'Evaluation of Subjective Symptoms of Fatigue' suggested by the working group for occupational fatigue of the Japan Society for Occupational Health [4] was used. 'Evaluation of Subjective Symptoms of Fatigue' has been used in the field of labor science and ergonomics in Japan. It consists of 30 terms of fatigue symptoms. 'General rate of complaints' was defined as the rate of complaints about all 30 symptoms and calculated by equation (1) for each subject.

$$\text{Rate of complaints (\%)} = \frac{\text{Total number of a corresponding fatigue symptom of each subject}}{\text{Total number of symptoms on the evaluation sheet}} \times 100 \quad (1)$$

To evaluate the vitality level, each subject listed up 20 items that they want to do on their free time before the survey, and they filled in whether they want to do them at the time of voting. Along with 'Evaluation of Subjective Symptoms of Fatigue', the vitality level was defined as the rate of applicable items about respective 20 items.

Subjects also reported the self estimated performance by marking a scale. The scale was the estimation on how subjects thought their productivity at work would be enhanced or interfered by the environment near their seat (+100: enhance their productivity, 0: interfere their productivity).

Table 3. Voting items

Subjective votes about indoor environment	Mental workload
●Thermal sensation -3 -2 -1 0 1 2 3 Cold Cool Slightly cool Neutral Slightly warm Warm Hot ●Complaints about indoor environment (check the applicable items) □High temp. □Stuffy air □Low temp. □Humid air □Adjustability of temp. □Dry air □ Nonuniform temperature □Not enough air velocity □Not enough lighting □Unpleasant odor □Glaring □Distracted by other people □Too much lighting □Draft □Noise □Dust and dirt	NASA-TLX Japanese Version The feeling of fatigue Evaluation of subjective symptoms of fatigue The feeling of vitality level Beforehand subjects list up 20 items what they want to do on their free time. And they fill in whether they want to do them at the time. Self estimated productivity The estimation on how subjects thought their productivity at work would be enhanced or interfered by the environment near their seat (+100: enhance their productivity, 0: interfere their productivity).

For the performance of work, their numbers of keystroke were automatically recorded during the operation of their computers, since much of their works involve in typing. For the analysis, the data for ten minutes at the beginning and the end of the operation time of their computers were eliminated to exclude the possible keystrokes for responding questionnaire.

ATMT was also conducted at the beginning and the end of office hours as the estimation of performance. In this test, subjects were asked to search and click on the target character "R" in twenty-five alphabets on their computers' screen. The distributions of the alphabets are presented randomly and repeatedly 70 times on their screen. For the analysis, the numbers of reaction per second at the end of their office hours were calculated.

The air temperature at the height of desktop near each subjects were averaged from ten o'clock to eighteen o'clock. The data sets of air temperature by the interval of 0.5°C were averaged, and corresponding subjective vote and their performance were averaged. The size of the plots shown in figures describes the number of corresponding subjects. For analysis of correlation between the air temperature and corresponding subjective vote and their performance, Pearson's product moment correlation coefficients weighted by the number of subjects were used.

RESULTS

Thermal sensation vote

The relationship of air temperature and thermal sensation vote with the linear regression model obtained from the plots is shown in Figure 2. Thermally neutral temperature was derived from the regression model as the temperature at which the thermal sensations vote becomes zero. The temperature was 28.6°C in this study. The reasons that thermally neutral temperature was relatively high were: air velocity in the room was 0.2-0.4m/s and was relatively high for offices, and subjects were able to adjust their clothes.

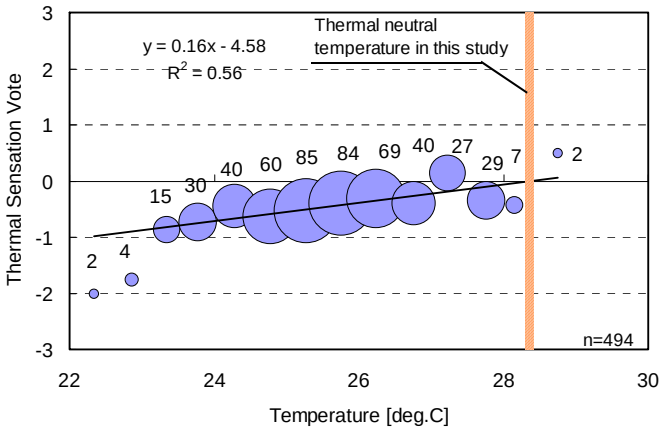


Figure 2. The relationship of air temperature and thermal sensation vote

Complaints about indoor environment

The percentages of complaints to all responses are shown in Figure 3. The percentage exceeded 10% were "Low temperature", "Draft" and "Noise". The equivalent sound level of the office was 60dBA, which it might have lead to the high rate of complaints on "Noise". Figure 4 shows the breakdown of these data for each air temperature range. Complaints about "Low temperature" and "Draft" were high under 23.0°C of air temperature in this room.

Mental workload

The relationship of air temperature and RTLX is shown in Figure 5. There was no significant correlation between air temperature and RTLX.

Fatigue

The relationship of air temperature and general rate of fatigue is shown in Figure 6. There was no significant correlation between air temperature and general rate of fatigue.

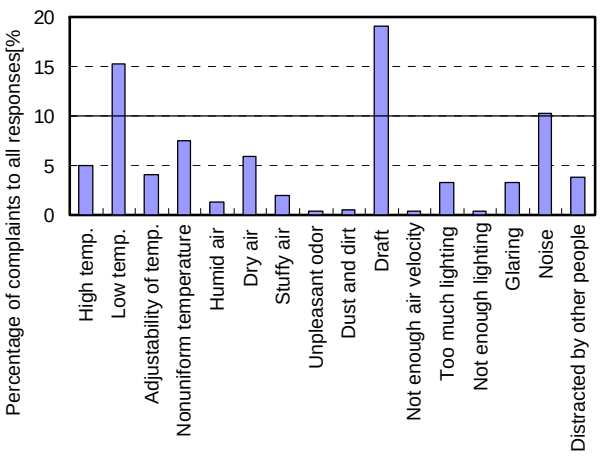


Figure 3. Percentage of complaint to all responses

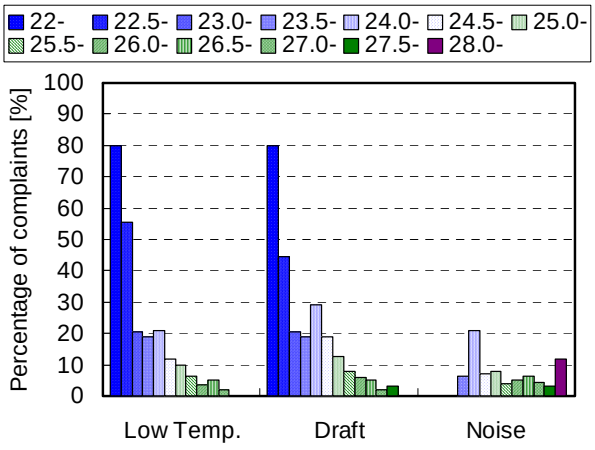


Figure 4. Percentage of complaints for each air temperature range

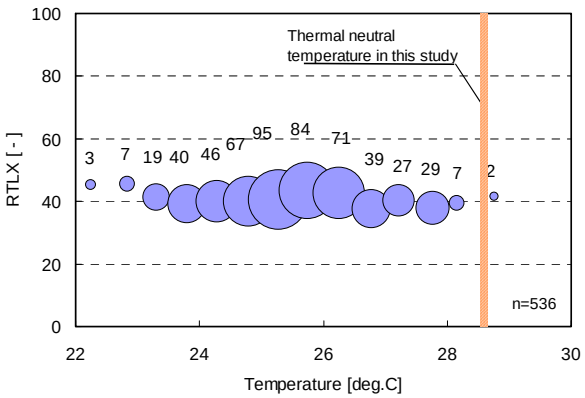


Figure 5. Air temperature and RTLX

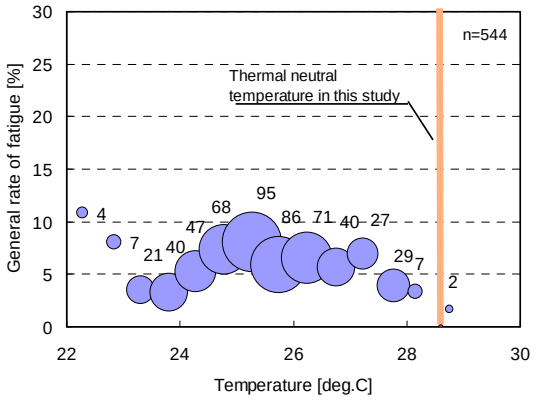


Figure 6. Air temperature and General rate of fatigue

Vitality level

The relationship of air temperature and the level of vitality is shown in Figure 7. The correlation coefficient of air temperature and the level of vitality was 0.47. From the result, the vitality level decreased when the air temperature decreased from the thermally neutral temperature.

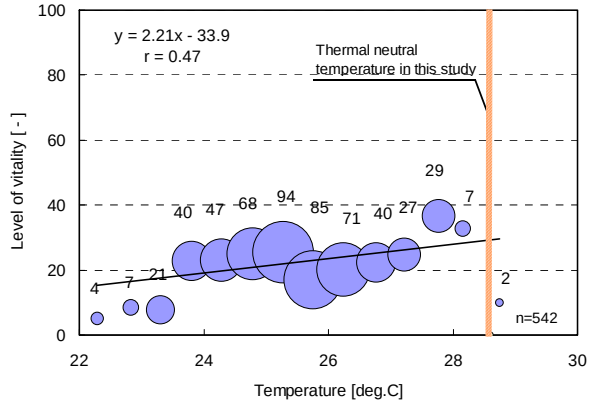


Figure 7. Air temperature and vitality level

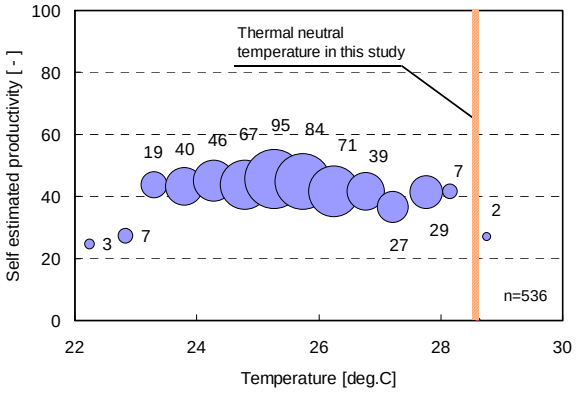


Figure 8. Air temperature and self estimated productivity

Self estimated productivity
The relationship of air temperature and self estimated productivity is shown in Figure 8. There was no significant correlation between air temperature and self estimated productivity.

The numbers of their keystrokes per day
The relationship of air temperature and the number of keystrokes per day is shown in Figure 9. The correlation coefficient of this relationship was 0.70. From the linear regression model obtained from the results, decrease in 1.0°C of air temperature from thermally neutral temperature of 28.6°C corresponds to the decrement in the number of keystrokes per day by 7.8%.

The numbers of reaction per second of ATMT
The relationship of air temperature and the number of reactions per second is shown in Figure 10. The correlation coefficient of this relationship was 0.85. From the linear regression model obtained from the results, decrease in 1.0°C of air temperature from thermally neutral temperature of 28.6°C corresponds to the decrement in the number of reactions per second of ATMT by 2.6%.

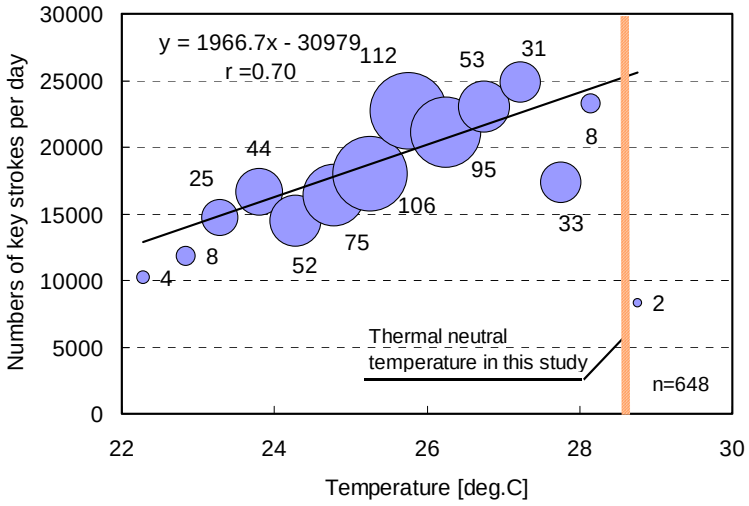


Figure 9. Air temperature and the number of keystrokes per day

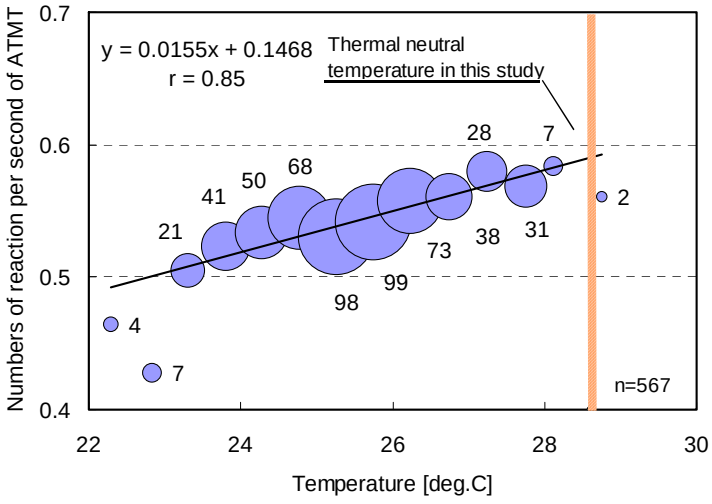


Figure 10. Air temperature and the number of reactions per second of ATMT

DISCUSSION

The results showed that the decrement in the total number of typing of one day was 7.8% and that in the numbers of reaction per second of ATMT was 2.6% as temperatures dropped by 1.0°C below thermally neutral temperature of 28.6°C. This result showed that overcooling brought the decrement of performance in the office. In our previous study of a year-long field survey of a call-center, the regression model of indoor air temperature and call response rate had shown that the rising of indoor air temperature by 1.0°C from 25.0 to 26.0°C would lead to the decrement in performance by 1.9% [5]. These studies showed the tendency that the deviation from the optimal temperature for office work lead to performance decrement. The relation of temperature and performance that had been developed by Seppänen et al [6] also showed this tendency.

It is important to specify the optimal temperature for work for creating the productive work place. However, it is not easy and the optimal temperature differed from one study to another. For example, Seppänen et al. mentioned that performance increases with temperature up to 21-22°C, and decreases at temperature above 23-24°C. On the other hand, in this study, thermally neutral temperature was 28.6°C and relatively high because of high air velocity in the room (0.2-0.4m/s) and the adjustability of clothes. Thermal environmental factors (not only air temperature, but also radiant temperature, air velocity, humidity, clothes and activity level) are needed for consideration. Additionally, the difference of task types may affect the optimal thermal environment for work. In this study, programmers' performances were estimated by the tasks, most of which requires the use of fingers such as keystrokes, and clicking response and they were relatively susceptible to cooler environment.

The results of this study and our previous call center study [5] showed the significant relationship between air temperature and performance at work. Tham et al. [7] and Niemelä et al. [8] also showed the significant relationship between air temperature and performance by the field studies in call centers. On the other hand, our previous laboratory experiment showed that it was difficult to evaluate the effect of thermal environment on productivity by measuring only task performance in the short-term exposure studies (about 2 hours) [9]. It was important to measure the human responses, such as fatigue level, physiological responses, and psychological responses, as the factors to influence workers' performance. For longer exposure, it became clearer that thermal environment affect physiological and psychological process such as fatigue, mental effort and so on, which would consequently affect workers' performance. The result from long-term exposure study (about 6 hours) had revealed that increase of fatigue level causes decrement in performance [10]. In the field study, relatively strong relationship of indoor air temperature and their performance could be obtained compared to laboratory experiments. The reason why the stronger relationship of indoor air temperature and their performance at the actual office work than that at laboratory experiments may be that the motivation level is higher in the short exposure studies and the human responses makes it hard to verify the direct relation between air temperature and performance.

CONCLUSIONS

A long-term field study was conducted in an office for seven months to clarify the effect of thermal environment on productivity. Seven male software programmers participated. The following results were obtained.

1) Complaints about “Low temperature” and “Draft” were high under 23.0°C of air temperature in this programmers’ room.
2) The vitality level decrease when the air temperature decreased from thermally neutral temperature of 28.6°C.
3) The decrement in the total number of typing of one day was 7.8% and that in the numbers of reaction per second of ATMT was 2.6% as temperatures dropped by 1°C below thermally neutral temperature of 28.6°C.
4) The result showed that overcooling brought the decrement of performance in the office.

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