International Conference on Applied Energy 2019
Aug12-15, 2019, Västerås, Sweden
Paper ID: 597

A STUDY OF PRODUCTIVITY LOSS WITH THE KOREAN INDOOR TEMPERATURE STANDARD IN SUMMER

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ABSTRACT

The purpose of this study is to understand the effect of an over-estimated cooling set-point temperature (28°C) on work productivity in Korea's public buildings during the summer season. Two experiments were conducted. The first experiment aimed at measuring work performance through typing and cognitive tests and detecting work stress using an electroencephalogram at 28°C. The second experiment was conducted at 24°C with the same contents as the first. The results showed that a cooling set-point temperature of "28°C" brings benefits in terms of energy consumption, but it drops work performance, thereby having an adverse effect on overall productivity.

Keywords: Indoor temperature, work stress, work performance, electroencephalogram, cognitive task.

1. INTRODUCTION

Due to COP21 of the United Nations Framework Convention on Climate Change held from November 30 to December 11, 2015 in Paris, France, there has been a growing interest in energy efficient policies [1]. Accordingly, The Korean government promised to reduce greenhouse gas emissions by 37 percent compared to Business As Usual (BAU) by 2030. In order to reduce energy consumption from the building sector, which accounts for 30-40% of the overall energy consumption, the government recommended that the set-point temperature of public buildings be over 28°C during the summer season. This reduction policy enables about 400 million kWh of energy savings per year and 170,000 tons of greenhouse gas emission reduction [2]. However, a scientific basis for the cooling set-point temperature "28°C" has not been established, and the public health and work environment of indoor workers have not been considered. Many previous studies have reported that inappropriate temperatures cause office workers to suffer thermal discomfort such as mental fatigue, thermal stress and drowsiness [3]. Thermal discomfort affects the productivity of laborers by reducing work performance and cognitive skill during working time [4]. Therefore, this study analyzed the effects of the indoor set-point temperatures on office workers' states from two aspects: (1) Work performance during cognitive and typing tasks; (2) Work stress in terms of neurophysiological responses.

2. MATERIAL AND METHODS

2.1 Experiment

To investigate the impact of indoor temperature on office workers' states, six healthy male subjects (mean age: 26.5 ± 1.6, range: 23 - 28) were recruited. They were given safety precautions and brief instructions before participating in the experiment. The experiment received approval from the Institutional Review Board (IRB) at Yonsei University [IRB No. 7001988-201901-HR0511-02]. The experiment was carried out in an artificial climate control chamber where the temperature and humidity can be controlled. The chamber is 2.4m in height, with base dimensions of 2.8m x 3.9m. It is possible to control the temperature from 10°C to 80°C, and humidity from 10%RH to 80%RH. To prevent external effects, the indoor environment conditions were set up as follows: illuminance =250 lux; CO_2 concentration < 1000ppm; PM2.5 concentration < 50μg/m^3.

Figure 1 shows the experimental procedure, which included two phases each with different indoor temperatures: 28°C (cooling set-point temperature); 24°C (optimal indoor temperature, also Predicted Mean Value (PMV) =0). The acclimatization took approximately 10 minutes, after which the subjects were guided to the experiment and wearing the EEG device. First, all subjects were given 2 minutes to evaluate the indoor thermal conditions through the use of questionnaires. After that, subjects began 30 minutes of simulated office work (i.e., 10 minutes of typing tasks and 20 minutes of cognitive tasks). The subjects had a 5 minute break between the typing task and cognitive task. In addition, clothing value for all subjects were unified into standard clothing for office workers during summer season (trousers, long-sleeved shirt (0.61 clo)) [5].

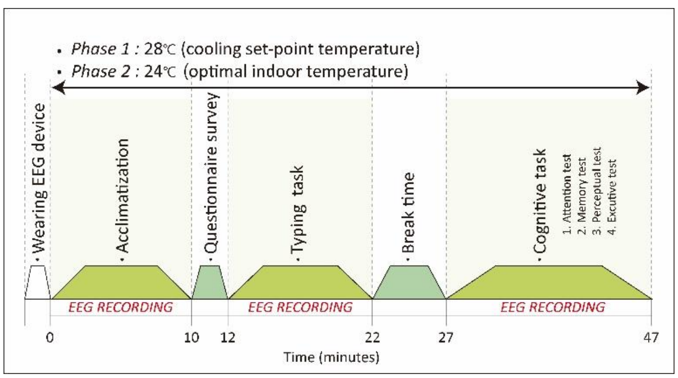

Fig 1 Experimental procedure

2.2 Measurement

• *Physical measurement:* The monitoring sensor was equipped to measure the environmental conditions of the artificial climate control chamber in real time. The indoor environmental factors to be measured are as follows: temperature (℃), humidity (%), CO_2 concentration (ppm), PM2.5 concentration (μg/m^3).

• *Questionnaire survey (10–12 min):* The questionnaire survey that evaluates indoor thermal conditions is as follows: (a) thermal comfort vote (TCV): 7-point-scale (1: very uncomfortable; 7: very comfortable) to evaluate the comfort at the current thermal conditions; (b) thermal satisfaction (TS): 7-point scale (1: very dissatisfied; 7: very satisfied) to evaluate the satisfaction at current thermal conditions; (c) thermal sensation vote (TSV): 7-point scale (-3: cold; 3: hot) to evaluate the thermal sensation at the current thermal conditions.

• *Typing task (12–22 min):* The indicator evaluating the performance of the typing task is the net characters per minute (CPM). The concept for the CPM is: (Total number of key pressed – Total cursor keys pressed + 2* Total backspace keys pressed). Only correctly typed words were counted, excluding all mistakes.

• *Cognitive task (27-47min)*: The four cognitive tasks were selected to evaluate attention performance (Go/No-go test), perceptual performance (Fast-counting test), working memory performance (N-back test, N=2), and executive performance (Stroop test). The response time (milliseconds) was used as a measure of performance of the cognitive tasks. All tests were conducted through the website (http://cognitivefun.net)

• *Neurophysiological Measurement*: Brainwaves were measured by an EEG device called the Emotive EPOC+. The channels of each active electrode are as follows: (a) frontal lobe: AF3, AF4, F3, F4, F7, F8, FC5, FC6; (b) temporal lobe: T7, T8; (c) occipital lobe: O1, O2; (d) parietal lobe: P7, P8. First, only specific frequency ranges of 30Hz were extracted from the raw signals with the use of a finite impulse response (FIR), and unwanted artifacts were removed using an independent component analysis (ICA). Then, a power spectral density (PSD) was used to separate the brainwaves in each frequency ranges. In this study, the following two wave indices are used as work stress indicators: (a) index of detecting drowsiness and mental fatigue using Ratio of Beta to Alpha wave; and (b) the index of detecting attention using the Ratio of Sensorimotor rhythm and mid beta to theta [6].

Table 1. Physical and psychological measurement (mean + standard deviation) of two conditions

	Physical measurement				Psychological measurement			
	Temperature (℃)	Humidity (%)	CO_2(ppm)	PM2.5(μg/m^3)	PMV	TCV	TS	TSV
Phase 1	28	61.2±10	930±212	16.5±7.8	1.12±0.1	2.2±0.5	2.2±0.3	2.2±1.3
Phase 2	24	51.3±15	893±173	17.3±8.7	-0.21±0.1	6±0.5	5.8±0.4	-0.8±1.3

Table 2. Performance of typing and cognitive task at 28℃, 24℃

Subject	Work Performance									
	Typing(CPM)		Attention(ms)		Perception(ms)		Memory(ms)		Executive(ms)	
	28℃	24℃	28℃	24℃	28℃	24℃	28℃	24℃	28℃	24℃
S1	308.6	328.6	432.7	372.2	1127	1176	928	919	719	815
S2	137.6	146.2	457.5	471.6	1374	1455	1072	724	902	740
S3	286	286	605	480.2	1630	1458	1025	844	1261	1050
S4	288	305.6	444.9	403.6	1419	1480	653	547	830	891
S5	216.2	223.8	411.4	380.3	1664	1374	1230	944	1046	905
S6	196.6	223.6	338.4	319.9	857	904	1021	717	814	773
Δ	+13.5 (5.3%)		-43.6 (9.7%)		-37.3 (2.8%)		-205 (26.2%)		-66.3 (7.1%)	

• *Energy usage measurement*: The amount of electricity power consumed to maintain the indoor temperature of each phase (i.e., 28°C, 24°C) was collected. A comparison between the amounts of electricity power used to keep temperatures to 28°C, 24°C from the average summer temperature of 32°C was conducted on the artificial climate control chamber (approximately 26m^3).

3. RESULT AND DISCUSSION

3.1 Physical condition

The experiment was conducted with temperatures fixed at 28 and 24 ℃ in two phases. In phase 1, the humidity was 61.2%, PMV; 1.12, CO_2 concentration; 930ppm, and PM2.5 concentration; 16.5μg/m^3. In phase 2, the humidity was 51.3%, PMV; -0.21, CO_2 concentration; 893ppm, and PM2.5 concentration; 17.3μg/m^3 (refer to Table 1). The difference of the humidity, CO_2 concentration and PM2.5 concentration between the two phases was smaller than the measurement error of equipment. Therefore, it was deemed that other factors (i.e., CO_2 concentration, PM2.5 concentration, Humidity) were controlled in addition to the temperature.

3.2 Psychological response

Before starting the task, the subjects were surveyed on the thermal environment conditions in each phase. The indices are as follows: (a) PMV and TCV index indicates warm conditions (1.12; 2.2) during phase 1, and on the other hand, neutral condition (-0.21; -0.8) during phase 2; (b) TCV and TS index indicates uncomfortable and dissatisfied conditions (2.2; 2.2) during phase 1, but comfortable and satisfied conditions (6; 5.8) during phase 2 (refer to Table 1).

3.3 Work performance

The performance of the typing and cognitive tasks was further improved in phase 2 (24℃) when compared to phase 1 (28℃). In terms of the typing task, the CPM showed a 5.3% improvement. In addition, it can be confirmed that the attention performance was improved by 9.7%, the perception performance by 2.8%, memory performance by 26.2%, and executive performance by 7.1% for all cognitive tasks.

3.4 Neurophysiological response

Among the channels, two, F3 (left frontal lobe) and F4 (right frontal lobe), were selected and analyzed in this study. This is because the frontal lobes are generally associated with the cognitive functions of the human brain [7]. Therefore, the brain wave indices of F3 and F4

Table 3.F3, F4 Brain wave indices of typing and cognitive tasks at 28℃, 24℃

Brain wave indices	Work Performance									
	Typing		Attention		Perception		Memory		Executive	
	28℃	24℃	28℃	24℃	28℃	24℃	28℃	24℃	28℃	24℃
RBA	0.300	0.317	0.268	0.234	0.310	0.290	0.373	0.293	0.533	0.355
RSMT	0.147	0.169	0.224	0.171	0.182	0.218	0.218	0.167	0.283	0.138

were extracted through PSD (refer to Table 3). The results revealed that in the typing task, RBA and RMST were increased further in phase 1 (28℃) than in phase 2 (24℃), while the RBA and RMST were reduced in all cognitive tasks.

3.5 Energy usage

The amounts of electricity power consumed when the temperature was maintained at phase 1 (28℃) and phase 2 (24℃) were compared. According to the results of the comparison, about 74Wh of electricity power per $1m^3$ was consumed in phase 1, while about 60Wh of the electricity power per $1m^3$ was consumed in phase 2

3.6 *Discussion*

In phase 2 (24℃, optimal indoor temperature) rather than phase 1 (28℃, cooling set-point temperature), the subjects showed higher levels of satisfaction with the thermal environment and tended to consider the indoor environment as neutral. In addition, their overall work performance was improved, and there was a dramatic increase, especially in memory ability (26.2%). These results suggest that the optimal indoor temperature has a positive impact on the cognitive function of the brain, thus reducing work stress. On the other hand, the electric power consumption was found to increase by 14Wh per $1m^3$ in phase 2.

4. CONCLUSION

The cooling set-point temperature of public buildings is 28℃. This standard can help achieve energy savings to obtain financial gains and solve environmental problems at the public level. However, it can also cause workers at public institutions to suffer from drowsiness and mental fatigue, thereby contributing to reducing work performance. This indicates a trade-off between energy savings and work productivity. Therefore, in future studies, there is a need to present the optimum temperature range that can alleviate the trade-off in consideration of the two aspects.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT; Ministry of Science and ICT) [grant number NRF- 2018R1A5A1025137]. In addition, this work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT; Ministry of Science and ICT) [grant number NRF- 2019R1C1C1007487].

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