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INFLUENCE OF UNSTEADY THERMAL STATE ON PRODUCTIVITY IN OFFICE BUILDINGS

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Abstract. Indoor air temperature has a significant effect on productivity of the employees in office buildings. It may reduce work performance and cause financial losses in a long term perspective. However, sudden variations of air temperature during the work day may have an impact on the work performance as well. The aim of this study was to assess the change of office work performance of the same individuals affected by unsteady air temperature.

Laboratory tests were performed in the test chamber. Office work was simulated in the chamber with two workplaces and two persons at the time. 48 individuals of age 19 to 30 were divided into three groups and took participation in performing productivity tests. A case with the temperature rise from +22 to +26 °C as well as case with the temperature drop from +22 to +18 °C was analyzed. The same tests were performed with the placebo group with a steady indoor climate conditions (constant air temperature of +22 °C).

Results of the study showed that overall accuracy of the execution of the tasks increased with the second fulfilment in the placebo group by 1,4 %. In case of the air temperature rise, performance reduced by 0,2 % and overall productivity improved by 4,1 % in case of air temperature drop.

Keywords: human performance, unsteady air temperature, laboratory tests.

1. Introduction

Air temperature is one of the most influential parameters of indoor climate and it has significant effect on work performance. But in many office buildings, thermal conditions are not well-controlled due to insufficient heating or cooling capacity, high internal or external loads, large thermal zones, improper control or operation of the HVAC equipment as well as other factors.

Due to outdoor air temperature variations, indoor air temperature may be out of the comfort range temporarily during the work day. Therefore, despite of the installation of modern facilities in newly build office buildings, occupants may be exposed to temporary thermal discomfort that affects their performance and productivity.

Seppänen et al (2006) outlined a relation between performance and air temperature based on various productivity studies. It showed a decrease in performance by 2 % per 1 °C increase of the temperature in the range of +25 – +32 °C and there was no effect on performance in air temperature range of +21 – +25 °C. It is stated that the maximum performance is achieved at +21,6 °C (Fig 1). Haneda et al (2008) have presented results of the research which revealed that both productivity and fatigue of the subjects increased as the time proceeded during the experiment.

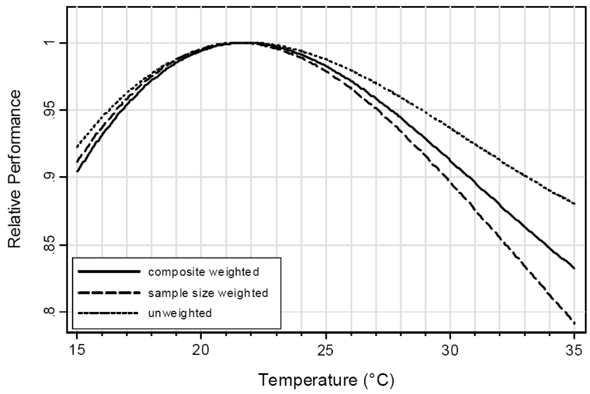

Fig 1. Normalized relation between performance and air temperature in rooms (Seppänen et al, 2006)

Accumulation of fatigue was more intense at the higher temperatures as well (+28,5 °C) (Haneda et al, 2008).

A study presented by Tanabe (2005) revealed that the subjects complained of the feeling of mental fatigue more and more cerebral blood flow was required to maintain the same level of task performance at hot condition than at the thermally neutral condition.

Research performed by Wyon et al (1979) showed significant interaction between temperature conditions for multiplication tests which were later verified by some other studies. Tsai-Partington test was also used in this study and the subjects achieved best results when the air temperature was +23 °C. Important trends related to the sex of the subjects were outlined. Female subjects tended to maintain performance at higher temperatures as they felt more comfortable in warmer environment.

Kosonen and Tan (2004) stated that task-related work performance correlates significantly with the human perception of thermal environment that in turn is dependent on temperatures. Yet, different combinations of thermal criteria (air velocity, clo, metabolic rate, etc.) can lead to similar PMV values, therefore it is important to document PMV during the productivity tests.

Wargocki et al (2005) outlined the impact of ventilation rate and air temperature on productivity of schoolchildren. The study revealed that after increasing of ventilation rate from 5 l/s per person to 10 l/s per person, performance of school-work increased by approximately 15%.

Assessment of work performance is important from both quality of life and financial point of view as well (Wargocki and Seppänen, 2006). Yet, considering climate change and the fact that HVAC systems of buildings are not always able to ensure indoor air parameters at the required level, occupants may be exposed to temporary thermal stress due to too low or too high air temperatures.

Šeidukytė and Paukštys (2008) revealed that in 43 % tested buildings with large glazed areas, temperatures were beyond the comfort range. The predicted percentage of employees satisfied with thermal environment working was not higher than 20% in tested offices.

The comfort air temperature range in Lithuania is regulated by the standards of hygiene. It may vary from +22 °C to +24 °C in case of performing sedentary job in the fixed workstation during the cold season, and from +23 °C to +25°C during the warm season. Relative humidity should be in the range of 40-60%, air velocity should not exceed 0,1 m/s – 0,15 m/s accordingly (HN 69:2003). No probable variations of parameters time-wise are given.

The aim of this study was to assess the change of the office work performance of the same individuals affected by unsteady air temperature.

2. Methods

In order to observe the impact of immediate change of thermal environment on the productivity of the occupants, laboratory tests were performed. Office work was simulated in the test chamber (13 m² of floor area) with two workplaces and two persons at the time. The chamber was installed in the other room with the constant air temperature of approximately +22 ºC. Air temperature in the chamber was controlled using the air handling unit.

During the experiment all other indoor climate parameters except air temperature were kept stable. Ventilation rate in the chamber was 20 l/s per person and CO_2 concentration varied in the range of 450 to 600 ppm. Mixing ventilation was installed in the chamber and the average air velocity in the occupied zone was below 0,1 m/s. Noise level was 43±3 dB(A). As the experiment was performed during the wintertime, the relative humidity indoors was approximately 35%.

The sketch and view of the test chamber is presented in Fig 2.

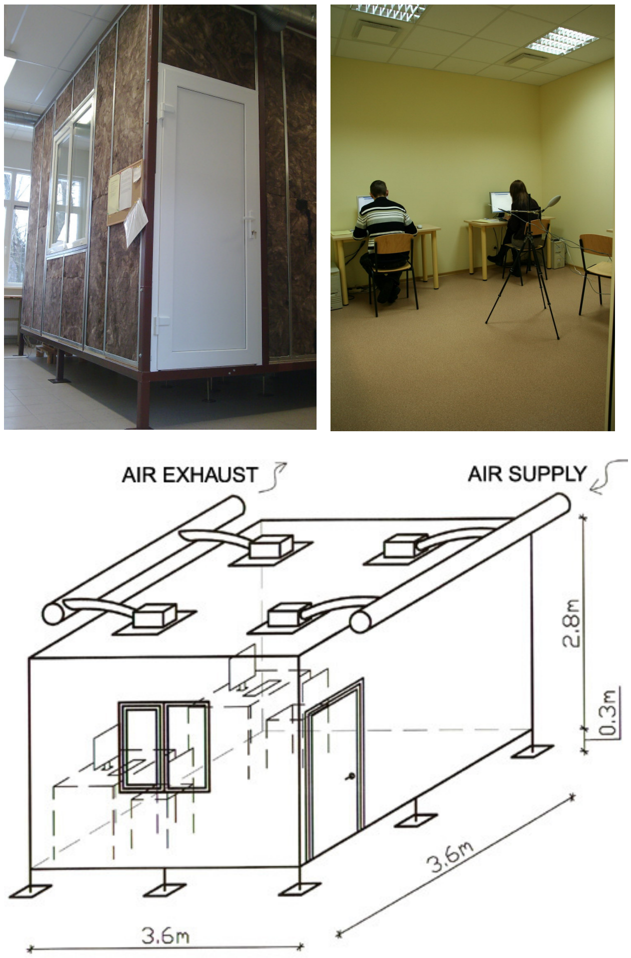

Fig 2. The view and the geometry of the test chamber

48 non-smoker individuals having no health problems took participation in the experiment. The records of six participants were rejected as being conspicuous from average of the results. The information about the subjects is presented in Table 1.

Table 1. Data of the subjects who took participation in the experiment

	Female subjects	Male subjects
Number of the subjects	14	28
Average age of the subjects	22	
Average height of the subjects	169 cm (162÷176 cm)	185 cm (173÷196 cm)
Average weight of the subjects	58 kg (56÷66 kg)	81 kg (60÷102 kg)
Average clothing	0,75 clo (0,7÷0,8 clo)	

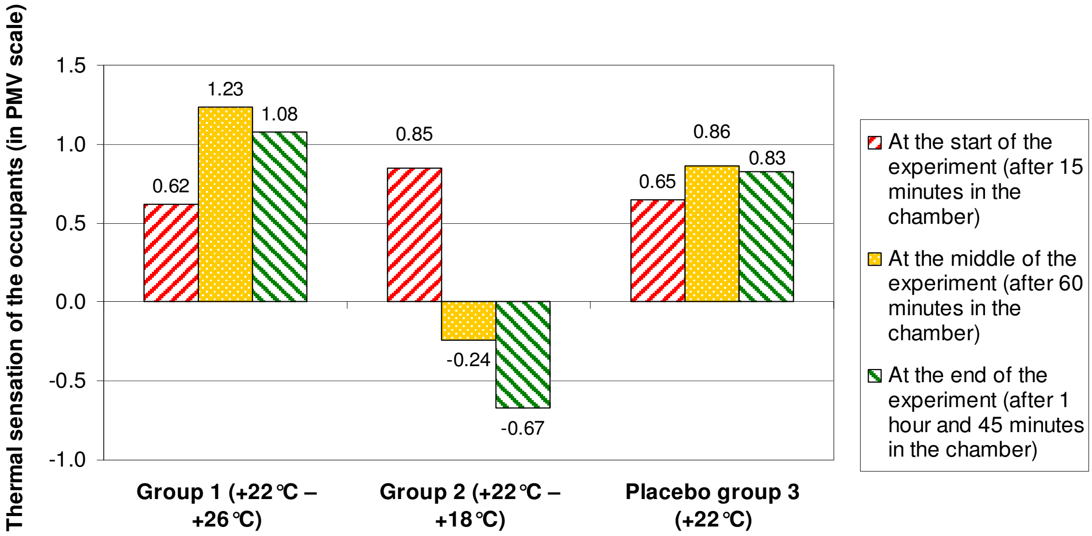

Fig 3. Results of the evaluation of the thermal sensation in the PMV scale of the subjects

Subjects did not have the exact knowledge about the aim of the experiment and what parameters will be changed during the course of the test. Requirements for clothing were given to the subjects in advance.

The time of the experiment was selected to be 1 hour and 45 minutes in order to avoid performance decrement because of the fatigue. The subjects were divided into three groups. A case with the temperature rise from +22 °C to +26 °C as well as case with the temperature drop from +22 °C to +18 °C was analyzed. The same tests were performed with the placebo group with a steady indoor climate conditions (constant air temperature of +22 °C). The timetable and changes of temperature are given in the Table 2.

Experiments were carried out during daytime (from 8 a.m till 5 p.m). Such tasks as Tsai-Partington test (connecting scattered numbers in sequence), arithmetic calculations as well as text typing were performed, see Table 2. Three times during the experiment, subjects were filling in questionnaires by indicating their thermal sensation (in the PMV scale of -3 to +3), perceived air quality, humidity perception as well as referring to the SBS symptoms felt.

Thermal comfort monitoring system was installed in the test chamber during the tests, measuring operative temperature, air velocity and relative humidity. PMV and PPD indices were calculated by the software.

3. Results

Three times during the experiment subjects were filling in the questionnaires. Results of the survey of thermal sensation are presented in Figure 4. At the start of the experiment air temperature was set at +22°C in order to ensure high work performance. The measured PMV value at the start of the experiment was 0±0,2. Yet, almost all subjects identified the initial conditions as slightly warm. The most sudden evaluations were observed in case of the temperature drop. The other results of the questionnaires are presented in Table 3 ant Table 4.

Table 2. Timetable of the implementation of the experiment

Procedures		Adaptation	Questionnaires	Tsai-Partington test (x3)	Arithmetic task (x3)	Text typing task (x3)	Tsai-Partington test (x3)	Arithmetic task (x3)	Text typing task (x3)	Questionnaires	Tsai-Partington test (x3)	Arithmetic task (x3)	Text typing task (x3)	Tsai-Partington test (x3)	Arithmetic task (x3)	Text typing task (x3)	Questionnaires
Sequence		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
Time, min		15	2	43						1	43						1
Temperature, °C	**Group 1**	+22°C					+22°C – +26°C							+26°C			
	Group 2	+22°C					+22°C – +18°C							+18°C			
	Group 3	+22°C															

Table 3. Results of the questionnaire survey performed during the experiment, part 1

	I am felling good, %			I feel rested, %		
	At the start of the experiment	**In the middle** of the experiment	**At the end** of the experiment	**At the start** of the experiment	**In the middle** of the experiment	**At the end** of the experiment
Group 1	88.2	81.8	79.2	71.8	69.8	69.0
Group 2	80.0	70.4	70.8	71.2	64.8	61.1
Group 3	91.9	84.5	81.0	74.9	70.8	58.0

The overall performance improvement in the placebo group was approximately 1 % and it was related to better accomplishment of the Tsai-Partington test. Temperature rise to the level of +26°C did not influence the overall productivity. Nevertheless, no overall improvement of productivity as in the placebo group was observed in this case. The rise of the temperature affected arithmetic calculations most, which were performed with 2% more mistakes than at the start of the experiment. Moreover, overall improvement of productivity was observed in case of reduced air temperature. 2,5% less mistakes while performing the arithmetic tasks were done and overall performance increased by 3,5%.

Main results of the experiment are given in the Fig 4.

Table 4. Results of the questionnaire survey performed during the experiment, part 2

	Easy to concentrate, %			I am ready to work, %		
	At the start of the experiment	**In the middle** of the experiment	**At the end** of the experiment	**At the start** of the experiment	**In the middle** of the experiment	**At the end** of the experiment
Group 1	82.1	73.5	73.3	86.2	82.1	77.7
Group 2	80.0	62.9	57.0	89.2	72.8	61.4
Group 3	86.6	76.6	74.8	94.3	85.6	69.3

4. Discussion

Evidence, that indoor environmental conditions substantially influence health and productivity, was gained. Building services engineers are interested in improving indoor environments and quantifying the effects. Yet potential health and productivity benefits are not generally considered while input of exploitation is calculated. Only initial cost, energy and maintenance costs are typically considered.

In this paper, the first part of the described experiment was presented. In order to validate the obtained results, more subjects will be involved in the study as well as the same pattern of the tests will be performed with different subjects during the warm season of the year.

5. Conclusions

1. Results of the study showed that sudden air temperature change has almost no effect on performance of the text typing tasks. Only in case when air temperature dropped from +22 °C to +18 °C the subjects performed text typing with 1,7 % lower accuracy.
2. Performance of Tsai-Partington test was influenced most by temperature change. However, the placebo group performed the test 4% better at the second part of the experiment. This indicates that there is a learning trend in performing this test. In the conditions of air temperature drop from +22°C to +18°C subjects were more concentrated and performed the Tsai-Partington test with 10 % higher accuracy. Yet, this effect may be temporary.
3. In case of the stable air temperature in the room, equal to +22 °C, the overall work performance in the second part of the experiment improved by 1,4 %. The rise of the temperature from +22 °C to +26 °C triggered the decrement of overall productivity by 0,2 % and in case of the temperature drop from +22 °C to +18 °C, overall productivity increased by 4,1 %.

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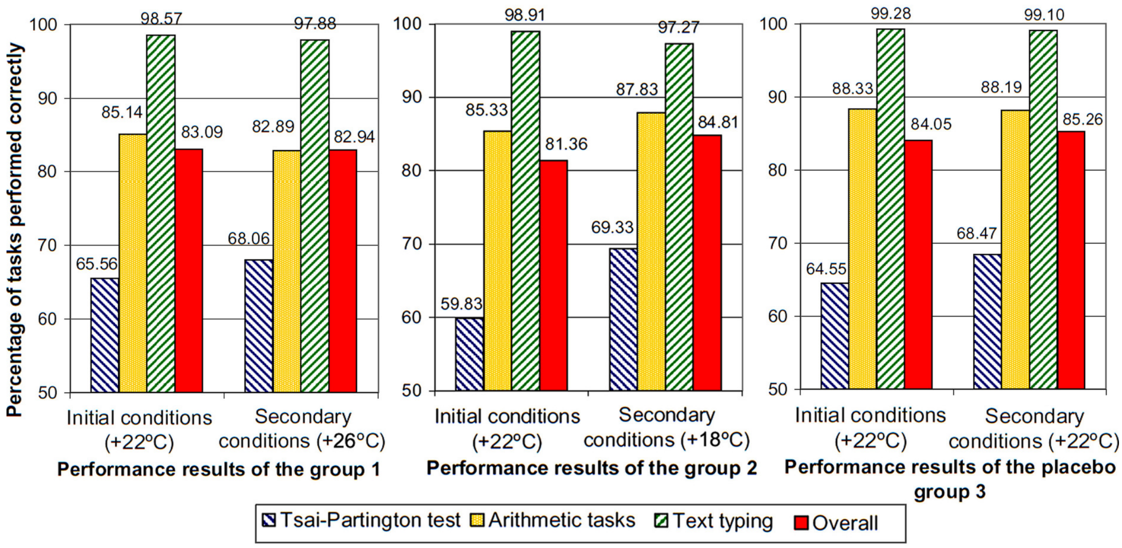

Fig 4. Work performance expressed from the accuracy of the tests performed by all three groups of subjects

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