The effect of draught on performance, comfort and stress – a laboratory study

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ABSTRACT

Thermal environment affects occupants' work performance and well-being. Office workers' complaints regarding thermal environment are often related to either too warm room temperature or draught. Efficiency demands have increased the heat loads in offices, and increased cooling is needed to control the room air temperature. Draught problems occurs typically in these situations when the workstation is located in the downfall area of the inlet jet.

The aim of this study was to examine the effect of draught on work performance, comfort, and stress in an office laboratory simulating a draughty situation caused by downfall of colliding jets from the chilled beams. The study had a repeated measures design with two conditions: condition A (temperature T=23 °C, target air speed v<0.1m/s, supply airflow Q= 30 l/s) and condition B (temperature T=23 °C, target air speed v=0.4m/s, supply airflow Q= 70 l/s). Thirty-one volunteer university students participated in the experiment. The session lasted altogether 2.5 hours including practice phase and both test condition phases. Thermal comfort, perception of air movement, symptoms, self-estimated work performance and workload were assessed with questionnaires. Work performance was measured with the N-back task and stress effects were studied with heart rate variability.

Condition had a significant effect on thermal comfort. Thermal sensation vote was cooler in condition B and more participants reported to be dissatisfied with the thermal environment in condition B. Majority of participants reported that air movement in condition B was unpleasant and 82% would have preferred less air movement. Draught also disturbed and annoyed more in condition B. No differences were found on self-estimated work performance, workload, symptoms, or perceived fatigue. The effects of draught were mainly seen in subjective responses. However, condition had also an effect on work performance and stress. Special attention should be given for reducing draught in offices.

KEYWORDS

Draught, Thermal comfort, Work performance, Heart rate variability, Laboratory experiment

1 INTRODUCTION

Thermal environment is an important factor of indoor environment. It affects occupants' work performance and wellbeing (Clements-Croome, 2006; Maula et al., 2016a; Seppänen et al., 2003; Seppänen et al., 2006). Optimal temperature for comfort is obtained when the occupant is in thermal neutrality. Fanger (Fanger, 1970) defined thermal neutrality for a person as the condition in which the occupant would not prefer either warmer or cooler surroundings.

Complaints regarding thermal discomfort in offices are often related to either too warm indoor environment or draught.

Draught is defined as unwanted local cooling of the body caused by air movement. Space efficiency demands have increased the heat load in offices, and increased cooling is needed to control the room air temperature. Typically, draught problems can occur in these situations when the workstation is located in the downfall area of the inlet jet. This phenomenon was confirmed by Koskela et al (Koskela et al., 2010) who studied airflow patterns and mean air speeds in a full-scale open-plan office laboratory. They found that downfall of colliding jets and large-scale circulation caused by asymmetric room layout of chilled beams and heat sources are main causes of draught risk.

There are many studies in literature about the effect of too warm environment, too cold environment or locally increased air movement on thermal comfort and perception (Parsons, 2003; De Dear et al, 2013, Maula et at., 2016b). However, the literature is lacking variety of studies about the effect of draught on occupants' performance and stress effects. More knowledge is needed about the performance, comfort and stress effects of real-life draught situation where draught is generated from increased heat loads and cooling, while room temperature itself is kept at optimal level.

The aim is to examine the effect of draught on work performance, comfort, and stress in an office laboratory simulating a draught situation caused by downfall of colliding jets from the chilled beams.

2 METHODS

2.1 Participants

Thirty-one volunteer university students participated in the experiment (14 females, mean age 25 years, range 19–43 years). The participants were beforehand advised to wear trousers, t-shirt, socks, and ankle-length shoes (0.71 clo; ISO 7730). The main activity was working with the computer (1.1 met; ISO 7730). The participants were compensated for their effort and time with a gift voucher worth 30 euros.

2.2 Experimental design and procedure

The experiment was carried out in spring 2022 in environmental chamber at the psychophysics laboratory, Turku University of Applied Sciences, Finland (Figure 1). The study had a repeated measures design with two conditions:

A. Temperature T=23 °C, target air speed v<0.1m/s, supply airflow Q= 30 l/s.
B. Temperature T=23 °C, target air speed v=0.4m/s, supply airflow Q= 70 l/s.

Target air speed is the measured mean air speed from horizontal plane above participant (1.5m from the floor, 10 cm * 10 cm measurement grid). The mean air speeds were sampled for 3 min with hot-sphere anemometers (Dantec Dynamics A/S, Denmark, accuracy of 5% of reading ±0.01 m/s). Condition B was built with 1300 W higher heat load, and therefore had 1300W higher cooling power, than condition A. Fresh outdoor air was supplied with two chilled beams.

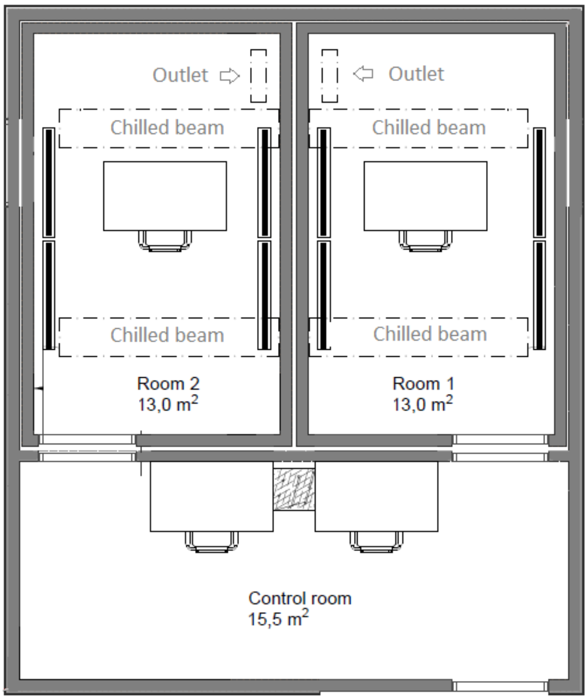

Figure 1: The layout of the psychophysics laboratory. The room height is 2.8 m. Condition A was in Room 1 and Condition B in Room 2.

The session lasted altogether 2.5 hours including 30 min practice phase and both condition phases, 60 min each. Condition phases had questionnaires at the beginning, in the middle, and at the end of phase. Performance tasks were done between questionnaires. The order of conditions was counterbalanced between participants to control possible order effects caused by, e.g. learning, habituation, fatigue, and expectations towards the test objectives.

2.3 Questionnaires

Thermal comfort, perception of air movement, symptoms, perceived fatigue, self-estimated work performance, and workload were assessed with questionnaires (MATLAB R2018a with Psychtoolbox).

Overall thermal sensation was asked using seven-point response scale (3 Hot, 2 Warm, 1 Slightly warm, 0 Neutral, -1 Slightly cool, -2 Cool, and -3 Cold, ISO 7730). Pleasantness of the air movement was asked, when the participants reported that they felt the air movement. Pleasantness was inquired with a five-point response scale (-2 Very unpleasant, -1 Slightly unpleasant, 0 Not pleasant or unpleasant, 1 Slightly pleasant, and 2 Very pleasant). Air movement preference was asked with three-point response scale (1 Less, 2 More, and 3 No change).

Symptoms, such as sweating, headache, feeling unwell, and nose, throat and eye symptoms were assessed with five-point response scale (1 = Not at all, 2 = Slightly, 3 = To some extent, 4 = Quite a lot, and 5 = Very much). Similar response scale was used with perceived fatigue, which was measured with a modified version of the Swedish Occupational Fatigue Inventory, SOFI, including three factors: tiredness, lack of energy and lack of motivation. Each factor included three items (tiredness: sleepy, yawning, drowsy; lack of energy: worn out, exhausted, drained; lack of motivation: uninterested, indifferent, passive, Åhsberg, 1998).

Self-estimated work performance and workload were asked with eleven-step response scale from 0 to 10.

2.4 Performance measures

Work performance was measured with the N-back task (Owen et al., 2005). The task was done twice in both sub-sessions to gain information of the possible interaction of thermal condition and exposure time on performance. To avoid empty phases during the session, the participants performed other task as well, but those tasks are not included in this paper. The tasks were introduced to the participants as equally valuable.

In N-back task, sequences of letters were presented on the display one letter at a time. Four difficulty levels were used (0-back, 1-back, 2-back, and 3-back). In 0-back, the task was to press a key on the keyboard labelled YES (leftward arrow) every time the letter ‘X’ appeared on the display and press NO (downward arrow) for all other letters. In 1-back, subjects were required to respond whether the presented letter was identical to the one immediately preceding it. In 2-back, subjects were required to respond whether the presented letter was identical to the one presented two trials back and in 3-back, subjects were required to respond whether the presented letter was identical to the one presented three trials back. Subjects were instructed to respond quickly, but accurately. Speed was measured with reaction time (RT, milliseconds) of each response. Accuracy was measured by the percentage of correct responses. The presentation order of difficulty levels was counterbalanced between and within participants. 0-back was the baseline level with no demands on working memory.

2.5 Physiological measures

Stress effects was measured with heart rate variability (HRV) using a sensor (Faros 180, Bittium Biosignals Ltd.) attached under the chest muscle line with a textile belt and Stingray adapter. The accelerometer sampling rate was 25 Hz, and the dynamic range was ±4 g. The ECG sampling rate was 250 Hz. R-R interval data were analyzed with designated software (Kubios HRV, Kubios Ltd.). Sensor was synchronized with the computer running the MATLAB having experimental tasks and questionnaires, and MATLAB also marked the exact durations of each session. These time markers were later entered into the HRV data. Analyses were done for the Stress index SI, which is the square root of the Baevsky’s stress index IS (Baevsky and Chernikova, 2017):

$$IS = AMo / 2Mo * MxDMn \tag{1}$$

where AMo is mode amplitude (number of intervals corresponding to mode value in % to sample size), Mo is mode (the most common interval value in a given dynamic series) and MxDMn is variation range (it shows the degree of interval variativity in a given dynamic series). The square root of the IS is used in Kubios software to make the index normally distributed.

2.6 Analysis

Statistical analysis were conducted with IBM SPSS Statistics for Windows, Version 26.0 (Armonk, NY: IBM Corp.). The normality of the data was tested with Shapiro-Wilk test. A repeated-measures ANOVA was used for normally distributed or similarly skewed data. The Greenhouse-Geisser correction was applied when Mauchly's test indicated violation of sphericity, and the corresponding p-values are reported. Wilcoxon's test was used for variables that were not normally distributed or similarly skewed.

3 RESULTS AND DISCUSSION

3.1 Thermal comfort and perception

Condition had a significant effect on the mean thermal sensation vote ($p<0.001$, Figure 2). The mean thermal sensation vote was -0.5 in condition A and -1.2 in condition B. Percentage of dissatisfied respondents was 24% in condition A and 62% in condition B.

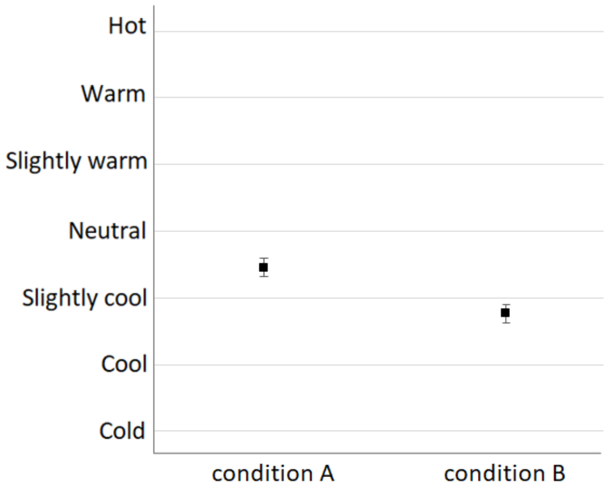

Figure 2: The mean thermal sensation votes in condition A and in condition B. Whiskers represent standard errors.

Participants reported that they felt the air movement in 88% of responses in condition B. Among those responses, 65% reported that air movement was unpleasant and 82% would have preferred less air movement.

All symptoms were minor (mean values below 1.8) and condition had no significant effect on them. Similarly, perceived fatigue was minor (mean values below 2) and no effect of condition was seen.

Condition did not affect self-estimated work performance or workload. However, draught disturbed and annoyed more in condition B ($p<0.001$).

3.2 Work performance

Condition had an effect on reaction times in 1-back at the beginning of exposure ($p<0.05$). Reaction time was 0.587 ms in condition A and 0.554 ms in condition B.

The thermal environment has affected work performance in N-back task also in previous studies. High room temperature has shown to decrease the work performance in N-back task (Maula et al., 2016a) and increased air movement in warm environment has shown to increase work performance in N-back task (Maula et al., 2016b).

3.3 Stress effects

Condition had a significant effect on the Stress index SI ($p<0.01$). The stress index SI was higher in condition B (mean value 7.22) than in condition A (mean value 7.15).

4 CONCLUSIONS

The effect of draught on on work performance, comfort, and stress was studied in a situation where draught is generated with increased heat loads and cooling, while room temperature itself is kept at optimal level. Draught mainly affected on subjective responses and stress. Slight effect of draught on work performance was observed. For these reasons, special attention should be given for reducing draught in offices.

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6 REFERENCES

Baevsky and Chernikova (2017). *Heart rate variability analysis: physiological foundations and main methods*; Cardiometry; No.10 May 2017; p.66–76; DOI: 10.12710/cardiometry.2017.6676 Available from: www.cardiometry.net/issues/no10-may-2017/heart-rate-variability-analysis

Clements-Croome, D (2006). *Creating the Productive Workplace*, 2nd edn, Abingdon, Oxon, UK, Taylor & Francis.

De Dear R, Akimoto T, Arens EA, Brager G, Candido C, Cheong KWD, Li B, Nishihara N, Sekhar SC, Tanabe S, Toftum J, Zhang H, Zhu Y. (2013). *Progress in thermal comfort research over the last twenty years*. Indoor Air. doi:10.1111/ina.12046

Fanger P.O. (1970). *Thermal comfort, Analysis and applications in environmental engineering*. McGrawHill. 1970 ISBN:0-07-019915-9

ISO 7730 (2005). *Ergonomics of the Thermal Environment. Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria*, International Organization for Standardization, Geneve.

Koskela H, Häggblom H, Kosonen R, and Ruponen M. (2010). *Air distribution in office environment with asymmetric workstation layout using chilled beams*. Elsevier Ltd. Building and Environment, volume 45, pages 1923-1931. ISSN: 0360-1323. DOI: 10.1016/j.buildenv.2010.02.007.

Maula H, Hongisto V, Östman L, Haapakangas A, Koskela H and Hyönä J (2016a). *The effect of slightly warm temperature on work performance and comfort in open-plan office*. Indoor Air, volume 26, issue 2, pages 286-297. DOI: 10.1111/ina.12209.

Maula H, Hongisto V, Koskela H and Haapakangas A (2016b). *The effect of cooling jet on work performance and comfort in warm office environment*. Elsevier Ltd. Building and Environment, volume 104, pages 13-20. ISSN: 0360-1323. DOI: 10.1016/j.buildenv.2016.04.018

Owen A.M., McMillan K.M., Laird A.R., Bullmore E. 2005. N-back working memory paradigm: A meta-analysis of normative functional neuroimaging studies. Human Brain Mapping, 25, 46-59.

Parsons, K. (2003) *Human Thermal Environments. The Effects of Hot, Moderate and Cold Environments on Human Health, Comfort and Performance*, London, UK, Taylor & Francis, 330.

Seppänen O., Fisk W.J., and Faulkner D. (2003) *Cost benefit analysis of the night-time ventilative cooling in office building*. In Proceedings of the Healthy Buildings Conference, Singapore.
Seppänen O., Fisk W.J., and Lei QH. (2006) *Effect of temperature on task performance in office environment*. Lawrence Berkeley National Laboratory, LNBL report 60946.
Åhsberg E. 1998. Perceived fatigue related to work. Arbete och Hälsa, 1998:19.