The effect of adjustable cooling jet on thermal comfort and perception in warm office environment – a laboratory study

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ABSTRACT

The aim was to study how the cooling jet from the ceiling, with individual control over the airflow, is perceived and how it affects the thermal comfort in warm office environment. 32 undergraduate university students participated in the experiment. Two thermal conditions were tested: (1) no cooling jet and (2) adjustable cooling jet from the ceiling. Subjects were able to use a controller with seven different settings to adjust the airflow coming from the nozzles so that the target velocity varied from 0.3 m/s to 1.5 m/s. The cooling jet was directed into the upper body.

The whole experimental session lasted for 110 minutes including acclimatization (30 minutes) and both thermal conditions (40 minutes each). The order of thermal conditions was counterbalanced between participants. Clothing insulation and activity level were controlled. Subjects' work performance was measured with two different tasks: short term memory task and working memory task. Whole body thermal comfort, local thermal comfort, symptoms and subjects perception were assessed with questionnaires.

Most of the subjects adjusted the airflow of the cooling jet. 65% of the subjects adjusted the jet so that at the end of session the target velocity was 1.1-1.3 m/s. Adjustable cooling jet improved thermal comfort, perceived indoor air quality and perception of the work environment. It also reduced symptoms, perceived fatigue, tiredness and subjective workload. Thermal environment with the adjustable cooling jet was perceived to be better for working efficiently for a long time. Condition did not affect work performance.

KEYWORDS

Individual control, Symptoms, Perception, Perceived indoor air quality, Air velocity

1 INTRODUCTION

Too high room air temperature (Maula et al., 2016a) and poor indoor air quality (Maula et al., 2017) can affect negatively on occupant's thermal comfort, perceived indoor air quality and work performance. Local cooling can be provided by increasing air movement. Standards allow elevated air speed to be used to increase the maximum operative temperature for acceptability (ASHRAE 55, 2010; ISO 7730, 2005; EN 15251, 2007).

Increased air movement has been found to reduce the negative impact of increased air temperature, relative humidity, and pollution level on perceived air quality (Melikov and Kaczmarczyk, 2012). The air movement was produced in their study with an air terminal device that was installed on the desk. They noticed that recirculated room air did not reduce the intensity of SBS symptoms, but clean outdoor air did so. Therefore, using clean outdoor air in local ventilation jet applications may be beneficial. However, installing an air terminal unit and ducting providing clean outdoor air into the desk might complicate the layout changes in offices. One solution is to integrate the cooling jet to the HVAC system and place the air terminal unit into the ceiling, which enables layout changes with less effort.

Maula et al. (2016b) studied the effect of cooling jet from the ceiling on thermal comfort and work performance of twenty nine subjects in warm office environment. The airflow rate of fresh air coming from the nozzles was kept constant, so that the target velocity in the facial region was 0.8 m/s, which is according to ASHRAE standard 55 (2010) the upper limit to air speed when sedentary office occupants do not have control over the local air speed. The room air temperature was 29.5 °C and the jet temperature in subject's facial region was 28.5 °C. They found that thermal comfort and perceived working conditions were improved, and indoor air was perceived fresher with the jet. The jet improved the speed of response in a working memory task with increasing exposure time. Self-rated performance was higher with the cooling jet. However, the diverse perception of the jet and the increased eye symptoms showed the need for individual control over the airflow already at the air velocity of 0.8 m/s.

Lipczynska et al. (2014) studied the impact of personalized ventilation combined with chilled ceiling on eye irritation with twenty four subjects in warm office environment. They noticed that the use of individual control of supplied personalized ventilation airflow resulted in acceptable air movement by most of the subjects. Lipczynska et al. (2014) suggested that the use of individual control over the airflow might be one of the main solutions to avoid possible eye symptoms caused by elevated air movement. The personalized ventilation device was installed in to the desk so that the airflow was coming from in front of subject, and therefore reults cannot be automatically applied when the airflow is coming from the ceiling.

Our aim was to study the effect of adjustable cooling jet from the ceiling on thermal comfort, symptoms and perception in warm office environment. This study is a continuation of the study by Maula et al. (2016b).

2 METHODS

The study was carried out in the office laboratory (12m^2) of Finnish Institute of Occupational Health in spring 2015 (Figure 1). Screens of 1.3 metres high were installed between workstations 1 and 2, and next to supervisors' workstation. The room air temperature was 29.4 °C, relative humidity was 15 % and supply air flow rate was 27 l/s per person. Fresh outdoor air was supplied with one terminal unit installed in the middle of the ceiling and with one cooling jet above the other workstation, i.e. workstation 2 (Figure 1). The inlet duct was divided into two branches outside the office laboratory: main branch into terminal unit and secondary branch into workstation 2. A duct fan was installed outside the laboratory into the secondary branch and a remote control was brought into workstation 2 (Figure 2). The cooling jet was produced with seven adjustable nozzles installed symmetrically into the end of secondary branch (Figure 2). Nozzles were adjusted so that the cooling jet was directed towards occupants' chest. Air velocity distributions and target velocities, i.e. maximum velocities in which the cooling jet hits the occupant, for each setting of fan control were measured separately of the human subject experiments (Figure 3). The direction of the cooling jet was not changed during the experiment. Noise level and lighting conditions met current recommendations for office environment.

Two thermal conditions were tested; (1) no cooling jet and (2) adjustable cooling jet. The cooling jet was isothermal. Participants were advised to adjust the airflow of the cooling jet whenever necessary, with the exception of performing the tasks. Subjects were able to adjust the airflow coming from the nozzles so that the target velocity i.e. maximum velocity on the subjects point, varied from 0.3 m/s to 1.5 m/s (Figure 3). The cooling jet was directed into the upper body.

Altogether, 32 participants (9 male and 23 female) were recruited. The participants were native Finnish speakers and aged between 19 and 38 years (average = 25). The study had a repeated measures design, i.e. each subject was exposed to both thermal conditions and served as their own control minimizing the effect of individual differences on results. Participants were tested one at a time. The order of thermal conditions were counterbalanced between participants to control possible order effects concerning, for example, learning and fatigue.

Clothing insulation and activity level were controlled. The participants were advised to wear trousers, short sleeve shirt, socks and ankle-length shoes. The estimated clothing insulation including office chair (0.1 clo) was 0.71 clo (ISO 7730, 2005). The main activity of the participants during the study was typing. The estimated activity level was 1.1 met (ISO 7730, 2005).

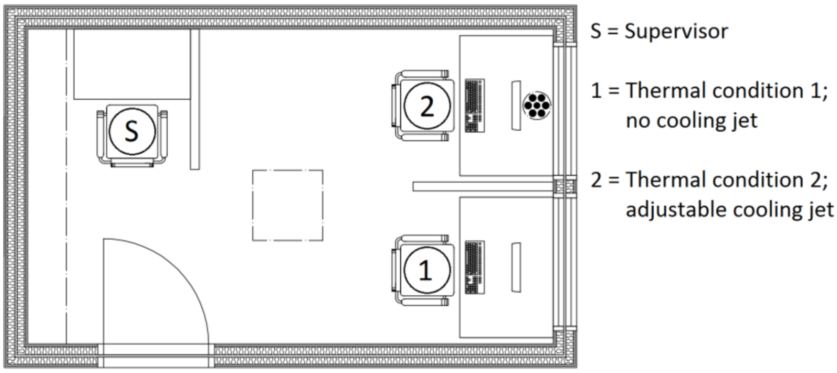

Figure 1: Layout of the office laboratory. Acclimatization was done in workstation 1.

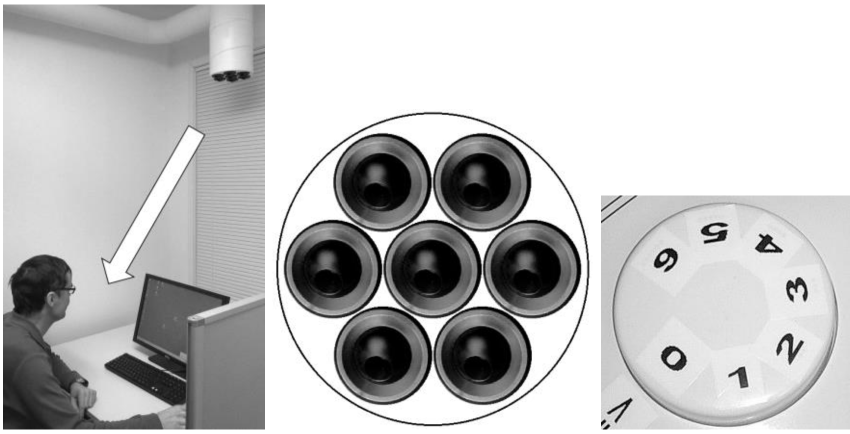

Figure 2: Left: The direction of the cooling jet. Middle: Seven nozzles installed symmetrically into the end of secondary branch of inlet duct. Right: Remote control of the duct fan.

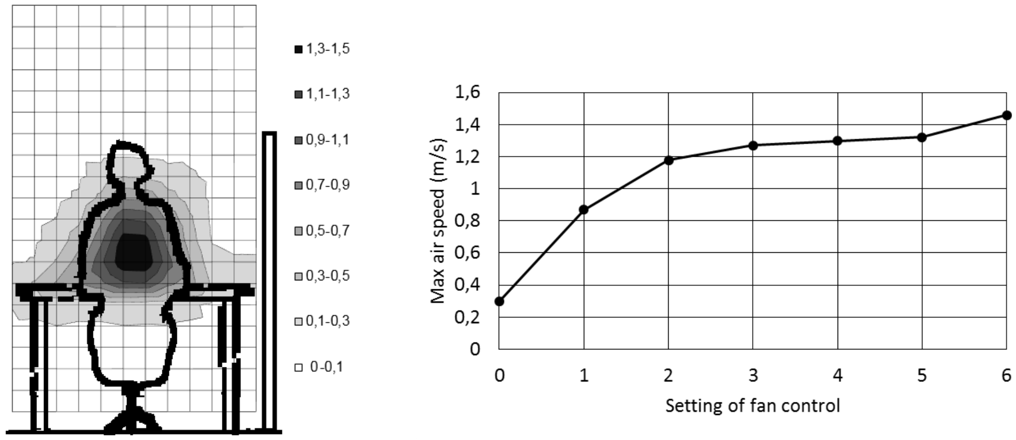

Figure 3: Cooling jet was directed towards occupants' chest as seen from velocity distribution measurements (m/s) with fan control adjusted to maximum (setting 6, left). A 10 x 10 cm measurement grid was used. Right: Target velocities (m/s) of each setting of fan control.

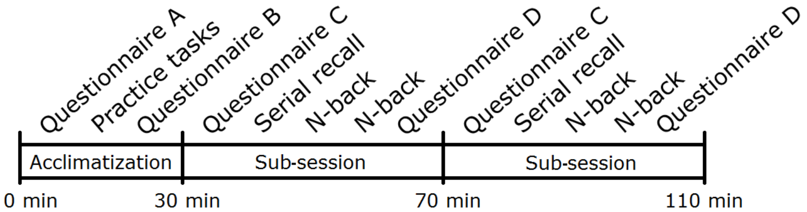

Figure 4: Procedure of the whole experimental session containing both thermal conditions (first sub-session had one thermal condition and the second sub-session had the other thermal condition).

The whole experimental session lasted for 110 min (Figure 4). It included an acclimatization phase (30 min) and both thermal conditions (40 min per sub-session). During acclimatization the participants filled questionnaires and practiced performance tasks. Questionnaires were filled in the beginning and at the end of the acclimation phase and during both sub-sessions. The sub-sessions were carried out right after another without a break.

Participants' performed two different tasks in both sub-sessions: short-term memory task (serial recall task; Maula et al., 2016b) and working memory task (N-back task; Owen et al., 2005). Whole body thermal comfort, local thermal comfort, symptoms, subjective performance ratings and overall experience of the environment were assessed with questionnaires, which were repeated throughout the session. In addition, the perception of cooling jet was assessed in workstation 2. Questions and response scales are presented in Maula et al., (2016b, Table 1).

Statistical analyses were conducted with IBM SPSS Statistics for Windows, Version 20.2 (Armonk, NY: IBM Corp.) with a confidence interval of 95 %. The normality of the data was tested with Shapiro-Wilk test. A repeated measures ANOVA was used when data was normally distributed or when distributions were similarly skewed. The Greenhouse-Geisser correction was applied when Mauchly's test indicated violation of sphericity, and the corresponding p-values are reported. Friedman and Wilcoxon's tests were used for variables that were not normally distributed if they also differed in the direction of skewness. Significant interactions were further analysed with t-test (two-tailed) or Wilcoxon test. Benjamini-Hochberg procedure was used in paired comparisons.

3 RESULTS AND DISCUSSION

Most of the subjects adjusted the airflow of the jet. 65% of the subjects adjusted the jet so that at the end of session the target velocity was 1.1-1.3 m/s.

Table 1 shows the results, in which the difference between thermal conditions are statistically significant. The adjustable cooling jet improved thermal comfort (Figure 5), perceived indoor air quality and perceived work environment. The median value of thermal sensation vote at the end of sub-session was +1.9 without the jet, and +0.4 with the adjustable cooling jet, respectively. Response scale was from -3 'cold' to +3 'hot' (Figure 5). Symptoms, subjective workload and cognitive fatigue were decreased with the jet. Eye symptoms were minor and thermal condition had no significant effect on them.

The perception of the jet was slightly diverse between participants. When participants were asked to name body parts where the jet was perceived as pleasant, all body parts under the direct influence of the jet were mentioned, especially the face (69% of participants reported the cooling jet to be pleasant in the face), arms (66%) and torso (41%). Respectively, some participants reported the jet to be unpleasant in the face (38%, including participants who liked the cooling jet in the face but not in the eyes) and front neck (25%). 9% of participants mentioned separately in open questions, that they would have wanted to be able to adjust also the direction of the jet.

No effect of thermal condition was seen on objective or subjective work performance.

Table 1: All results, in which the difference between thermal conditions are statistically significant, and *p*-values. The condition, which was better for occupant, is marked with "X".

Questionnaire		***p***	**No cooling jet**	**Adjustable cooling jet**
Thermal comfort	Whole body thermal sensation	<.001		X
	Local thermal sensation*	<.05		X
Symptoms	Sweating	<.001		X
	Headache	<.01		X
	Nasal symptoms	<.05		X
	Feeling of being unwell	<.05		X
	Difficulties in concentration	<.01		X
Cognitive fatigue	Tiredness	<.05		X
	Lack of energy	<.01		X
	Lack of motivation	<.001		X
Subjective workload	Workload during the most difficult task	<.05		X
	Exertion	<.01		X
Disturbance of performance	Heat	<.001		X
	Draught	<.001	X	
	Stuffiness	<.001		X
Perceived air quality		<.001		X
Perceived work environment	Pleasantness of environment	<.001		X
	Draughtiness	<.001	X	
	Stuffiness	<.001		X
	Overall experience of the environment	<.001		X
	The possibility to work effectively in that temperature	<.001		X

*All body parts

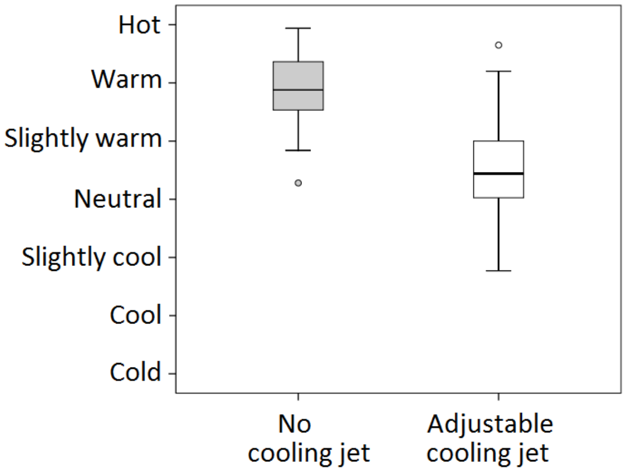

Figure 5: The distribution of whole body thermal sensation at the end of sub-session in both thermal conditions. 72% of participants were dissatisfied with the thermal environment at the end of the sub-session without the jet, while 22% of participants were dissatisfied with the adjustable cooling jet, respectively.

4 CONCLUSIONS

The results suggests that providing local cooling with a ceiling based adjustable cooling jet can improve thermal comfort, perceived indoor air quality and perceived working conditions in warm office environment. Additionally, symptoms, subjective workload and cognitive fatigue might be reduced with jet. These findings can be utilized in the development of energy-efficient air conditioning systems for offices where overheating occurs. However, it seems that individual control is needed, not only on airflow, but also on the direction of the jet. In the future, the effect of individual control on both the jet airflow rate and flow direction in otherwise similar conditions should be studied.

5 ACKNOWLEDGEMENTS

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