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The effect of cooling jet on work performance and comfort in warm office environment

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ABSTRACT

The aim of our study was to determine the effect of a cooling jet on performance and comfort in warm office environment. We compared cognitive performance, subjective workload, cognitive fatigue, thermal comfort, symptoms, perceived working conditions and perception of airflow in warm temperature (29.5 °C) in two conditions: with and without the jet. Twenty-nine students participated in the experiment in which a repeated measures design was employed. The jet improved the speed of response in a working memory task with increasing exposure time but did not affect other performance measures. Self-rated performance was higher and frustration was lower with the jet. Tiredness increased with increasing exposure time without the jet, but remained constant with the jet. Thermal comfort and perceived working conditions were improved, and indoor air was perceived fresher with the jet. Eye symptoms increased over time with the jet. The results support the use of cooling jet in offices with high thermal loads where individual control over the air temperature is not possible via air conditioning. It seems, however, that there is a need for individual control over the jet already when the target velocity is set to the upper limit according to ASHRAE standard.

Practical implications: A cooling jet from the ceiling can be used to provide beneficial local cooling in warm offices. Cooling jet seems to increase thermal comfort and perceived indoor air quality, but also improve subjective working conditions. The use of local cooling may enable energy savings by allowing the room air temperature to rise without causing thermal discomfort.

1. Introduction

Too warm room air temperature can affect occupant's thermal comfort and performance negatively. Room air temperature can be controlled with an air conditioning system which typically provides consistent cooling to the whole space. The costs and the energy consumption of air conditioning can be significant and improperly designed air conditioning can produce new complaints such as draught and feeling of cold. Local cooling may enable energy savings by allowing the room air temperature to rise without causing thermal discomfort.

One way of providing local cooling with lower energy use is to increase air movement with local and well-designed jets. The standards ASHRAE 55 [1], ISO 7730 [2] and EN 15251 [3] allow elevated air speed to be used to increase the maximum operative temperature for acceptability. According to ASHRAE standard, if sedentary office occupants do not have control over the local air speed, the upper limit to air speed should be 0.8 m/s for operative temperatures above 25.5 °C.

There are numerous ways of providing local air movement, such as a fan which circulates the room air or a jet providing fresh air. The room air temperatures as well as the temperature difference between the jet and room air can be different. The distance between the jet source and the occupant can vary, resulting in different temperature and air freshness in occupied zone through induced room air. Air flow direction and air speed can also vary. All these parameters may affect the perception of the local air movement.

Huang et al. [4] studied the user requirements for local air movement with a series of laboratory experiments and with an online survey in workplaces in China. They concluded that the airflow generated by table fans can be used as an effective method to maintain a comfortable environment at temperature range 28–32 °C. However, increasing air movement may not be beneficial

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when indoor air temperature is above skin temperature (34 °C–37.5 °C; Liu et al. [5]).

Both the velocity and the direction of the cooling jet are important design factors. Melikov et al. [6] and Zeng et al. [7] reported large differences in the jet velocity preferred by the subjects. The preferred velocities were not the ones corresponding to thermal neutrality, but the ones that decreased the warmth sensation without causing too much discomfort due to draft. According to the experiments done with a thermal manikin (Yang et al. [8]), the target velocity of 0.8 m/s is strong enough to prevent the thermal plume from the manikin and to efficiently provide cooling to manikin's body. Gong et al. [9] identified the acceptable velocity range to facial region to be between 0.3 and 0.9 m/s. Melikov et al. [6] reported that in warm conditions the lower part of the body and the neck were cooled more by a vertical jet than by a horizontal jet. The subjects preferred higher velocities with a horizontal than with a vertical jet. Chludzińska and Bogdan [10] determined proper airflow direction by experiment personalized ventilation with 20 volunteers. Airflow was directed to the face and to the ankle level. Chludzińska and Bogdan noticed that higher efficiency in summer conditions is obtained by supplying airflow to the face than to the ankles. Yang et al. [11] found that neck is much more sensitive to a vertical jet exposure from the ceiling than face.

Melikov and Kaczmarczyk [12] studied the impact of air movement on perceived air quality and SBS symptoms by comparing the use of recirculated room air and clean outdoor air in a various combinations of temperature, relative humidity and pollution levels. The air movement was produced with an air terminal device that was installed on the desk. The increased air movement reduced the negative impact of increased air temperature, relative humidity and pollution level on perceived air quality. The recirculated room air did not reduce the intensity of SBS symptoms, but clean outdoor air did so. Therefore, using clean outdoor air in jet applications may be beneficial.

Installing an air terminal unit providing clean outdoor supply air into the desk might complicate the layout changes in offices. Integrating the cooling jet to the HVAC system and placing the air terminal unit into the ceiling, might be a solution which enables layout changes with less effort. CFD simulations and measurements in laboratory conditions representing a full-scale open-plan office have shown that the heat sources, i.e. layout, have a notable influence of the flow pattern in office rooms [13]. Therefore, direct comparison to the effect of cooling jet from the desk (air terminal unit close to the user) and from the ceiling (air terminal unit further from the user) on SBS symptoms is difficult.

As seen above, modifying different parameters of a cooling jet may have significant effect on the subjects' perception of the jet, and the effect is not always easy to predict. Therefore, there is a need for more research of the effect of a cooling jet on occupant comfort and SBS symptoms with different types of air terminal units and cooling jet parameter solutions.

Seppänen et al. [14] suggested a U-shaped curve for the relation between performance and temperature. The model is based on performance measures such as text processing, addition and multiplication. However, the effect of warm temperature on performance seems to be task-dependent (Maula et al. [15]; Hancock et al. [16]). In a meta-analysis by Hancock et al. [16] temperature range from 26 °C to 30 °C was found to affect mainly cognitive performance while psychomotor performance remained unaffected. Warm temperature (29.5 °C) has been found to decrease performance in a working memory task (Maula et al. [15]). In warm temperatures (up to 30 °C), jets were found to have no effect on performance in a memory task (table fan; Cui et al. [17]), addition (table fan; Cui et al. [17]), pattern matching (table fan; Cui et al. [17]) or multiplication task (jet with fresh air above the display; Melikov et al. [18]). However, supplying a jet was found to improve the performance in warm conditions in the problem solving task (Sudoku) when fresh supply air was used in the jet above the display (Melikov et al. [18]). No studies were found which investigated the effect of a cooling jet on working memory performance in warm conditions. Additional research in this field is justified both from academic and practical point of view.

Based on our review, there is very little knowledge how cooling jet from the ceiling affects occupants perception, symptoms and working memory performance in warm office environment. It is important to investigate a jet solution which could also be implemented in a real product and integrated to the air conditioning system.

Our aim was to study the effect of a pre-defined cooling jet from ceiling on cognitive performance in a warm office environment. Our second aim was to assess the effect of the jet on subjective workload, cognitive fatigue, somatic symptoms, perceived working conditions and thermal comfort. Our third aim was to study the perception of the jet.

2. Methods

2.1. Open-plan office laboratory

The experiment was conducted in an open-plan office laboratory (82 m^2) in Turku, Finland, during spring 2013 (Figs. 1 and 2). The room had twelve desks and it was designed to resemble a neutral full-scale open-plan office. Four desks were used because two participants were present simultaneously. Screens with height of 1.3 m were installed between the desks to eliminate visual contact between the subjects. The room did not extend to the building facades which made the control of thermal environment easier.

2.2. Subjects

Twenty-nine undergraduate university students (16 female and 13 male) participated in the experiment. All subjects were native Finnish speakers and aged between 20 and 33 years (Median = 24). A 40 € compensation was paid for the participation. The subjects

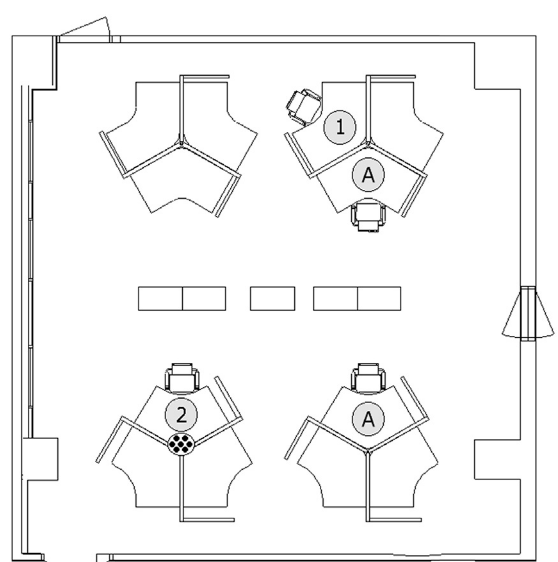

Fig. 1. Open-plan office laboratory and the workstations used in the experiment (A = acclimatization, 1 = Without the jet, and 2 = With the jet).