# PERCEPTION OF A COOLING JET FROM CEILING - A LABORATORY STUDY

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## ABSTRACT

The effect of a cooling jet from ceiling on thermal comfort, perception and subjective performance in warm office environment (29.5 °C) was studied. Altogether, 29 participants (13 male and 16 female) participated. All participants were tested in both thermal conditions and the order of the thermal conditions was counterbalanced between the participants. During the experiment, participants filled questionnaires and performed computerised tasks. Using the cooling jet significantly improved the whole body and local thermal comfort. It also improved the perception of the whole working environment. The indoor air was perceived fresher when the cooling jet was provided. Fatigue increased in time significantly only when the cooling jet was not provided. Eye symptoms increased in time only with the cooling jet. The cooling jet increased the sensation of draught, but still the warm room air temperature was perceived to impair the performance more than draught. The room air temperature was perceived to be better for working effectively for a long period of time with the cooling jet.

## KEYWORDS

Thermal comfort, cooling jet, perception, symptoms, self-rated performance

## 1 INTRODUCTION

Room temperature is an important part of the indoor environment. Too warm room air affects negatively occupant's thermal comfort and performance (Häggblom et al. 2011). Local cooling can be produced by increasing the air movement (Melikov et al. 2013).

Table fans are commonly used in offices during warm summer periods. Huang et al. (2013) studied the user requirements for air movement with an online survey in China and a series of climate chamber experiments. They concluded that the flow generated by electric fans can be used as an effective cooling method to maintain a comfortable environment at 28 °C-32 °C. However, in open-plan offices with high density of workstations the fans also increase substantially the thermal load of the office increasing the need of cooling and the energy consumption. Supplying an air jet from the ceiling can be integrated to the air conditioning system thus removing the need for a local fan.

Toftum (2014) summarized the factors influencing the perception of air movement. According to the summary, occupants feeling warmer than neutral do not feel draught at air velocities up to 0.4 m/s. In the high temperature range up to 30 °C, very high air velocities, such as 1.6 m/s, were found to be acceptable. However, they concluded that very high air movement should be under the control of the exposed occupant.

ASHRAE 55(2010) and ISO 7730 (2005) standards allow elevated air speed to be used to increase the maximum operative temperature for acceptability under certain conditions.

According to the ASHRAE standard, if sedentary office occupants don’t have control over the local air speed in their space, the upper limit to air speed should be 0.8 m/s for operative temperatures above 25.5 °C.

The aim of this study was to investigate how the cooling jet from ceiling is perceived and how it affects the thermal comfort and subjective work performance.

## 2 METHODS

The study was carried out in the open-plan office laboratory (82 $m^2$) of FIOH in spring 2013. The room had twelve workstations and was designed to resemble a neutral clerical office. Four workstations out of the twelve were used in this study (Figure 1). The HVAC of the office laboratory was adjusted to room air temperature 29.5 °C, relative humidity 20 % and supply air flow rate 280 l/s. Supply air was blown with five terminal units and with one cooling jet. The cooling jet was produced with seven adjustable nozzles installed symmetrically into the end of one of the inlet ducts (Figure 3). Noise level and lighting conditions met current recommendations.

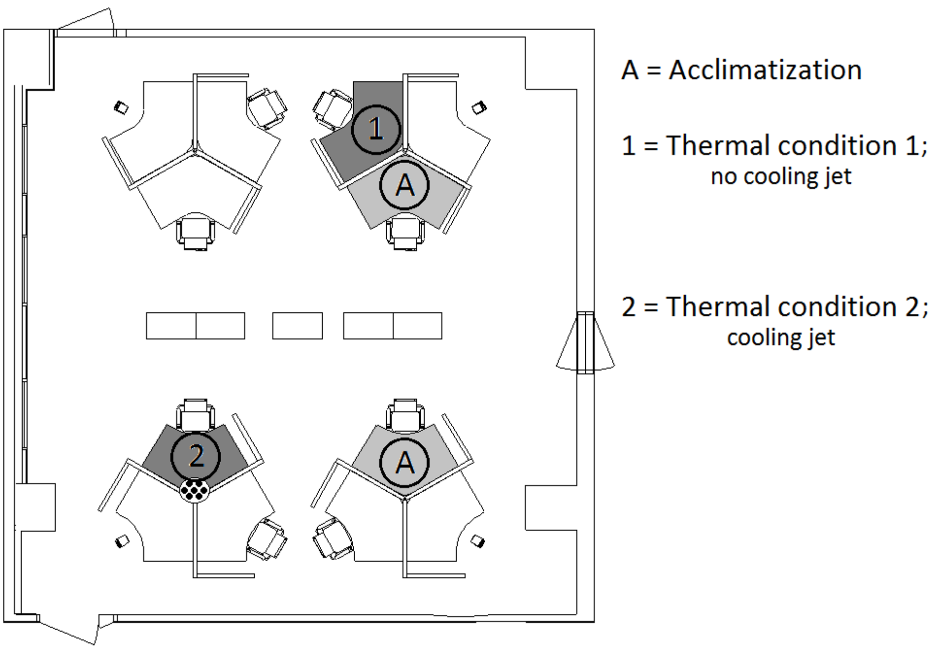


Figure 1: Layout of the open-plan office laboratory.

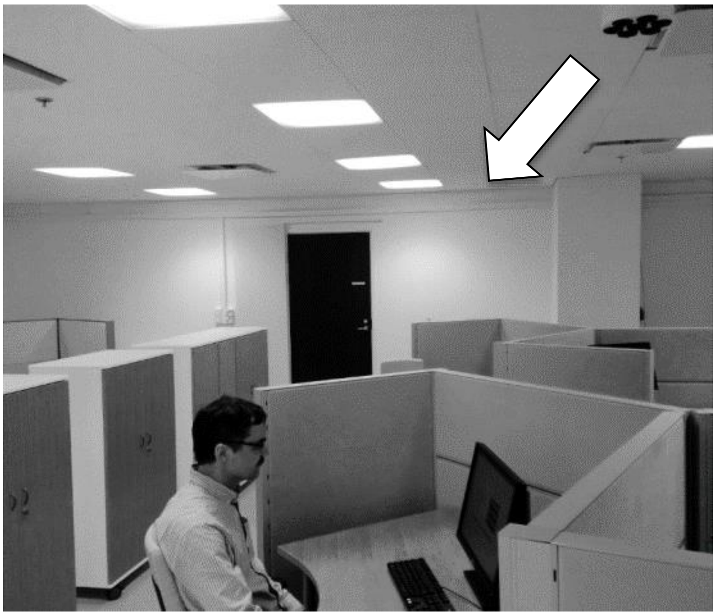

Figure 2: Seven nozzles installed symmetrically into the end of one of the inlet ducts to produce the cooling jet.

Two thermal conditions were tested; (1) no cooling jet and (2) cooling jet with fresh supply air (ΔT = -3.5 °C and target velocity 0.8 m/s). Air velocity was measured in the occupied zone with hot-sphere anemometers while the dummy subjects (heat load 90 W/dummy) were present to simulate a sitting person (Zukowska-Tejsen et al., 2012). The cooling jet in thermal condition 2 was located in front of the occupant in the suspended ceiling (height 2.55 m). The angle of the cooling jet was 45° from the vertical axis. Target velocity of the cooling jet was set to upper limit of acceptable air speed without personal control according to ASHRAE standard 55 (2010) and ISO standard 7730 (2005). Both thermal conditions were tested simultaneously in the open-plan office laboratory.

Altogether, 29 participants (13 male and 16 female) were recruited. The participants were native Finnish speakers and aged between 20 and 33 years (average = 24). The study had a repeated measures design. All participants were tested in both thermal conditions two at a time. The order of thermal conditions was counterbalanced between participants. 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. The main activity of the participants during the study was typing. The estimated activity level was 1.1 met.

The experiment day started with 30 minutes acclimatization (Figure 3). Workstations meant for acclimatization didn’t differ from the thermal condition without the cooling jet. The purpose of the acclimatization was to secure that each participant had similar acclimatization despite of in which thermal condition they took part in first. During acclimatization the participants filled questionnaires and computerised performance tasks were introduced to them. After the acclimatization, participants moved to the experimental workstation and the first session started with questionnaires. After the questionnaires the participants performed computerised tasks followed by questionnaires at the end of the session. The session in both thermal conditions lasted for 40 minutes. After the first session the participants changed places with each other and the second session in different thermal condition but with an identical procedure started immediately. There were no breaks in between the two sessions.

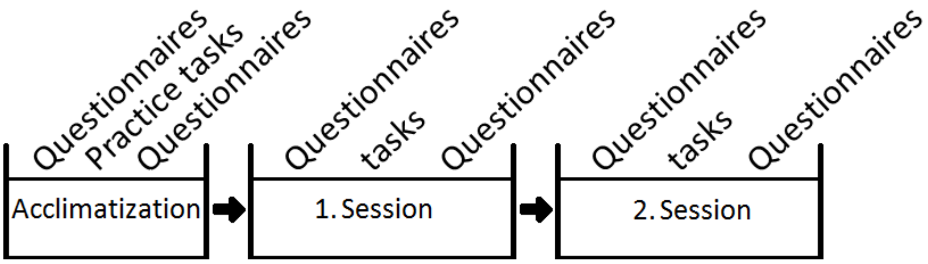


Figure 3: Test procedure

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. Thermal comfort was evaluated using a seven-point thermal sensation scale. Fatigue was measured with a modified version of the Swedish Occupational Fatigue Inventory (SOFI; Åhsberg et al., 1995, Åhsberg et al., 1998) including three factors which were sum variables of three items (tiredness: sleepy, yawning, drowsy; lack of energy: worn out, exhausted, drained; lack of motivation: uninterested, indifferent, passive).

Statistical analyses were conducted with SPSS Statistics 20 with a confidence interval of 95 %. The normality of the data was tested with Shapiro-Wilk. A repeated measures ANOVA was used when data was normally distributed or when distributions were similarly skewed. Whenever parametric methods were used, the results were also checked with the nonparametric Wilcoxon test. When an interaction effect was found, paired comparisons between conditions were performed using t-test or Wilcoxon. Benjamini-Hochberg procedure was used in paired comparisons.

## 3 RESULTS AND DISCUSSION

Table 1 shows the percentage of participants experiencing the cooling jet to be pleasant or unpleasant in certain body parts. The perception of the cooling jet was contradictory. Over 50 % of the participants reported the cooling jet to be pleasant in the arms, face or at the top of the head. Respectively the face and the top of the head received most votes of the airflow being unpleasant. On the open questionnaires some participants reported the airflow to be unpleasant in the eyes but to be pleasant everywhere else in the face. Those answers are included in both pleasantness categories. Also the intensity of the cooling jet distributed the opinions. Some of the participants would have preferred more air flow and some less.

Table 1: The percentage of participants reporting airflow pleasant or unpleasant in certain body parts.

| | **Top of the head** | **Face** | **Neck** | **Front neck** | **Torso** | **Arms** | **Hands** |
|---|---|---|---|---|---|---|---|
| Pleasant | 52 | 66 | 7 | 38 | 45 | 72 | 31 |
| Unpleasant | 21 | 41 | 10 | 10 | 0 | 10 | 0 |

The differences in thermal comfort were statistically significant (p<.01, Figure 4). 67 % of the participants considered the thermal conditions to be acceptable with the cooling jet, while only 28 % considered them to be acceptable without the cooling jet. No gender differences were found. The improvement of thermal comfort under the influence of the cooling jet was statistically significant in each body part except the thighs. However, a trend of the cooling jet improving thermal comfort in thighs was found (p=.068). Thermal comfort was significantly better with the cooling jet even in legs and feet, although they were not under direct influence of the airflow.

The occurrence of fatigue was minor. Fatigue increased in one measured factor, tiredness, toward the end in both thermal conditions, but the increment of fatigue was significant only in the condition without the cooling jet (p<.01; Figure 5). Eye symptoms increased in time only in the condition with the cooling jet (p<.001), but the intensity of eye symptoms was minor even at the end of the session.

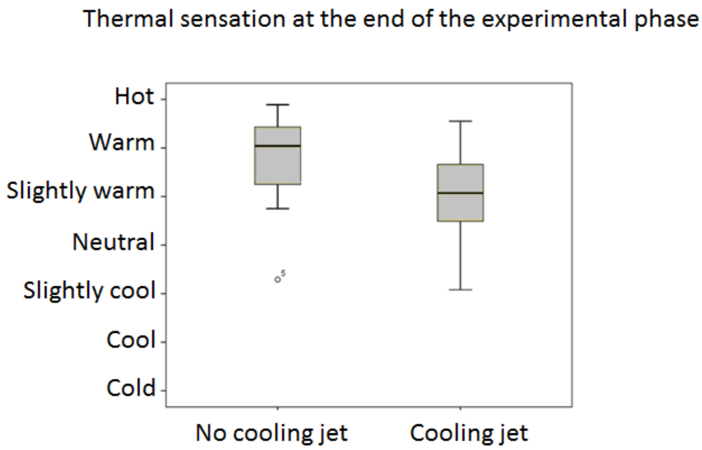


Figure 4: Thermal sensation votes

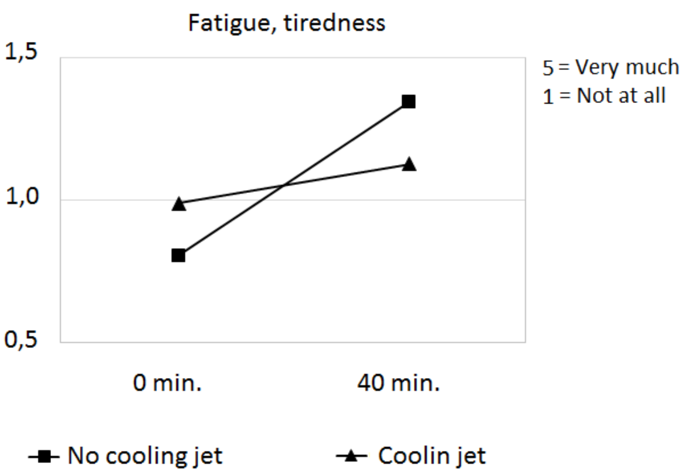


Figure 5: Fatigue, factor tiredness

The indoor air was perceived fresher when the cooling jet was provided ($p<.01$). Under the cooling jet the air temperature was perceived better ($p<.001$) but there was more sensation of draught ($p<.001$). The whole working environment was perceived better in the thermal condition with the cooling jet ($p<.05$).

There was a trend that the subjective performance was better when working under the influence of the cooling jet, but the difference between the conditions was not statistically significant ($p=.064$). However, the participants were more frustrated during the most difficult task in the condition with no cooling jet ($p<.05$). The stuffiness of the room air was perceived to impair the performance more without the cooling jet than with cooling jet ($p<.05$). Draught disturbed the performance more in the condition with the cooling jet ($p<.01$), but in that thermal condition heat was perceived to be more disturbing than draught ($p<.01$). The room air temperature in the condition with the cooling jet was perceived to be better for working effectively for a long period of time ($p<.05$).

## 4 CONCLUSIONS

The results show that providing local cooling with a supply air jet improves the thermal comfort and the perception of the working environment in a warm office. The study was carried out with a cooling jet with air speed in the upper acceptable limit when local control over the cooling jet is not provided. The perception of the cooling jet was contradictory. Results showed the need for individual control over the airflow already at the air velocity of 0.8 m/s. In the future, the effect of individual adjustment in similar conditions on the thermal comfort, perception and subjective performance should be studied.

## 5 ACKNOWLEDGEMENTS

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