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Experimental evaluation of an intermittent air supply system – Part 2: Occupant perception of thermal climate

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ABSTRACT

A newly proposed intermittent air jet strategy (IAJS) provides satisfactory indoor climate while promising a substantial energy saving potential, as shown in technical (objective) measurements. The strategy creates non-uniform airflow and non-isothermal conditions critical for sedentary operations at elevated temperatures. The current study explored human perception of thermal environment under an IAJS. Assessment of thermal sensation, thermal comfort, and thermal acceptability were collected based on responses from 36 participants. Participants sat in a classroom setup and performed sedentary work. Their clothing had an insulation of 0.51 clo (T-shirt on upper body). Participants were exposed to homogeneous ($v < 0.15$ m/s) and nonhomogeneous (0.4 m/s $< v <$ 0.8 m/s) velocity conditions across three temperature conditions: 22.5 °C, 25.5 °C and 28.5 °C. The participants found air speeds to be undesirable at lower temperatures, but reported an improved thermal sensation, comfort and acceptability at higher temperatures. As shown here, IAJS generated neutral operable conditions between 24.8 °C and 27.8 °C, within an air speed range of 0.4 m/s to 0.8 m/s. Additionally, air movements induced thermal alliethesia resulting in improved comfort and acceptance of the thermal climate even at lower air speeds in warm temperature conditions. Hence, the current study supports the energy saving potential with IAJS in view of the human perception of the indoor environment.

1. Introduction

The built environment has become one of the largest energy demanding sectors taking over 20% of the total global energy demand [1], and accounts for more than 15% of the carbon dioxide (CO_2) emissions [2]. However, according to the report by the intergovernmental panel on climate change (IPCC), the building sector (residential and commercial) has a high potential for energy and emissions reduction [3]. This potential is especially high on building services such as heating, ventilation and air conditioning (HVAC) of which climate control is the most energy intensive component. However, this potential entails a trade-off between balancing energy requirements and occupant satisfaction.

Today, strategies to modify commonly used homogeneous indoor environmental conditions, i.e. mixing ventilation (MV), are motivated by the need for energy and emissions reduction. However, the deviations from optimal operational conditions of homogeneous indoor climates may have adverse implications on the occupants' experience of the indoor environment [4]. To determine the optimal conditions, building researchers/engineers rely on the standards [5–7] which estimate temperature conditions within which 80% of the occupants will be satisfied. An alternative is to make indoor environments nonhomogeneous or transient. One way of achieving this is through use of elevated air velocities in the occupied zone in neutral-to-warm environments.

Room air velocity is one of the main factors that influence occupants' experience and perception of indoor climate and, as such, it is a prerequisite for thermal comfort. Today, more ventilation/cooling strategies that optimizes elevated air movements and localized cooling have been suggested and investigated [8–17]. The results are promising with regard to their effects on occupant thermal comfort at higher operative temperatures and energy use reduction.

When using elevated air movements in buildings, some guidelines as stipulated in the standards [5–7] should be followed to avoid discomfort associated with air movements. For example, ASHRAE standard 55 [6] contains a Figure (Figure 5.3.3A in the standard but reproduced here as Fig. 1) that clearly show the proposed range of velocities as a function of operative temperature

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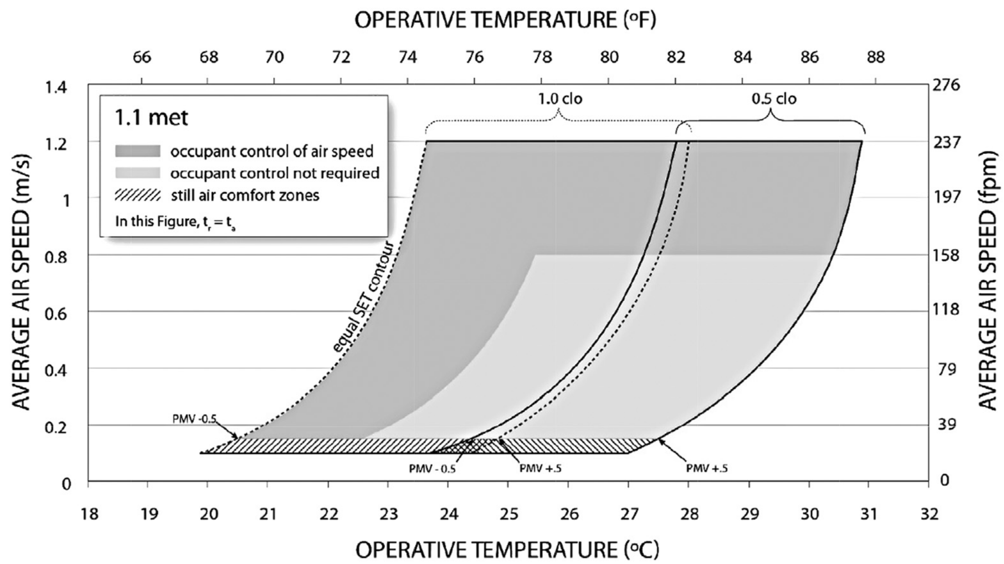

Fig. 1. Range of proposed air speed as a function of operative temperature and occupant control requirements (Fig. 5.3.3A from ASHRAE Standard 55, 2013).

with boundaries in which personal control of air velocity is required and where it is not. It is worth noting that the derived relationships are based on an equal mean radiant temperature (t_r) and room air temperature (t_a). If differences occur such that the $t_r < t_a$, the cooling effect of air movements is less effective, and if $t_r > t_a$ the cooling effect of air movements is more effective [18]. It is for this reason that elevated air movements are more effective in warm indoor climates. The standard [6] also proposes use of the SET* method (Standard Effective Temperature) when estimating the cooling effect with air speeds above 0.2 m/s in the occupied zone. For more details about the SET* method, refer to ASHARAE 55 [6] or/and Schaivon et al. [19].

Evaluation of thermal comfort with the predicted mean vote (PMV) model has inherent discrepancies as discussed in a report by Charles [20] and in other studies [21–24]. Thus, in the applicable context of elevated air movements, ASHRAE 55 recommends the SET* model for air speeds exceeding 0.20 m/s. However, Yang et al. [25] raised a possible issue with the SET* method for non-isothermal conditions, because the method assumes that the velocity magnitude experienced by each body part is the same. The problem here is that some air moving devices, e.g., cooling jets/fans, generate non-uniform velocity fields around the occupant; the resulting velocities at the head is not the same as the velocity at the hands or feet. Thus, Yang et al. [25] found that the method may overestimate the cooling effect of air movements.

Because of possible overestimation and underestimation of current evaluation methods, using human participants makes logical and practical sense as it helps obtain a better understanding of the systems actual influence on occupants' experience of the indoor climate. CEN/EN 15251 [7] recommends that the direct subjective reaction of the occupants to the tested system can be used as an overall evaluation of the generated indoor environment. For this reason, the current study aims to investigate the effect of an intermittent air jet supply system on occupants' perception of the thermal climate. Specifically, the participants estimated overall thermal sensation (OTS), local thermal sensation (LTS), thermal comfort, thermal preference and acceptability as a function of velocity and room air temperature. With these tools, the current study contributes to exploring a practical implementation of a newly developed intermittent air jet strategy (IAJS) as a primary ventilation system in spaces with high occupancy like classrooms.

2. Method

This article is the second part of an experimental evaluation of an IAJS and focuses on the occupants' thermal perception of the ventilation strategy. The first part investigated laboratory measurements of thermal comfort and air quality in a classroom setup [15]. As shown in the first study, despite the intermittent air supply, the system generated satisfactory measured ventilation conditions in the occupied zone with a room air change rate of 3.74 h^{-1} (equivalent to a system running continuously at 8.1 l/s). The strategy also creates unsteady non-isothermal airflow characteristics around the occupant, which improved the measured thermal comfort indices compared to a mixing system. In the study reported herein, we investigate the influence of the aforementioned airflow characteristics on occupants under different airflow/velocity and temperature exposures. A detailed description of the research methodology and approach is reported in the sections below.

2.1. Participants

Forty participants were recruited for the experiment; two participants dropped out and another two were excluded from the analysis as they did not follow instructions. The participant's anthropometric data are shown in Table 1.

The test participants were paid to participate in the study, with requirements of being nonsmokers and non-snus users (moist tobacco/nicotine powder placed under the upper lip). Before the test sessions, all participants took part in a training session to become familiar with the test procedure and the questions they were going to answer during the experiment proper. The use of trained participants is recommended in the standard [26] as they normally

Table 1
Participants' anthropometric data.

Sex	No.	Age	Height (m)	Weight (kg)	BMI[b]
Female	14	26,31 ± 4,25[a]	1,67 ± 0,07	68,08 ± 20,40	24,20 ± 6,60
Male	22	27,75 ± 5,04	1,74 ± 0,12	73,63 ± 13,94	24,36 ± 4,68
Total	36	27,24 ± 4,86	1,72 ± 0,11	71,68 ± 16,85	24,30 ± 5,48

[a] Standard deviation.
[b] Body Mass Index = weight (kg)/[height (m)]^2.