Building and Environment 95 (2016) 240–250

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Experimental evaluation of an intermittent air supply system – Part 1: Thermal comfort and ventilation efficiency measurements

Alan Kabanshi [a, b, *], Hans Wigö [a], Mats Sandberg [a]

[a] Department of Building, Energy and Environmental Engineering, University of Gävle, Sweden
[b] Center for the Built Environment, University of California, Berkeley, Berkeley, CA 94720, USA

ARTICLE INFO

Article history:
Received 13 July 2015
Received in revised form
20 August 2015
Accepted 23 September 2015
Available online 28 September 2015

Keywords:
Air jet diffuser
Ventilation strategy
Tracer gas
Ventilation efficiency
Thermal comfort
Occupancy density

ABSTRACT

Spaces with high occupancy density e.g.; classrooms, auditoriums and restaurants, provide challenges to ventilate at a lower energy use due to elevated temperatures. To meet occupants' thermal comfort requirements traditional systems use a lot of energy. Alternative ventilation strategies that optimize high air movements in the occupied zone allow human activities at elevated temperatures while attaining improve occupants' perception and acceptance of the indoor climate at a low energy use. This paper presents an experimental evaluation of a novel ventilation strategy for high occupancy spaces that provides fresh air and thermal comfort in the sitting zone through a controlled intermittent air jet system. The strategy uses ceiling mounted high momentum air jet diffusers (AJD) made from ventilation duct fitted with nozzles that generate confluent jets. The jets coalesce into a single two-dimensional jet which is directed downwards in the sitting zone. This paper presents an experimental evaluation/analysis of the proposed system with regard to ventilation efficiency and thermal comfort measurements in a classroom mockup. Results show that the system qualifies to be used as a primary ventilation system and has local air change index >1 inside the jet, and a ventilation efficiency >50%. The system also provides better thermal climate than mixing and displacement ventilation at elevated temperatures.

1. Introduction

The strategy used to ventilate a defined space determines the quality of the indoor climate and the amount of energy that will be used to achieve ventilation. Today, ventilation is not just a matter of delivering or diluting air, but it rather extends to a wider perspective: occupants' satisfaction, health, quality of life and productivity [1–6]. Many of these factors emphasize the importance of providing an acceptable indoor climate. However, additional aspects' involving energy use and environmental sustainability have proven equally important and has thus joined the wagon. To work within these requirements, conventional systems like mixing ventilation prove to be complex and have an increased operational cost due to high energy use. Current strategies to reduce energy usage with conventional ventilation systems typically involve lowering airflow rates and/or heating/cooling capacity which ultimately compromise the quality of indoor climate.

Various ventilation strategies like personalized ventilation or ventilation systems that are incorporated with personal comfort systems are being developed and employed as an alternative to the traditional ventilation [3,7]. These strategies are aimed to achieve energy requirements and at the same time deliver acceptable indoor climate. It is, however, still challenging to achieve both low-energy use and acceptable indoor climate in spaces with high occupancy density like classrooms.

Classroom environments are challenging to ventilate at low energy use due to elevated temperatures associated with the high occupant density. Importantly, the nature and function of classrooms require comfortable thermal considerations due to the effects of heat stress on learning and performance [2,6]. Therefore, the strategy of increasing air movements as demonstrated in some studies allows comfortable operations at elevated room temperatures [8–12]. The common method of providing air movements in classrooms, in hot climates like the tropics, is use of circulatory fans; ceiling fans take a predominant share [13–15]. As much as

* Corresponding author. Department of Building, Energy and Environmental Engineering, University of Gävle, Sweden.
E-mail address: kabanshi@berkeley.edu (A. Kabanshi).

http://dx.doi.org/10.1016/j.buildenv.2015.09.025
0360-1323/

fans are low energy using devices they take away environmental esthetic value and to carter for large spaces more/or bigger fans are needed. An alternative strategy may be use of personalized ventilation, specifically ceiling mounted personalized ventilation as it would be convenient for classrooms [16,17]. Fong [18] points out challenges associated with personalized ventilation, and two of those apply to ceiling mounted personalized ventilation: not conducive for mobile occupants and requires a background ventilation system.

This paper introduces and explores another strategy that uses Air jet diffusers (AJD) as fresh air terminal devices. This strategy is referred to as air jet strategy (AJS) in this paper. In AJS, the diffusers supply high intermittent airflow into the sitting zone, with the aim of simulating some airflow characteristics similar to natural wind and minimizing the risk of draft associated with elevated air movements [19–23]. Natural wind has airflow characteristic that is shown to have a high cooling effect and minimal draft risk [24]. The AJS tries to simulate some of the dynamic airflow characteristic of natural wind: unsteady-intermittent airflow, low and high frequency air movements with a goal of improving ventilation efficiency and thermal comfort at a low energy use.

Energy saving is the motivation and one of the most important aspect of this strategy. This will be extensively discussed in the second part of experimental evaluation of AJS. However, a brief overview is that the system provides energy saving possibilities: 1) Supplying high intermittent airflow velocities in the occupied zone improves convective cooling and thus, attains comfort states at elevated room temperatures which results in reduced mechanical-cooling demand [24]; 2) The intermittency in supply (continuous switch ON/OFF of the supply fan during occupancy) means the ventilation system runs at half the time as the traditional system. This should result in about 50% electric energy saving on the supply fan assuming the same fan size is used.

The challenge that comes with this method of air distribution is that while the intermittency enhances convective cooling at minimal draught risk, it also reduces the amount of air supplied to the room. The total volume of air delivered due to intermittent supply is lower than that of the mixing and displacement systems for any given occupancy period. This challenge gives motivation to answer the question, "Can AJS deliver acceptable ventilation in the room with its intermittent supply?" Addressing this question was the main aim of this study along with other motivations to evaluate the generated room air velocities, temperature distribution and thermal comfort. The system performance was also compared with mixing and displacement systems.

2. Methodology

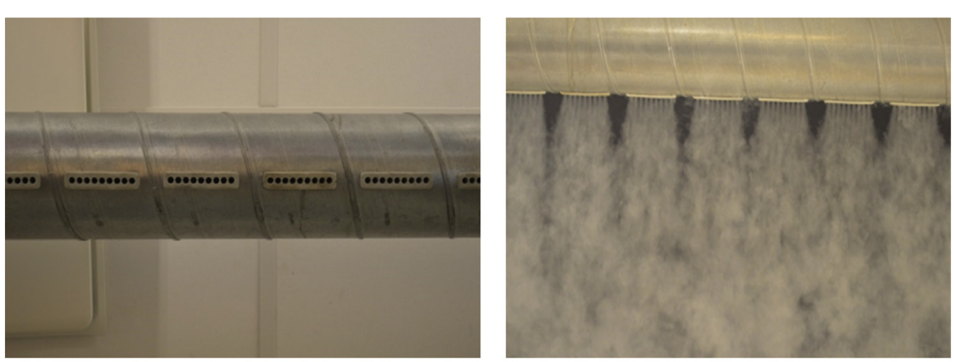
2.1. System description

The AJD is made out of a ventilation duct (160 mm diameter) that is fitted with plastic batches having single row specially designed circular nozzles: 9 nozzles, each with a diameter, $d_0 = 10$ mm, arranged in a horizontal row with equidistant spacing ($S = 1.5d_0$). The nozzle batches are fitted 4.5 d_0 apart from one end of the pipe to the other covering a column of the occupied zone as shown Fig. 1a. The diffusers are mounted on the ceiling and they generate confluent jets that merge to form a long-horizontal two dimensional single jet (the jets merge at $4d_0$ within the batch and between the batches they merge at $10d_0$). This is illustrated in Fig. 1b which shows the smoke visualization of the merging jets. The resulting jet sweeps a width of 150 cm (or 75 cm from the centerline on either sides of the nozzle) at a height of 0.80 m from the floor. This strategy uses single row of jets as Ghahremanian [25] had shown that a single row of jets, after merging produce a higher center line velocity and low turbulence compared to a single jet or array of jets. Thus AJS tries to apply these properties of single row of confluent jets to maximize on energy saving and increase concentration of outdoor air at the breathing height (1.1 m from floor). In short, the AJD is a high momentum ceiling mounted mixing diffuser that is hypothesized to have lower mixing than a mixing ventilation system.

2.2. Test room

The measurements were conducted in the controlled environmental chamber at the University of Gävle, with room dimensions of 7.2 m × 8.4 m and a ceiling height of 2.5 m. The room was designed as a classroom with three independent air supply systems: AJS, displacement and mixing ventilation system.

Mixing and displacement systems ran on the same fan but were independently operated (when one was in use the other was disconnected). The room had two displacement diffusers and four ceiling mounted mixing diffusers. The air jet system had a separate airflow circuit supplying air into the room. All systems ran with an airflow rate of 180 l/s and the exhaust was common in all cases. The room was arranged in a 3 column sitting arrangement each equipped with an air jet diffuser as shown in Fig. 2a. The classroom had windows located on the wall shared with the outdoor temperature control chamber. The outdoor temperature control chamber is designed to simulate



a. Air jet diffuser

b. air jets merging into a long single jet

Fig. 1. a Confluent nozzles installed on a ventilation pipe to make the air jet diffuser and b smoke visualization of the system in operation.