Human perception relation between thermal comfort and air movement for ceiling mounted personalized ventilation system

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Abstract. As one kind of newly developed personalized ventilation (PV) system, the relation was explored between thermal comfort and air movement perception/acceptability/preference with tropical subjects, who had become passively acclimatized to hot conditions in the course of their day-to-day life. The tests were conducted in field environmental chamber (FEC) of National University of Singapore. 32 subjects (16 males and 16 females), performed normal office work, can choose to expose to four different PV airflow rates (4, 8, 12, 16 L/s) so as to simulating individual control. Ambient temperatures of 26°C and 23.5 °C and PV air temperatures of 26 °C, 23.5 °C and 21 °C were utilized to conduct parametric variation studies. Each combination was maintained for 15 minutes during which the subjects responded to computer-administered questionnaires. Under different PV airflow rates and ambient/PV temperature combinations, the relation between thermal comfort and air movement perception/acceptability/preference was analyzed.

Introduction

Personalized ventilation (PV) system supplies conditioned outdoor air to each workplace. A primary PV system, in conjunction with a secondary ambient total volume or mixing ventilation (MV) system, is capable of creating a localized environment with better inhaled air quality and thermal comfort in an energy-efficient manner [1-6]. One of the barriers in the acceptance of conventional PV system is the need to have extended PV air ducts/pipes, which are considered to affect indoor aesthetics and limit the flexibility of indoor furniture layout [7]. In order to overcome this barrier, a new type of PV in which the PV air terminal device (ATD) is mounted on the ceiling is developed. The outlet diameter of the ATD is reduced so as to supply the personalized air to the occupied zone of each workplace [8].

In all previous studies involving PV designs, the ATDs are installed on the furniture (desk and chair), i.e. close to the occupant. Relatively small body area is exposed to the personalized flow. The new PV with ceiling installed ATD is different because it supplies the personalized air from above in relatively longer distance to the occupant. Thus, the personalized airflow spreads and has a target area which covers larger area of occupant’s body. The influence of PV airflow rates and ambient/PV temperature combinations on the heat loss from the whole body and the local heat loss from body segments has been studied in detail and reported [8]. For conventional PV system, human perception relation between thermal comfort and air movement has been studied under either isothermal or non-isothermal conditions. It is essential for the practical implementation of the newly developed ceiling mounted PV system to have a better understanding of human perception relation between thermal comfort and air movement. This research is the focus of the present study.
Research Methodology

The human response evaluation of the primary ceiling mounted PV system operating in conjunction with a secondary ambient mixing ventilation (MV) system in a hot and humid climate is carried out by conducting a series of subjective assessments with tropically acclimatized subjects. The details of the research methodology are described in the following sections of the paper.

2.1 Experimental facilities

The subjective assessments are performed in the Field Environmental Chamber (FEC). This 11.7 m (length) × 7.2 m (width) × 2.7 m (height) chamber is built to simulate a typical office environment with 16 workstations (Fig. 1 and Fig. 2). The ambient or secondary air-conditioning to the chamber is provided by a secondary air handling unit (SAHU) and ceiling-based mixing air distribution system. Six swirl supply diffusers are evenly distributed on the ceiling of the chamber. Six return air grilles are evenly located on the ceiling and a completely ducted return route is employed. The airflow rate through the supply diffusers is balanced by manual dampers installed on the branch of each diffuser. The supply air temperature and flow rates are regulated by adjusting the off-coil temperature and fan speed using an automated control system to provide ambient cooling and to achieve the desired indoor temperature. The PV system is the primary system serving conditioned outdoor air for ventilation to the chamber. It provides each workstation with 100% outdoor air through a newly developed prototype of the PV ATD mounted on the ceiling above the workstation.

The ATD studied, named the ceiling mounted PV ATD, is a nozzle made of aluminum, with a round outlet having a diameter of 95mm. The nozzle device has a diameter of 160mm on the other side, which can be connected to ductwork by suitable transition. The length of the nozzle device is 140mm. The generated free circular jet is suitable for ventilation of large areas where long throws are required. The nozzle delivers personalized air with relatively low turbulence intensity (lower than 20% as measured). The reason, for choosing low turbulence intensity ATD is to reduce the mixing, i.e. heat and mass exchange, between the primary PV air and the secondary ambient air so as to achieve the desired body cooling effect and to improve air quality at user’s breathing zone.

2.2 Experimental conditions

The PV airflow rates were controlled and measured at the outlet of PV ATD. Four PV airflow rates (4, 8, and 12, 16 L/s) and PV air temperatures of 26 °C, 23.5 °C and 21 °C were adopted as experimental interventions in this study at ambient temperatures of 26 °C and 23.5 °C. In the chamber, 16 workstations were divided into 4 groups, with 4 workstations in each group. The ceiling mounted ATD at each of the 4 workstations was different, respectively 4, 8, 12, 16 L/s respectively. Thus 4 subjects who participated in the same time in the experiments could choose a workstation with any of the flow rates.

2.3 Subjects

Thirty-two subjects, 16 male and 16 female university students, participated in the experiments. The subjects were instructed to eat normally before attending the experiments and not to consume...
alcohol and medication 24 hours before the experiment. They were also asked to wear normal office attire.

2.4 Questionnaires

Subjects were asked whether they felt any air movement at any body segment. If they felt, they were required to assess the air movement. To evaluate the perception of air movement at each body part, the following scale categories and weights were adopted on the same diagram of human body: +3 Much too air movement; +2 Too breezy; +1 Slightly breezy; 0 Just right; -1 Slightly still; -2 Too still; -3 Much too still. Subjects were asked to assess their acceptability for air movement at different body parts: top of head; face; neck; chest, shoulder and upper arm; lower arm and hands; back; and lower body. The end-points of the linear visual scales were coded as -1 (very unacceptable) and 1 (very acceptable), with an interval in between 0 (just unacceptable) and 0 (just acceptable) for assessment of air movement acceptability.

2.5 Experimental Procedure

Both 16 male and 16 female subjects were divided into eight groups randomly with 4 members in each group, 2 male and 2 female subjects. Subjects were required to acclimatize for 30 minutes in the control room, which was maintained at the same ambient temperature as the experimental chamber. At the beginning of the exposure in the experimental chamber, each group member could choose one of 4 workstations with different PV airflow rates (4, 8, 12, and 16 L/s) based on their preference. They were exposed to the PV flow for 15 minutes. The subjects could then either move to adjacent workstation or keep staying in the same workstation, which was based on their air movement preference. The subjects had the possibility of changing workstation four times during the first hour. The subjects were encouraged to try the different PV airflow rates in order to be able to move at the end of the 1 hour exposure to the workstation with most preferred air movement. The subjects, depending on their preference were or were not exposed to all four PV airflow rates. The actual PV airflow rates were blind to the subjects. At the end of the first hour, the subjects were asked to move to a workstation which they had not visited and to stay there for 30 minutes. After that, the subjects could make their final choice of the workstation with the most preferred PV airflow rate. The subjects who had visited all 4 workstations during the first hour were allowed to stay in their preferred workstation. During the last 30 minutes of the experiment the subjects stayed 30 minutes at the workstation with the most preferred environment. Then the experiment for the particular subject ended.

Results and discussion

The relationship between subjects thermal comfort acceptability and the air movement perception, acceptability and preference was explored. The results are presented in Fig. 3 to Fig. 5, respectively. Each point in the figures is based on the mean subjective response obtained for the combinations of personalized airflow rate, personalized temperature and ambient air temperature. From Fig. 3, the optimum value of thermal comfort acceptability appears when air movement perception is between ‘just right’ and ‘slightly breezy’. Positive linear correlation is observed between air movement acceptability and thermal comfort acceptability because both of them are influenced by local air movement as shown in Fig. 4. Fig. 5 demonstrates that the optimum value of thermal comfort acceptability appears when air movement preference is between ‘less air movement’ and ‘no change’, which verifies the results from Fig. 4.

The results of the analyses reveal that the subjects felt thermally most comfortable when they perceived the air movement between “just right” and “slightly breezy”. Still or too breezy air movement perception decreased subjects thermal comfort. Subjects’ thermal comfort increased with the increase of air movement acceptability (Fig. 5) and was maximum when they reported no change in air movement or slightly less air movement.
Fig. 3 Quadratic regression of thermal comfort acceptability and whole body air movement perception.

Fig. 4 Linear regression of thermal comfort acceptability and whole body air movement acceptability.

Fig. 5 Quadratic regression of thermal comfort acceptability and whole body air movement preference.

Conclusions

The relationships explored between subjects’ thermal comfort acceptability and air movement reveal that the air movement was optimal when it was perceived between ‘just right’ and ‘slightly breezy’. Stronger air movement caused more cooling while weaker air movement increased the warmth discomfort and thus decreased the acceptability of the thermal environment. However it should be noted that subjects preferred higher air velocity at ambient temperature 26°C and lower air velocity at ambient temperature 23.5°C.

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References


