Field application of enhanced displacement ventilation system in an office of a Zero Energy Building in the Tropics

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ABSTRACT

Conventional Displacement Ventilation (DV) system has been installed in an office of a Zero Energy Building (ZEB). Enhanced DV (EDV) system, consisting of fans mounted to the chair, which has been demonstrated in laboratory and field environmental chamber studies earlier was implemented for the first time in a full-scale office environment to assess its effectiveness of improving the thermal sensation of the occupants. Objective measurements and subjective assessments were conducted in the office with 12 occupants over a period of 2 weeks. Results show that the EDV is capable of improving the thermal comfort and sensation, and the personalised control feature can lead to higher occupants' thermal satisfaction. In conclusion, EDV system has been successfully implemented in the field with no issue of draft as tropically acclimatized subjects prefers higher air movement.

KEYWORDS

Enhanced displacement ventilation, Tropics, Thermal sensation, Air movement, questionnaire

1 INTRODUCTION

Displacement ventilation cooling uses a low-velocity (0.15 to 0.2 m/s) stream of moderately cooled air introduced via diffusers located through a raised floor (Hamilton, 2004). The cool supply air slowly rises as it pick up heat from heat sources. These heat sources create upward convective flows in the form of thermal plumes which create better IAQ in the space (Yu et al., 2004). The contaminated warm air then rises towards the ceiling and exhausted from the space. As such, DV system helps to maintain a better indoor environment, which enhances comfort and contributing towards the overall sustainability of the building. In the last few years, its application has been extended to classrooms, offices and other commercial spaces (Nishioka et al., 2000). There have been extensive researches on the performance of the DV system in temperate countries but very few in the Tropics. As Singapore aims to have at least 80% of the buildings to attain the minimum Green mark standards by 2030 (Building and Construction Authority, 2010), it is necessary to adopt a more energy efficient air-conditioning and mechanical ventilation system (ACMV). The application of DV system was seen extended to the office of zero energy building in Singapore.

However, DV system works best in a space with high ceiling to floor ratio, such as in industrial applications or public halls. There are some limitations when used in offices as

temperature gradient will be generated in the space. Hence, novel enhanced displacement ventilation (EDV) system was first implemented by Sun, (2010), with the intention to enhance convective cooling around the occupants in normal office served by the DV system. Li (2010) improvised on the work of Sun (2010) and developed a 2-fan EDV system. This study aims to assess the performance of the EDV system in a full-scale study of a relatively lower floor-to-ceiling height office served by DV system with respect to thermal comfort and thermal sensation.

2 EXPERIMENTAL SET-UP

Figure 1 shows the office, 18(L) x 18(W) x 2.7m (H), in a ZEB served by conventional DV system having 12 occupants with feedback of thermal dissatisfaction based on a survey conducted previously. The conditioned air is supplied to the room via circular floor diffusers on the raised floor to maintain air temperature of between 23.5 and 24.5degC. The EDV chair, as shown in Figure 2, is to replace the existing chair at four locations where the level of thermal comfort was of higher level of dissatisfaction.

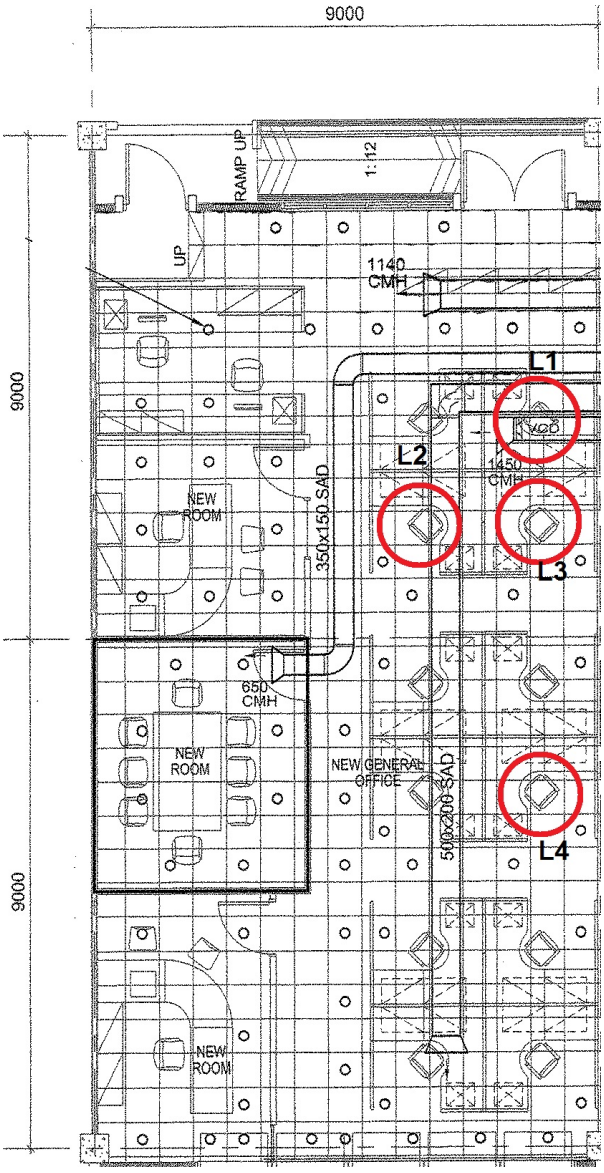

Figure 1: Layout of the office with the 4 EDV systems

Figure 2: The EDV chair

2.1 Objective Measurements

Objective measurements and subjective assessments were conducted between 9th and 20th December. Continuous measurements of air temperature and relative humidity using Hobo data loggers were taken between 9th and 15th Dec with DV system only and between16th and 20th December with the EDV system. In addition, spot measurements of air velocity and air temperature at different height using omni-directional anemometer system were taken on 13th and 17th in which both indoor and outdoor on these two days having similar condition. A detailed description of each measuring location is stated as follows and shown in Figure 3:

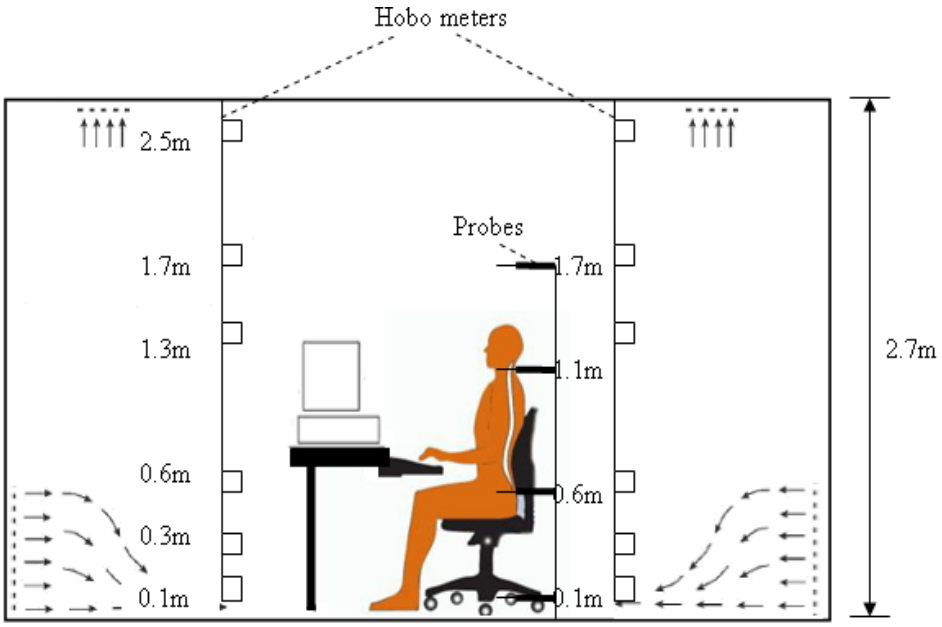

Figure 3: Locations of measurement on vertical plane

- Room air temperature (Tr) and RH measuring locations were measured at locations L1, L2, L3 and L4 with HOBO® meters. The HOBO® meters were placed at five heights: 0.1 m, 0.3 m, 0.6 m, 1.3 m and 1.7m.

- Air temperature (T), mean velocity (V), and turbulence intensity level (Tu) in the region around the occupants (locations L1, L2, L3 and L4) were measured with omni-directional anemometer. The probes were positioned at four heights, 0.1 m, 0.6 m, 1.1 m and 1.7 m respectively. The probe at 0.6 m height was close to the waist region of the subjects and the probe at 1.1 m height was right above the shoulder.

2.2 Subjective Assessment

The main objective of the questionnaire survey was to assess if the EDV system improves the thermal comfort of occupants. The ASHRAE scale, (−3) cold, (−2) cool, (−1) slightly cool, (0) neutral, (+1) slightly warm, (+2) warm and (+3) hot, was used for the assessment of subjects' Overall thermal sensation (OTS) and local thermal sensation (LTS) of 14 specific body parts (head, chest, back, stomach, right and left arms, hands, thighs, calves and feet). The overall thermal comfort (OTC) and local thermal comfort (LTC) of body segments was assessed using the Bedford's scale, (−3) much too cold, (−2) too cold, (−1) comfortable cool, (0) neither warm nor cool, (+1) slightly warm, (+2) too hot and (+3) much too hot.

3 RESULTS AND DISCUSSION

The average temperature measured in the office was between 24 and 25degC with relative humidity of about 60% over the period of measurement. Temperature profiles on 13th and 17th Dec where spot measurements were carried out for DV and EDV systems are similar. This provides a basis for fair comparison between them. The most preferred fan speed amongst the four EDV systems with fan discharge angle pre-adjusted at 30^{o} to the horizontal plane was "medium". Feedback from subjects shows that 'high' fan speed leads to draught sensation in areas like the waist, neck and facial region. Vertical temperature profiles at the four locations are similar for DV and EDV systems. Figure 4 showing a typical temperature profile at location L1. It shows that the temperature profile became steeper with the EDV system (with fan) between 0.6m and 1.7m as the fan is mounted at 0.6m. It demonstrated the effectiveness of the fan in bringing cool air from the DV diffuser up to subjects.

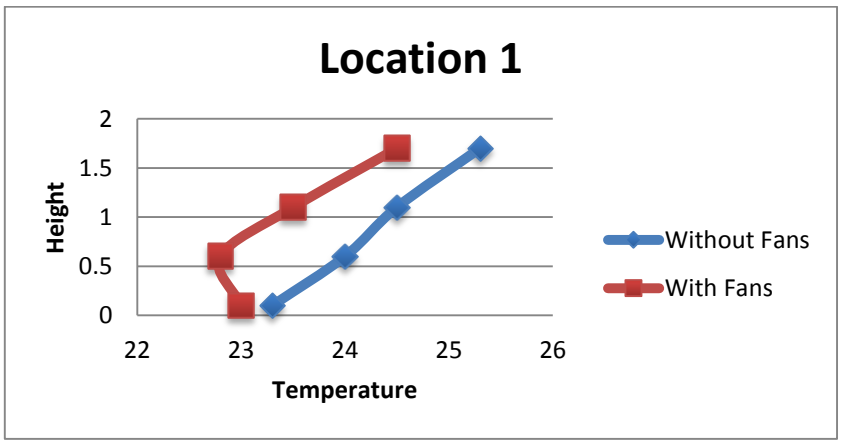

Figure 4: Temperature profile

Subjects were exposed to higher velocity at 0.6m as shown in Figure 5. The fans help to enhance the convective airflow up to a limited height given their capacity.

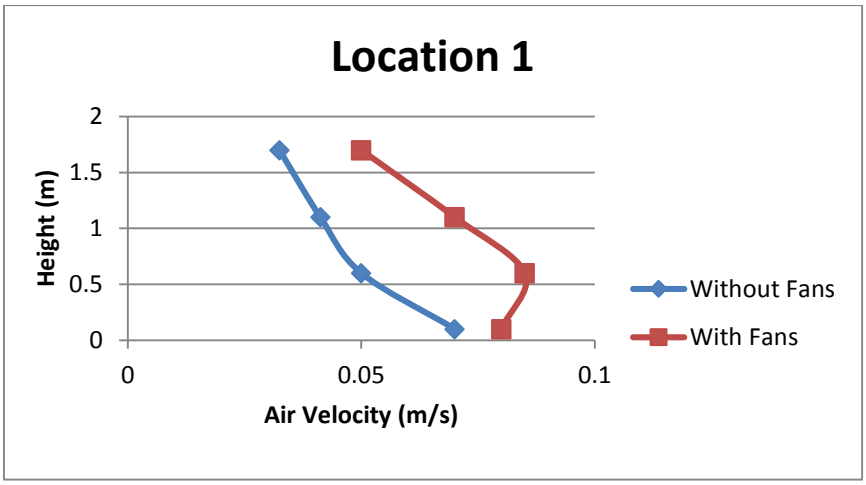

Figure 5: Air velocity profile

Figure 6 shows the average overall thermal sensations of the subjects. The average ambient temperature recorded in the office was about 24.5degC when the questionnaires were being completed. It is observed that the subjects felt slightly warm without the fans (0.75). However, subjects experienced close to comfortably cool (-0.25) and neutral condition when the EDV systems (Fans on) are used. Hence, it provides better thermal sensation to subjects.

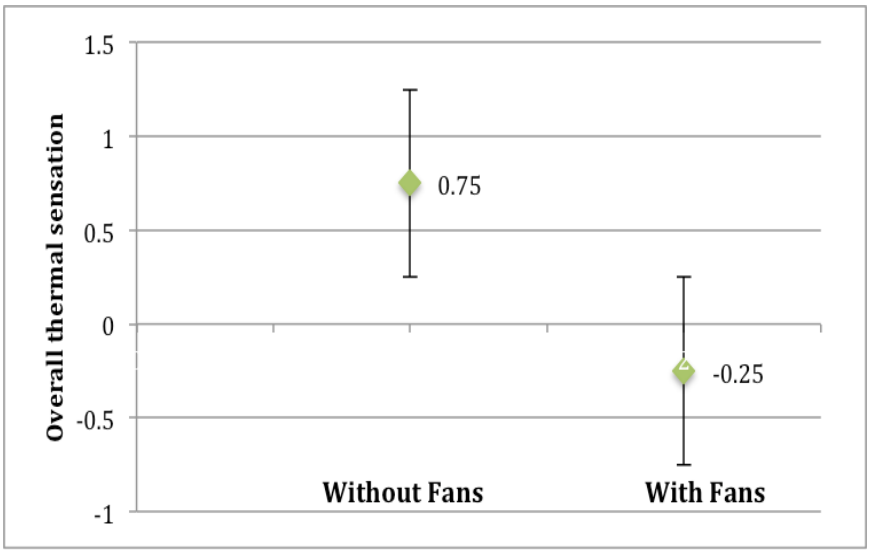

Figure 6: Overall thermal sensation

Figure 7 shows the local thermal sensation of different body segments at ambient air temperature of about 24.5degC before and after the introduction of EDV system. It demonstrates that the subjects would feel more comfortable with the EDV system at more body segments, i.e. closer to the average rating of 0. It was observed that the subjects did not experience a significant difference below the thighs when the fans were turned on. This is obvious given that the fans are mounted near the thigh region and therefore would not affect the thermal sensation of lower body segments such as the calves and feet. On the other hand,

the right/left hand regions experienced the coolest thermal sensation (-0.75), followed by right arm/left arm (-0.5) after the introduction of the EDV system. It was also observed that without the fans, the upper body segments such as the torso, chest and shoulder have warmer thermal sensations as compared to with fans. The fans help to bring cool air upwards and thus provide convective cooling around the upper body segments.

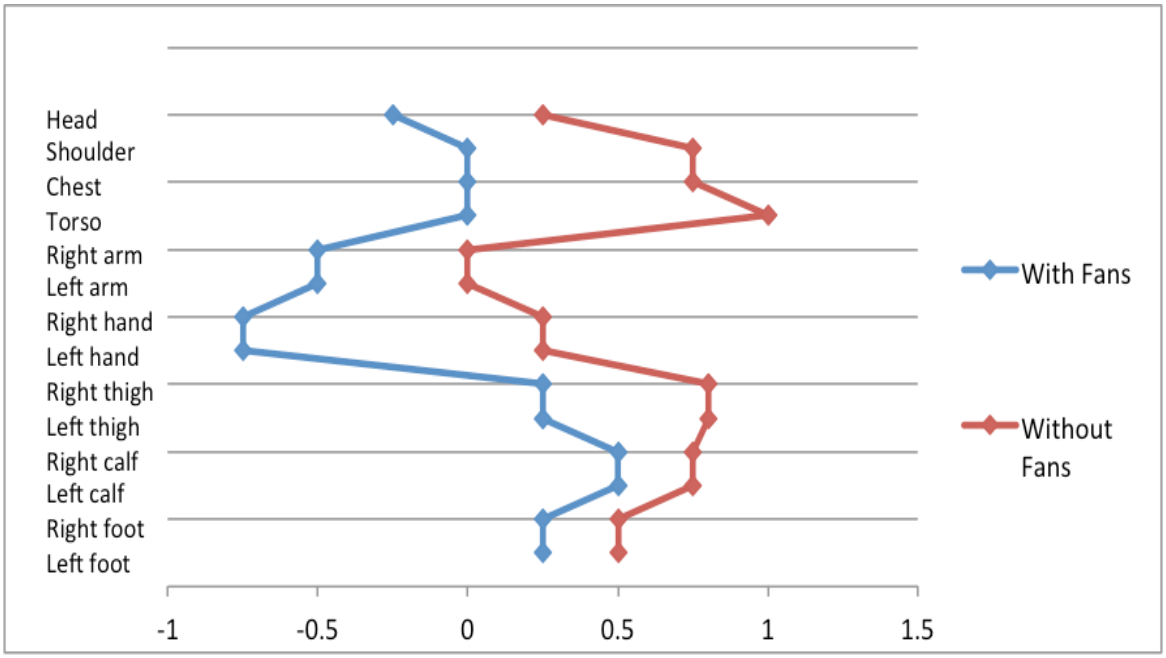

Figure 7: Local thermal sensation of body segments

4 CONCLUSIONS

75% of the subjects felt that the EDV chair is effective in providing better thermal comfort sensation especially when ambient temperature in the office was high. This concurs with the vertical temperature and air velocity profiles. Subjects experienced more air movement when the EDV system is in operation. Hence, the EDV system is successfully applied in the field.

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