Preliminary findings of a pilot study of personalized ventilation in a hot and humid climate

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ABSTRACT
The concept of personalized ventilation (PV) is at the cutting edge of technological developments in the area of air-conditioning and is fundamentally based on improving ventilation to every individual in the built environment. A PV system provides occupants with control so that they can adjust their individual thermal environment as well as achieve good indoor air quality. Recent studies in Singapore have shown that the use of a PV system in conjunction with a secondary air-conditioning system significantly enhances thermal comfort and IAQ acceptability as well as the perception of freshness in the air. It has been observed that the use of a PV system tends to lower the average temperature of air in the breathing zone, to which enhanced Perceived Air Quality may be attributable. An interesting preliminary observation that needs further substantiation is the increased thermal comfort and air movement acceptability at higher draft rating values.

INDEX TERMS
Personal control; Perceived air quality; Thermal comfort; Ventilation system; Tropics

INTRODUCTION
The personalized ventilation (PV) concept has tremendous potential for enhancing the acceptability of Ventilation, Indoor Air Quality and Thermal Comfort in air-conditioned buildings by supplying clean fresh air directly to the occupant's breathing zone without mixing with contaminated re-circulated air. Whilst studies involving the PV concept have been explored in some detail in temperate climates, similar studies in hot and humid climates have just begun (Bauman *et al.*, 1993; Kaczmarczyk *et al.*, 2002; Melikov *et al.*, 2002). This paper reports our findings from a pilot study in a tropical climate.

METHODS
The experiments were conducted in a controlled environment Indoor Air Quality (IAQ) chamber, developed in the Department of Building at the National University of Singapore. The IAQ chamber, as shown in Figure 1, is equipped to function with six work stations provided with six independent PV air terminal devices. The indoor environmental conditions in the chamber are controlled by two dedicated air-conditioning systems—a primary system consisting of the PV air, which is 100% outside fresh air and a secondary system consisting of a conventional ceiling-supply air-conditioning system, which supplies between 90 and 100% re-circulated air.

The experimental design, shown in Table 1, consisted of 17 different environmental conditions, characterized by a combination of room ambient temperature (23 and 26°C), PV air temperature (20, 23 and 26°C) and the PV airflow rate (7, 11 and 15 lps/person). The conditions are designated by these values, listed in this order, e.g. 23-20-15 designates an

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ambient temperature of 23°C with 15 l/s of PV air at 20°C. The experimental design also included a reference condition with just the secondary system operating under the same conditions, without PV air.

The experimental protocol included the measurements of ambient and PV air temperatures, thermal comfort parameters within the occupied zone, breathing temperature in the occupant breathing zone (Figure 2) and concentration levels of various indoor pollutants (including SF_6 as a tracer gas for evaluating ventilation effectiveness). SF_6 was used to simulate a pollutant and dosed in the secondary air-conditioning system and the computation of ventilation effectiveness is discussed elsewhere (Sekhar *et al.*, 2003). A detailed questionnaire was employed to solicit the subjective responses of the subjects during all the experiments. Responses of thermal comfort and IAQ acceptability were graded in a continuous range between 'very acceptable (1)' and 'very unacceptable (–1)'. Statistical tools were used to test for the significance level of the subjective response at 5% level of significance.

RESULTS AND DISCUSSION

The subjective responses such as perceived air quality and thermal comfort were analysed statistically by ANOVA to test if there is significant difference among multiple experiment treatments, i.e. all the PV conditions or all PV and MV (mixing ventilation) conditions. The statistical analysis shows that there was a significant difference between the 17 experimental conditions, i.e. a significant difference in subject's thermal comfort and perceived air quality between all the PV conditions or all PV and MV conditions. However, it was not possible to identify what caused the differences in perception.

The acceptability of PAQ and thermal comfort of all experimental conditions were grouped separately into two groups: one with PV and another without PV. For PAQ and thermal comfort, the conditions with PV generally have a higher acceptability than the conditions without PV. The PAQ (thermal comfort) range for PV conditions is from 0.12 to 0.60 (0.09–0.58) and that without PV is from –0.13 to 0.34 (–0.17 to 0.31). Also, the condition with the highest acceptability is 26-20-15 while the condition 26-0-7 is considered as unacceptable, which suggested that even at a higher ambient temperature of 26°C, subjects still favour the condition as long as PV is supplied. (26-0-15: 26°C is the ambient temperature; 0 means no PV is supplied and 15 is the airflow rate in l/s; 26-20-15: same as before expect that PV is supplied at 20°C.)

The mean responses of thermal comfort and PAQ acceptability for each of the subjects are also compared and presented in Figures 3–5. There is a consistently higher acceptability for both PAQ and thermal comfort for all the subjects except one. In terms of SBS symptoms, conditions with PV are perceived to be fresher by a significantly higher number of the subjects.

The measured results of the breathing temperatures are presented in Figure 6. In the case of a secondary system integrated with a PV system, it is seen that a space temperature of 23°C, accompanied by a PV air temperature of 23 or 20°C, achieves an overall breathing temperature that is significantly lower. Such an environmental condition in the microclimate is perceived to have a higher acceptability.

Ventilation effectiveness characteristics of PV systems are significantly higher than mixing ventilation, as shown in Figure 7.

It was observed that most of the subjects had placed the PV ATD close to their breathing zone or face, and it is hypothesized that any level of draft was indeed perceived to be pleasant. Scatter plots of thermal comfort acceptability and air movement acceptability versus draft rating for all experimental conditions and conditions employing PV are presented in Figures 8 and 9, respectively. It is observed that the measured values of draft rating are perceived by the subjects to be acceptable from the thermal comfort perspective and, indeed, the thermal comfort acceptability increases at higher draft rating values, although the correlation coefficient is not strong ($r^2 = 0.54$). A similar trend is observed with air movement acceptability and the correlation coefficient is slightly larger ($r^2 = 0.78$).

From an analysis of breathing zone temperatures, ventilation effectiveness characteristics and PAQ and thermal comfort acceptability, it has been observed that the PV system has the potential to save energy in tropical designs (Sekhar *et al.*, 2003).

CONCLUSIONS

The use of a PV system in conjunction with a secondary air-conditioning system significantly enhances thermal comfort and IAQ acceptability as well as the perception of freshness in the air. It has been observed that the use of a PV system tends to lower the average temperature of air in the immediate breathing zone, to which enhanced PAQ is attributable. Preliminary findings suggest the tropical subjects perceive an increased thermal comfort and air movement acceptability at higher draft rating values. This, however, needs to be substantiated further with larger sample sizes. It was observed that most of the subjects had placed the PV ATD close to their breathing zone or face, which supports the fact that any level of draft was indeed perceived to be pleasant. Finally, PV systems have the potential to reduce ventilation energy consumption in tropical buildings (Sekhar *et al.*, 2003).

ACKNOWLEDGEMENTS

The financial support of the National University of Singapore under a research grant, R-296-000-043-112, is gratefully acknowledged. The authors would also like to acknowledge the contribution of Professor David Wyon of the International Centre for Indoor Environment and Energy at the Technical University of Denmark.

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Table 1 Experimental design conditions

Room air temperature	26												23				
Use of PV	With PV									Without PV			With PV		Without PV		
Personalised air temperature	20			23			26			-			20	23	-		
Personalised air flow rate (l/s)	7	11	15	7	11	15	7	11	15	7	11	15	7	7	7	11	15

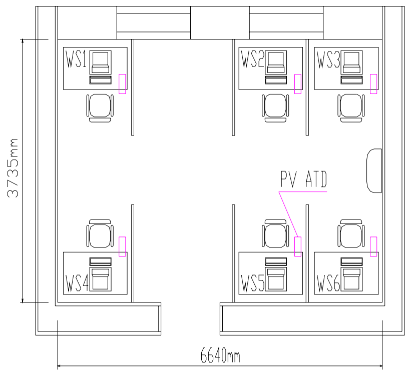

Figure 1 Indoor air quality chamber.

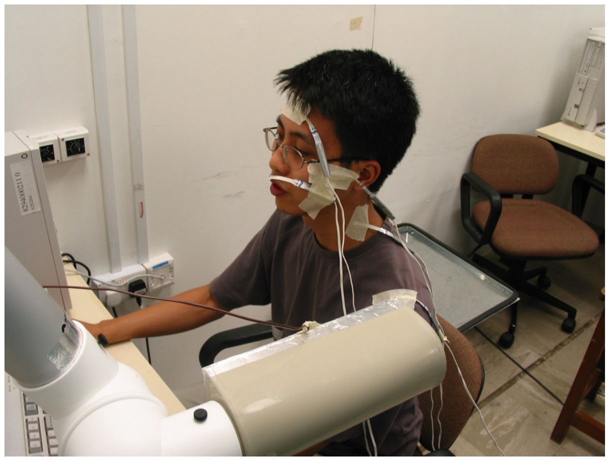

Figure 2 Breathing zone measurements.

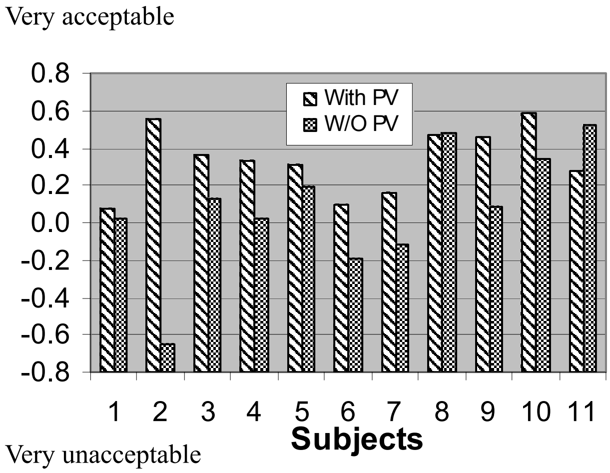

Figure 3 Mean responses of thermal comfort acceptability (y-scale).

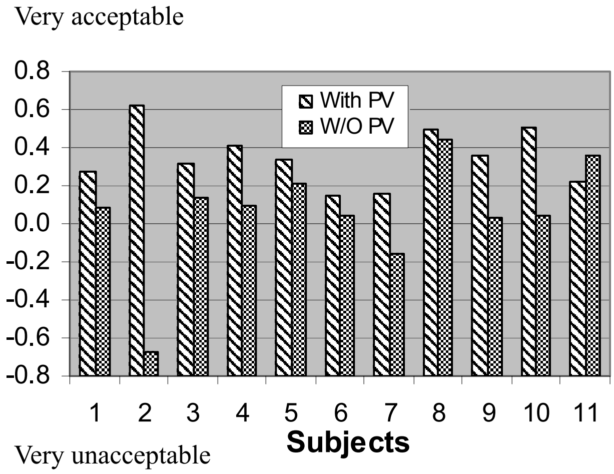

Figure 4 Mean responses of IAQ acceptability (y-scale).

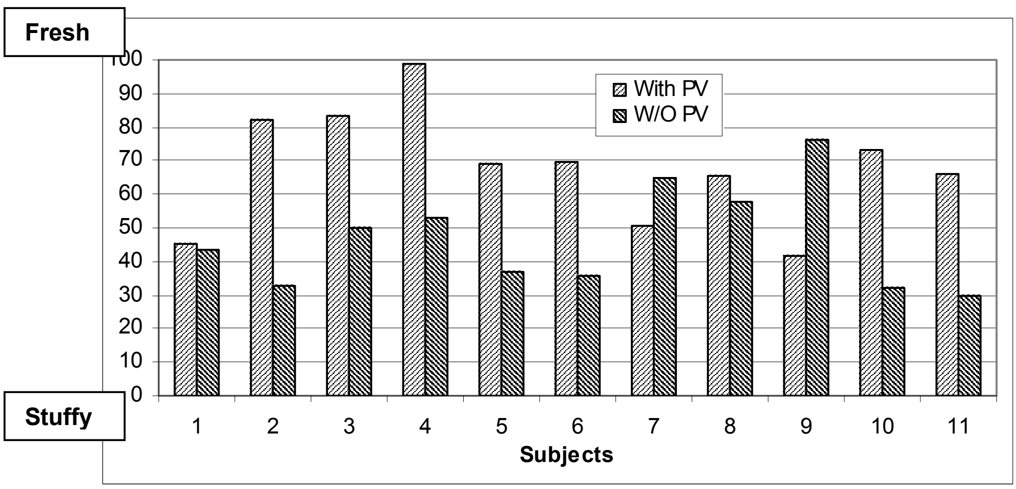

Figure 5 Mean responses of SBS symptoms (freshness).

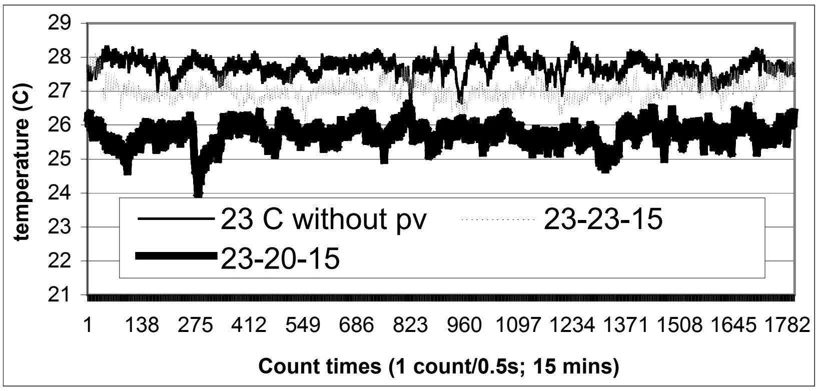

Figure 6 Breathing temperature at 23°C ambient temperature.

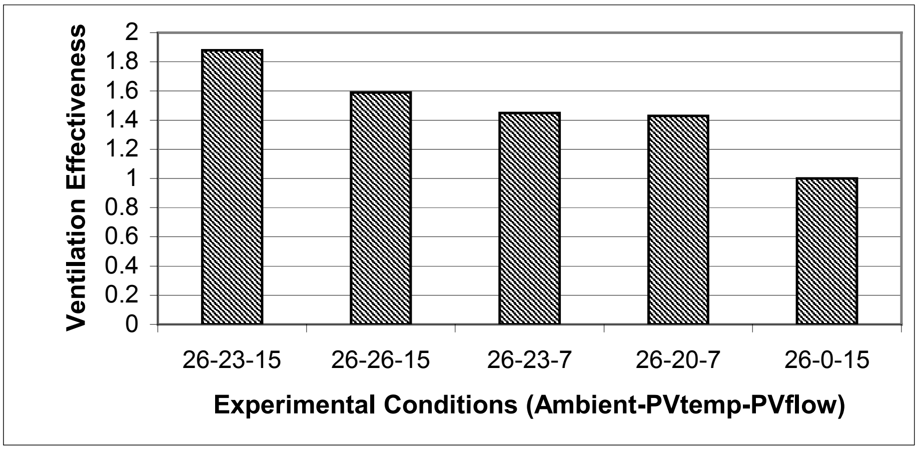

Figure 7 PV and MV ventilation effectiveness comparison.

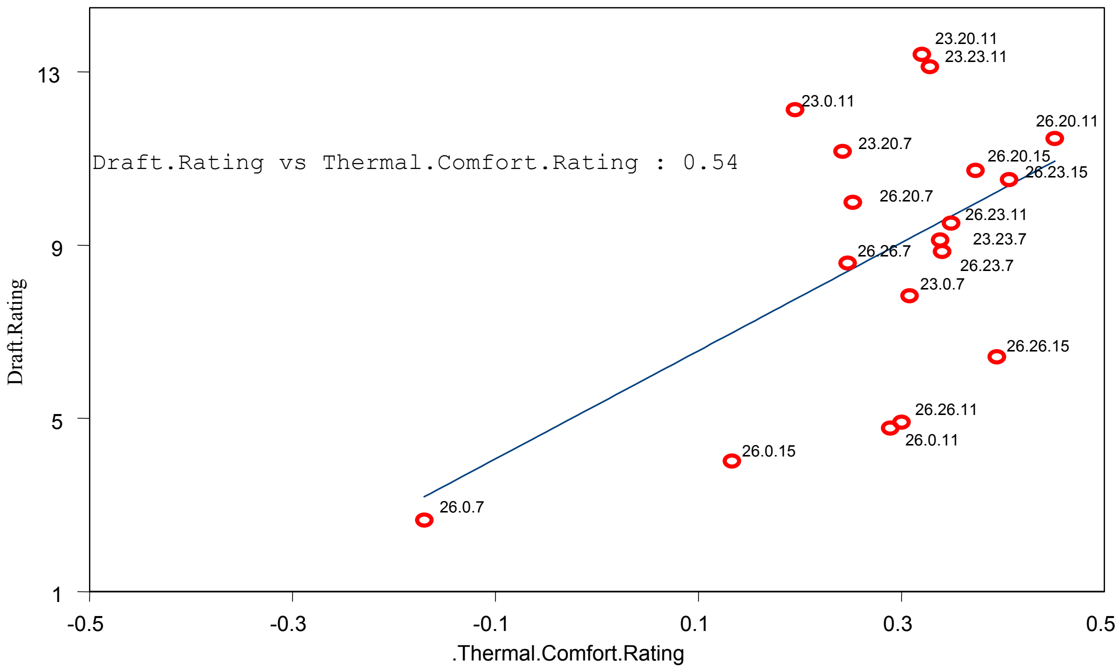

Figure 8 Thermal comfort acceptability versus draft for all conditions.

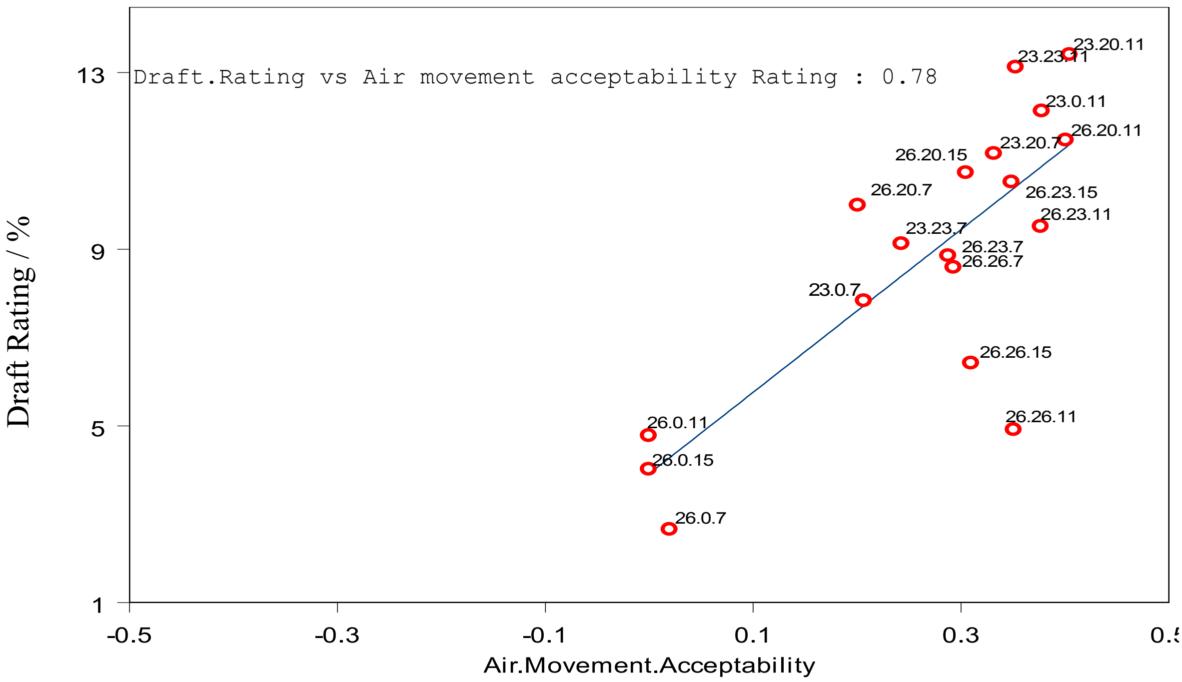

Figure 9 Air movement acceptability versus draft for all conditions.