The SBS symptoms and environmental perceptions of office workers in the Tropics at two air temperatures and two ventilation rates

K.W. Tham[a,*], H.C. Willem[a], S.C. Sekhar[a], D.P. Wyon[b], P. Wargocki[b], P.O. Fanger[b]

[a]*Department of Building, National University of Singapore, Singapore;* [b]*International Center for Indoor Environment and Energy, Technical University of Denmark, Denmark*

ABSTRACT

A blind intervention study in which air temperature and the outside air supply rate were changed in a 2 × 2 design was carried out in a call centre in Singapore. The reported intensity of headache and difficulty in concentrating were reduced by 19.5% ($P < 0.03$) and 13.2% ($P < 0.02$), respectively, when the outside air supply rate was increased from 9.8 to 22.7 l/s/person, and were increased by 8.8 % ($P < 0.07$) and 9.3% ($P < 0.04$) when the intervention was reversed. At the lower outside air supply rate the intensity of the symptoms cold hands and cold feet decreased by 22.9% ($P < 0.01$) and 25.9% ($P < 0.01$), respectively, when the air temperature was raised from 22.5 to 24.5°C, increasing by about 15% when this intervention was reversed. Subjects were able to detect the difference between 22.5 and 24.5°C in terms of overall thermal comfort sensation, with 24.5°C being considered more comfortable.

INDEX TERMS

Temperature; Fresh air provision; SBS symptoms; Perception; Tropics; Intervention

INTRODUCTION

In the Tropics, office workers may experience continuous moderate thermal stress throughout the working day, depending on the zone set point temperatures. In addition, outside air supply rates are kept low to minimize the cooling energy used for cooling and dehumidification. A substantial proportion of office occupants work in conditions that may lead to discomfort and moderate incidence of SBS symptoms (Sekhar *et al.*, 2003). The effect of temperature on physiological strain and thermal comfort has been studied extensively (Gagge *et al.*, 1967; Fanger, 1970; Gonzalez and Gagge, 1973; Berglund and Cunningham, 1986). These studies have led to the establishment of thermal comfort standards that maintain the thermal sensation and response of a standard person within reasonable limits. However, other personal factors that cause individual differences might introduce a shift in preference. This is particularly true when the groups of people under consideration are from different anthropometric and socio-cultural backgrounds and from different climatic regions (Duncan and Havath, 1988; Nakano *et al.*, 2002).

Studies on the relationship between ventilation rates and human responses are relatively scarce, although some have attempted to relate short-term health effects, usually termed Sick Building Syndrome (SBS) symptoms, to the outside air supply rate. It is only recently that a statistically significant impact of ventilation rate on work output has been reported (Wargocki *et al*. 2000, 2002). The findings of these studies are not necessarily applicable in the Tropics. The present study is an attempt to evaluate the effects of the thermal environment and of outside air supply rate on the SBS symptoms and other subjective perceptions of office workers in the Tropics.

METHODS

Subjective responses were obtained on visual–analogue scales from 26 permanent Customer Service Officers (CSOs) in a banking call centre in Singapore. Responses were obtained every Thursday for 9 weeks, once in the morning and again in the afternoon. Survey forms were

* Corresponding author. E-mail: bdgtkw@nus.edu.sg

distributed between 10.00 and 11.30 a.m. and again between 3.00 and 4.30 p.m. Over 9 consecutive weeks, two parameters, air temperature and outside air supply rate, were alternately modified in a 2 × 2 balanced experimental design. The experimental conditions were selected so that the effects of increasing and decreasing air temperatures at the lower and higher ventilation rates, and of increasing and decreasing the outside air supply rate at two temperatures separated by only 2°C, could be fully explored. Figure 1 summarizes the full experimental design.

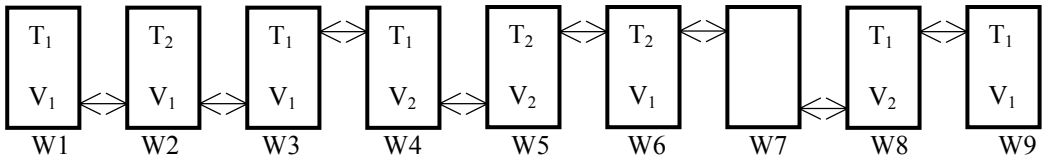

Figure 1 Environmental settings for each intervention week from week (W) 1 to 9.

Temperature and relative humidity data loggers were deployed at six locations, five in the call centre and one in the return air duct in the AHU room. Further details on the air conditioning system can be found in Tham *et al.* (2003). The outside air supply rates were calculated from data obtained using a tracer gas pulse injection method once a week on Thursday afternoons (INNOVA system). The interventions were carried out every Friday afternoon and workers were kept blind to the changes. The initial intention of the study was to select two temperature levels within the thermal comfort region prescribed in the relevant Standard, separated by 3°C. It was found that the air handling system was unable to achieve this, so a 2°C nominal difference was selected: 22.5°C (T_1) and 24.5°C (T_2). The outside air supply rates were initially intended to be 4.5 l/s/person (V_1) and 12 l/s/person (V_1), based on nominal occupancy, but based on actual occupancy, these ventilation rates provided 9.8 and 22.7 l/s/person, respectively. The ventilation was balanced to ensure that the building was under positive pressure, so infiltration was not a factor.

Within-subjects analysis was performed based on paired data from each subject. All subsets of data were tested for Normality, after which pair-wise comparisons of two successive weeks based on combined morning and afternoon data with temperature changes at constant ventilation rate or ventilation changes at constant temperature were performed to identify statistically significant effects on SBS symptoms and perceptions. Parametric statistical analysis (paired Students *t*-test) was applied to normally distributed data, otherwise a non-parametric procedure (Wilcoxon Matched-pairs Signed-rank test) was used. All *P*-values are two-tailed.

RESULTS

Temperatures and Outside Air Supply Rates

Figure 2 shows the typical daily temperature profiles at the 22.5 and 24.5°C set points. It can be seen that intended air temperatures were maintained within an acceptable range during the call centre operation hours of 8.30 and 17.30. Tracer gas measurements indicate that the outside air supply rate was maintained at two reasonably distinct levels, averaging 9.8 and 22.7 l/s/person, based on actual occupancy.

Questionnaire Responses

The number of returned survey forms ranged between 13 and 21, due to the operators' varying work schedules. The marked scales were converted into numerical values as a percentage of full scale. Thermal comfort, perception of warmth, humidity level, stuffiness, air movement, thermal sensation, and skin humidity level were grouped as perceptual parameters of thermal comfort, whilst 13 SBS symptom and nine neurobehavioral scales were used to assess different aspects of health.

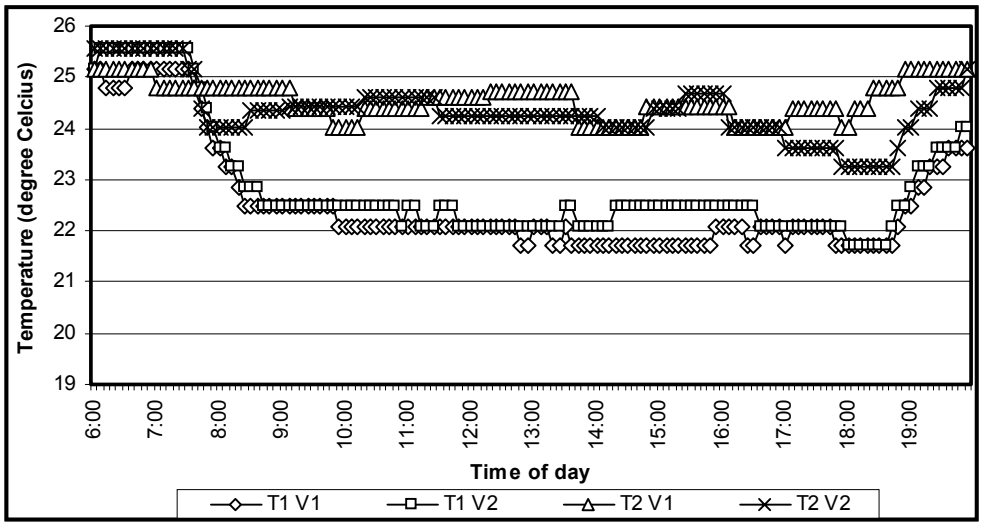

Figure 2 Typical daily (Thursday) temperature profile.

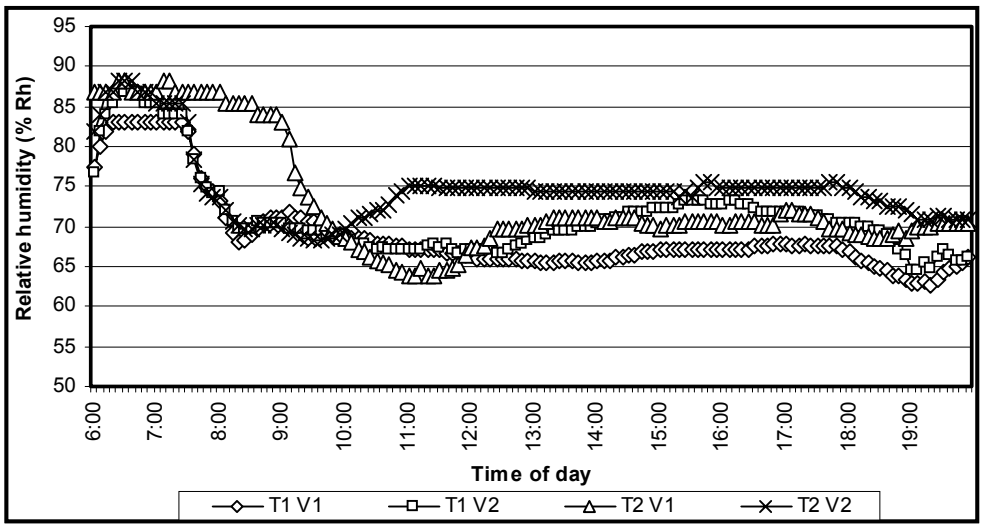

Figure 3 Typical daily (Thursday) relative humidity profile.

Analysis of variance revealed that morning and afternoon ratings of thermal comfort rating, perceived air quality and SBS symptoms ratings did not differ significantly ($P > 0.1$). This suggests that the results are unlikely to be confounded with 'time of day' effects. Subsequently, subjective ratings were analysed using the combined morning and afternoon data. The acceptability of air quality did not differ between experimental weeks at the ($P < 0.05$) level, i.e. they were unaffected by the temperature and ventilation rate interventions. Tham *et al.* (2003) report that except for changes in carbon dioxide levels, the increase in outside air supply rate did not lead to any statistically significant reduction in a number of other indoor pollutant concentrations, but the interventions were found to significantly affect the intensity of several SBS symptoms. This finding emphasizes that human responses are more sensitive and more relevant indicators of air quality than physical or chemical measurements, and implies that the interventions affected the concentration of other pollutants that were not measured.

Table 1 Impact of temperature and ventilation rate on selected SBS symptoms

SBS symptoms	Environmental condition		Intensity changes (%)	*P* (<)
	Temperature (°C)	Fresh air (l/s/person)		
Cold hand	⇑ (22.5 to 24.5)	9.8	⇓ 22.9	0.01
	⇓ (24.5 to 22.5)	9.8	⇑ 13.9	0.01
Cold feet	⇑ (22.5 to 24.5)	9.8	⇓ 25.9	0.01
	⇓ (24.5 to 22.5)	9.8	⇑ 15.2	0.01
Eyes irritation	⇑ (22.5 to 24.5)	22.7	⇓ 6.4	0.03
	⇓ (24.5 to 22.5)	22.7	⇓ 1.2	>0.6
Throat irritation	⇑ (22.5 to 24.5)	22.7	⇓ 8.7	0.01
	⇓ (24.5 to 22.5)	22.7	⇑ 1.2	>0.5
Dry eyes	⇑ (22.5 to 24.5)	9.8	⇓ 11.7	0.01
	⇓ (24.5 to 22.5)	9.8	⇓ 2.3	>0.6
Dry throat	⇑ (22.5 to 24.5)	9.8	⇓ 10.0	0.05
	⇓ (24.5 to 22.5)	9.8	⇑ 3.7	>0.4
Headache	⇑ (22.5 to 24.5)	9.8	⇓ 10.2	0.05
	⇓ (24.5 to 22.5)	9.8	⇑ 4.8	>0.3
	24.5	⇑ (9.8 to 22.7)	⇓ 19.5	0.03
	24.5	⇓ (22.7 to 9.8)	⇑ 8.8	0.07
Difficulty to concentrate	⇑ (22.5 to 24.5)	9.8	⇓ 9.0	0.03
	⇓ (24.5 to 22.5)	9.8	⇑ 7.2	>0.07
	24.5	⇑ (9.8 to 22.7)	⇓ 13.2	0.02
	24.5	⇓ (22.7 to 9.8)	⇑ 9.3	0.04

Note: ⇑ denotes increase; ⇓ denotes decrease.

DISCUSSION

Headache intensity and difficulty in concentrating were reduced by 19.5% ($P < 0.03$) and 13.2% ($P < 0.02$), respectively, when the outdoor air supply rate was approximately doubled (9.8–22.7 l/s/person). This is in agreement with previous findings (Wargocki *et al*., 2000). The increased ventilation rate also reduced call handling time, as reported by Tham *et al.* (2003), supporting the causal relationship suggested by Wargocki *et al*. (1999, 2000).

Both cold hands and cold feet symptoms were greatly affected by the change in temperature settings, although this could only be shown to be statistically significant at the lower ventilation rate. Cold hands and cold feet intensity decreased by more than 20% ($P < 0.01$) when the air temperature was raised by 2°C, and increased by about 15% ($P < 0.01$) when the air temperature was decreased.

The increase in air temperature reduced eye and throat irritation by 6.4% ($P < 0.03$) and 8.7% ($P < 0.01$), respectively, at high ventilation rates while eye and throat dryness decreased by 11.7% ($P < 0.01$) and 10.0% ($P < 0.05$), respectively, with increased temperature at the lower ventilation rate only.

As seen in Figure 4, thermal comfort rating improved following a 2°C temperature increase when the outside air supply rate was 9.8 l/s/person. The Tropical subjects tended to be more comfortable when the air temperature was at 24.5°C, as it is closer to thermal neutrality (Figure 5). However, the same effect could not be observed at the high outside air supply rate. It should be noted that the relative humidity exceeded 70% at the higher outside air supply rate (Figure 3), and that this may have affected responses.

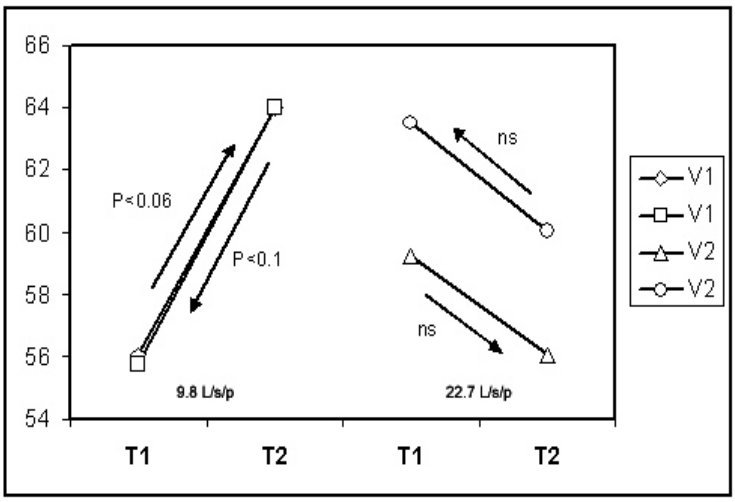

Figure 4 Thermal comfort ratings (0: very uncomfortable to 100: very comfortable).

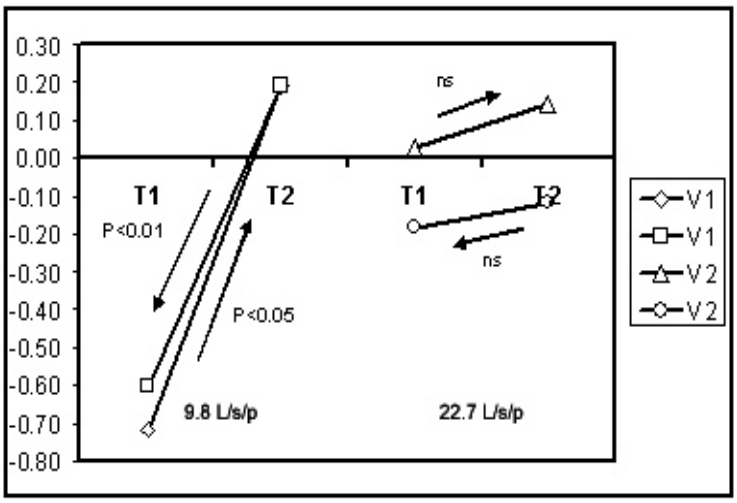

Figure 5 Thermal sensation ([–3]: cold – [0]: neutral – [+3]: hot).

CONCLUSIONS

This study indicates that thermal comfort would improve and SBS symptom intensity would decrease if office workers acclimatized to Tropical environments were provided with environmental conditions closer to thermal neutrality and with a considerably higher outside air supply rate than is currently the case.

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