A principal component analysis of perception and SBS symptoms of office workers in the tropics at two temperatures and two ventilation rates

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ABSTRACT
Correlation analysis of subjective responses of tropically acclimatized office workers in a field study conducted over nine continuous weeks using a 2 × 2 balanced design with temperature and fresh air ventilation rates as control variables revealed that several related SBS symptoms are highly correlated. Thermal comfort and acceptability of air quality exhibit a strong correlation, whereas perceived indoor environmental variables have poor correlations among themselves. Principal component analysis further improved measures to variability by combining coherent variables into six factors. Analysis of variance of factor scores derived for each factor suggested that thermal comfort induced by temperature changes plays an important role in the occupant's perception and reported SBS symptom intensity. The 'acceptability of air quality-thermal comfort' and 'perceived indoor environmental' factors were significantly influenced by temperature rather than the fresh air levels interventions. 'Behavioural symptoms' factor was significantly correlated with 'perceived indoor environmental quality' factor (R^2 = 0.70).

INDEX TERMS
Principal component analysis; Perceived air quality (PAQ); Thermal comfort; Sick building syndrome (SBS); Tropics

INTRODUCTION
Recent studies and reviews highlight potential productivity increase associated with indoor air quality improvements (Wargocki *et al.*, 1999; Milton *et al.*, 2000; Wargocki *et al.*, 2002). Work performance has been reported to be statistically significantly related to the presence and levels of pollution, which are strongly associated with fresh air supply provision. Moderate thermal stress has also been associated with human physiological strain and perception, which later affects working performance (Wyon, 1998; Parson, 2002). The mechanisms by which human work output may be affected should be better understood to enable the optimization of the indoor environmental parameters.

Human sensory performance plays an important role in the detection of the indoor air contaminants by means of irritation effect and odour senses, which subsequently determines the perceived air quality (Fanger, 1988) and, to a certain extent, prevalence of SBS symptoms (Hudnell *et al.*, 1992, Wargocki, 2001). Establishing relationships between indoor air quality parameters and SBS symptoms have been a challenging task over the past few decades. Most of the recent studies have consistently shown the direct impact of fresh air supply on the intensity and number of reported SBS symptoms (Sundell, 1994; Jaakkola and Miettinen, 1995; Seppanen *et al.*, 1999). In addition, Fang *et al.* (1998) showed that enthalpy strongly influences human sensory evaluation. Even clean air may be perceived as being of much lower quality when it is either hot or humid or both (high enthalpy). Tham *et al.* (2003b) discusses recent findings in the Tropics, which examines the impact of temperature on perception of indoor environmental variables and reported SBS symptoms. The present paper

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reports the post hoc analysis of occupants' perception and SBS symptoms from the same data set using principal component analysis.

METHODS

This study was carried out for nine weeks using the blind intervention approach in a call centre in the Tropics. Participants were aware of indoor environmental measurement but were kept blind to the weekly interventions. The experimental design was balanced such that possible combinations of two levels of fresh air and temperature were fully studied (Figure 1). The interventions were carried out on Friday afternoons and the environmental condition maintained for a week. Conducted in a call centre occupied by 26 customer service officers (CSOs), three supervisors and seven office staff, the experimental procedure required the CSOs to provide their feedback twice on every Thursday: once each in the morning and afternoon. Daily operation of the call centre includes providing information and guidance for specific type of enquiries about taxation. The experimental plan is a non-repeatable matrix, which is a slight modification to the study by Wargocki *et al.* (2002). The initial intention of the study was to select two temperature levels within the comfort region of thermal comfort standard with at least 3°C difference. However, the air handling system was unable to achieve such requirement and thus, a 2°C difference between 22.5 and 24.5°C was implemented. The fresh air provisions were set at 9.8 and 22.7 l/s/person, which correspond to lower and higher ventilation rates. More details about the environmental variables and air conditioning system of the building are given in Tham *et al.* (2003a).

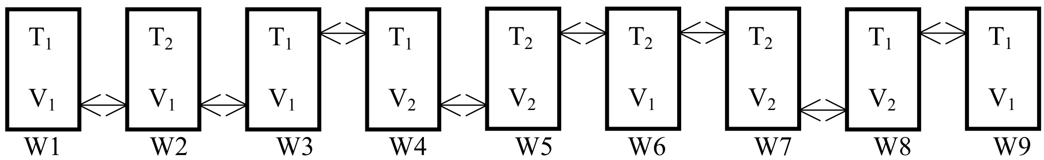

Figure 1 Environmental settings for each intervention week from week (W) 1 to week 9 (note: T_1 = 22.5°C, T_2 = 24.5°C, V_1 = 9.8 L/s/person, V_2 = 22.7 L/s/person).

Subjective responses were obtained from surveys utilizing linear visual analog scales (VAS) distributed between 10.00 a.m. to 11.30 a.m. and 03.00 p.m. to 04.30 p.m. The marked scales were then converted into scores (0–100%) and subjected to Shapiro–Wilks normal distribution test. In order to identify any significant change due to interventions, parametric statistics (paired *t* test) for normally distributed data, or otherwise, a non-parametric analysis was carried out. Findings of this analysis are reported in Tham *et al.* (2003a,b). The present paper highlights the post analysis of the above data by means of an exploratory analysis using principal component analysis in order to evaluate the interrelationships among variables and reduce the dimensionality of the data sets. The data set from each individual respondent in the morning and afternoon sessions were subjected to factor analysis. Factor analysis using principal component method was conducted after noticing the relationships among the perceptual responses and SBS symptoms. These relationships were expressed in several factors representing clusters of data that may better explain variances as well as other observable phenomena. For each of the extracted factor, a score can be derived from every individual data set. These scores were further analysed using the analysis of variance and correlation analysis.

RESULTS

Within-subject analysis of the transitions, i.e. between week 1 and week 2, week 2 and week 3, and so on for the acceptability of air quality did not indicate any statistically significant difference. The same result was found for time of day analysis between morning and afternoon (Figure 2), except for week 6 ($P < 0.05$) when ventilation rate was decreased from 22.7 to 9.8

l/s/person. It is pertinent to note that no significant changes in terms of indoor pollutants concentrations were found in the fresh air interventions except for the levels of carbon dioxide ($P < 0.01$). Seppanen *et al.* (1999) reported that one or more SBS symptoms were significantly affected by carbon dioxide levels, although the concentrations found in the present office environment were well below the recommended threshold limit for carbon dioxide levels (ASHRAE 62, 1989). As reported in Tham *et al.* (2003b), fresh air interventions only affected the behavioural symptoms such as headache and difficulty to concentrate, and other significant effects of the prevalence of SBS symptoms are associated with temperature changes.

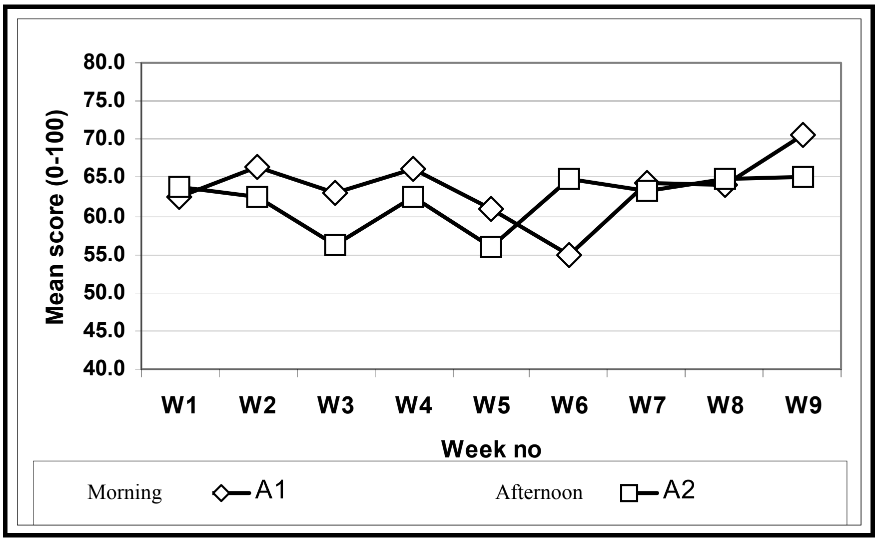

Figure 2 Acceptability of indoor air quality during morning and afternoon sessions.

Correlation		Pearson's coefficient	*P*
Thermal comfort	Acceptability air quality	0.81	<0.01
Dry nose	Flu-like symptoms	0.72	<0.01
Cold hand	Cold feet	0.94	<0.01
Fatique	Difficulty to concentrate	0.88	<0.01
Fatique	Depression	0.82	<0.01
Difficulty to concentrate	Depression	0.88	<0.01

Several high bivariate correlations with low partial correlations indicated possible clustering of related variables of perception and SBS symptoms as the underlying processes that may further affect other variables. In agreement with Fang *et al.*'s (1998) results, this study also found a high correlation between thermal comfort ratings and perceived air quality although the subjects of this study were acclimatized to the Tropical climate. Behavioural symptoms also exhibited the most significant correlations, which were significantly influenced by both thermal comfort and ventilation rate (Tham *et al.*, 2003b).

Table 1 Significant correlations among perceptual and reported SBS symptoms

Principal component analysis successfully identified six coherent subsets from all the subjective responses (perceptual and SBS symptoms) that are relatively independent of one another. The oblique rotation method was used as this factor analysis allows for correlations among variables. This resulted in a more reasonable set of factors than that obtained via orthogonal rotation. Table 2 indicates the extracted factors from selected variables with factor loadings greater than 0.4. The criteria in retaining these factors were eigenvalues greater than 1 and observation of the screen plots. The results also revealed several variables with insignificant factor loadings on the extracted principal components, i.e. eyes-related symptoms, depression and self-rating of effort.

The first factor (BHVR SYMP) can be broadly categorized as the behavioural symptoms, which include tension, difficulty to think, dizziness and headache. It also indicates that self-assessed productivity and alertness were inversely related to the intensity of these symptoms. Indoor environmental quality determinants such as lighting, noise, dustiness, humidity, stuffiness, and air movement levels were found to have high factor loadings on the second factor (PCV IEQ), whereas the third factor (NOSE SYMP) was explained by three nose-related symptoms. PCA also found that thermal sensation and thermal-related symptoms were highly loaded into a single factor (THERMAL). Previous analysis reported in Tham *et al.* (2003b) has shown that occupants were able to differentiate temperature changes from 22.5 to 24.5°C or otherwise. Temperature interventions also significantly affected both cold hand and cold feet symptoms. The fourth factor therefore supported the postulation of a direct impact of temperature on occupant's perception and the related SBS symptoms. Olfactory sense was exhibited in the subsequent factor where perceived odour was clustered with perceived sweating intensity and nose irritation levels. Another finding also recognizes the clustering of perceptual response of thermal comfort and acceptability to air quality (PAQ PTC).

Table 2 Principal components of perceptual and SBS symptoms (factor loadings >0.4)

COMPONENT	BHVR SYMP.	PCV. IEQ	NOSE SYMP.	THERMAL	ODOR-IRT.	PAQ-PTC
TENSION	0.801					
SELF-PRODUCTIVITY	–0.778					
DIFFICULTY TO THINK	0.710					
FATIGUE	0.705					
DIZZINESS	0.683					
HEADACHE	0.598					
ALERTNESS	–0.526					
LIGHTING LEVEL		0.700				
NOISE LEVEL		0.675				
DUSTINESS		0.651				
HUMIDITY LEVEL		0.634				0.411
STUFFINESS		0.530				–0.463
BLOCK NOSE			0.872			
FLU-LIKE SYMPTOM			0.862			
THERMAL SENSATION				–0.807		
WARMNESS LEVEL				0.775		
COLD HAND				–0.764		
COLD FEET				–0.744		
ODOUR LEVEL					0.705	
SWEATING					0.670	
NOSE IRRITATION					0.484	
ACCEPTABILITY TO AIR QUALITY						0.882
THERMAL COMFORT LEVEL						0.830
AIR STILLNESS		0.403				–0.416
DRY NOSE			–0.456			

DISCUSSION

Figure 3 shows comparisons of individual factor scores of perception towards thermal comfort and indoor air quality (PAQ PTC) at different combined temperature and fresh air levels. The result signifies the importance of temperature levels, with lower temperature considered more acceptable for its air quality and thermal comfort. While the data suggest that increase in fresh air provision leads to improvement, this was reported only when temperature was kept as low as 22.5ºC. In contrast, at higher temperature (24.5ºC), higher fresh air level was found to cause lower acceptability to air quality and thermal comfort. This phenomenon may have been caused by higher relative humidity levels, i.e. 74% RH, when fresh air intake was kept high, which in combination with the higher temperature resulted in a higher enthalpy.

Perception of indoor environmental quality (PCV IEQ) is strongly influenced by thermal environment as well as fresh air provision (Figure 4). A greater improvement of perceived environmental quality could be achieved by lowering temperature (enthalpy) when fresh air provision was kept at a lower setting. This suggests that perceived indoor environmental quality may be more acute at higher pollution levels for the same temperature difference. As seen in Figure 5, there exists a linear correlation between PCV IEQ and BHVR SYMP factors. An increase in the reported behavioural symptoms (the higher the score, the higher the BHVR SYMP) may therefore be attributable to worsened PCV IEQ (the higher the score, the worse the PCV IEQ).

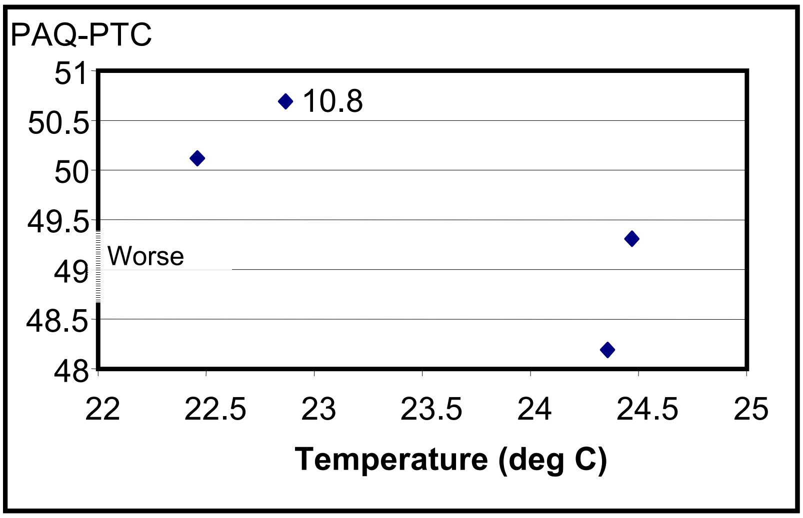

Figure 3 PAQ-PTC mean factor scores at four combined temperatures and ventilation rates ($P < 0.08$).

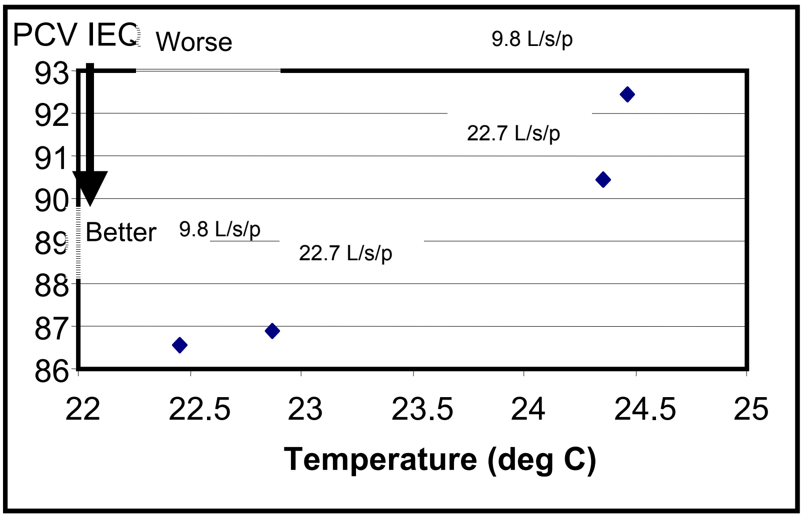

Figure 4 PCV IEQ mean factor scores at four combined temperatures and ventilation rates ($P < 0.05$).

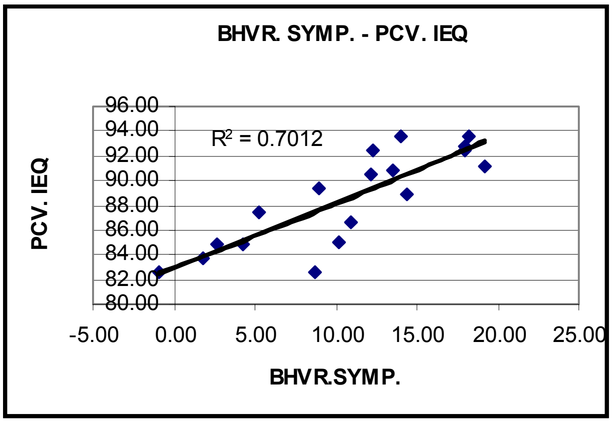

Figure 5 Linear regression between principal components.

CONCLUSION

A principal component analysis has been successfully employed to explain the correlations among subjective variables; and between environmental variables, i.e. temperature and fresh air provision and subjective responses for Tropically acclimatized office workers in the range of conditions studied, i.e. temperature between 22.5 and 24.5ºC and ventilation rates between 9.8 and 22.7 l/s/person. Lowering temperature leads to a better-perceived thermal comfort and acceptability of IAQ ($P < 0.08$). Reducing temperature from 24.5 to 22.5ºC resulted in a greater improvement of perceived indoor environmental quality at lower fresh air level, 9.8 l/s/person, than higher fresh air level, 22.7 l/s/person ($P < 0.05$). A moderately strong relationship ($R^2 = 0.70$) has been found to exist among variables associated with perceived indoor environmental quality (PCV IEQ) and several behavioural symptoms (BHVR SYMP).

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REFERENCES

ASHRAE (1989). *ASHRAE Standard 62-1989*. Ventilation for acceptable indoor air quality. Atlanta, USA: American Society for Heating, Refrigerating and Air-conditioning Engineers.

Fang, L., Clausen, G. and Fanger, P.O. (1998). Impact of humidity on perception of indoor air quality. *Indoor air* **8**, pp. 80–90.

Fanger, P.O. (1988). Olf and decipol. *Building Services and Engineering Research Technology*. **9**, 155–157.

Hudnell, H.K., Otto, D.A., House, D.E. and Molhave, L. (1992). Exposure of human to a volatile organic mixture. *Archives of Environmental Health* **47** (1), 31–38.

Jaakkola, J.J.K. and Miettinen, P. (1995). Type of ventilation system in office buildings and SBS. *American Journal of Epidemiology* 141 (8), pp. 755–765.

Milton, D.K., Glencross, P.M. and Walters, M.D. (2000). Risk of sick leaves associated with outdoor air supply rate, humidification and occupant complaints. *Indoor Air* **10**, 212–221.

Parsons, K.C. (2002). The effects of gender, acclimation state, the opportunity to adjust clothing and physical disability on requirements for thermal comfort. *Energy and Buildings* **34**, 593–599.

Seppanen O.A., Fisk, W.J. and Mendell, M.J. (1999). Association of ventilation rates and CO_2 concentrations with health and other responses in commercial and institutional buildings. *Indoor Air* **9**, 226–252.

Sundell, J., Lindvall, T. and Stenberg, B. (1994). Association between type of ventilation and airflow rates in office buildings and the risk of SBS symptoms among occupants. *Environment International* **20** (2), 239–251.

Tham, K.W., Willem, H.C., Sekhar, S.C., Wyon, D.P. and Wargocki P. (2003a). Temperature and ventilation effects on working performance of office workers (Study of call center in the Tropics). *Healthy Buildings 2003*, Singapore (submitted).

Tham, K.W., Willem, H.C., Sekhar, S.C., Wyon, D.P. and Wargocki, P. (2003b). SBS symptoms and perception of office workers' at two different temperatures and ventilation rates in the Tropics. *Healthy Buildings 2003*, Singapore (submitted).

Wargocki, P. 2001. Measurements of the effects of air quality on sensory perception. *Chemical Senses* **26**, 345–348.

Wargocki, P., Wyon, D.P., Baik, Y.K., Clausen, G. and Fanger, P.O. (1999). Perceived air quality, Sick Building Syndrome (SBS) symptoms and productivity in an office with two different pollution loads. *Indoor Air* **9**, 165–179.

Wargocki, P., Wyon, D.P., Nielsen, J.B. and Fanger, P.O. (2002). Call centre occupant response to new and used filters at two outdoor air supply rates. *Proceedings of 9th International Conference on Indoor Air Quality and Climate*, Vol. 3, pp. 449–454.

Wyon, D.P. (1998). Documented indoor environmental effects on productivity. *DANVAC Conference 'Green Buildings'*, Copenhagen.