Some Effects of Ventilation on People: Perceptions, physiological Responses and Mental Performance

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ABSTRACT
This study explores the plausible mechanism linking outdoor air supply rates and work performance through the perceptual responses and a target salivary biomarker. An extended objective is this study is to perform comparative study between the healthy and the asthmatic groups of subjects. A total of 160 young adults participated as voluntary subjects in two phases. The study was conducted in the Field Environmental Chamber which simulates an office setting. Subjects rated the air quality at 18.0L/s/p to be most acceptable, followed by 9.0L/s/p and the least acceptable at 4.5L/s/p ($P<0.001$). Increasing outdoor air supply rate from 4.5 to 9.0L/s/p reduced the intensity of neurobehavioral-related symptoms but a reversed trend occurred when outdoor air supply rate was further increased to 18.0L/s/p ($P<0.001$). Lower salivary α-Amylase concentration occurred with the doubling of outdoor air supply rate from 9.0 to 18.0L/s/p ($P<0.005$). The typing speed performance was lowest at 18.0L/s/p ($P<0.003$). The non-asthmatics rated the higher outdoor air supply rate at 12.0L/s/p as more acceptable than the lower setting at 6.0L/s/p ($P<0.03$, 1-tailed). The same group also had higher salivary α-Amylase concentration when exposed to 12.0L/s/p ($P<0.05$). In the asthmatic group, higher outdoor air supply rate reduced the perceived odour intensity by 20.8% ($P<0.05$). Different mechanisms relating the ventilation parameter and the occupants' responses are suggested for both subject groups.

1. INTRODUCTION

Ventilation is an essential requirement in achieving and maintaining clean, healthy and acceptable indoor air quality. The amount of outdoor air supply rate determines the dilution factor or the removal rate of indoor air pollutants so that their concentrations fall within the safe and acceptable ranges. Unfortunately, for many buildings in the tropics, low outdoor air supply rates are not uncommon due to the conflict with energy conservation requirements, which mean the use of high air recirculation rate for the air-conditioning system. On the other hand, the increasing awareness and needs for good indoor air quality in the recent years arising from emerging studies on perceptual and health responses have provided the much-needed support for improving ventilation in the occupied premises.

Several studies have demonstrated that increased ventilation may lead to improvement in the work performance of office workers and a lesser tendency of office workers applying for sick leave, thus enabling the company to gain more working days from its employees as a result of the reduced sick leave. According to Milton et al. (2000), there is a constant association of increased sick leave with lower levels of ventilation rates. In another study conducted by Wargocki et al. (2000), subjects were asked to perform simulated office tasks and were exposed to three outdoor air supply rates, i.e. 3.0, 10.0 and 30.0L/s/p. Their results indicated that the work performance of the

subjects were increased by 1.7% with every two-fold increase of the outdoor air supply rate, hence suggesting that higher ventilation resulted in better work performance.

While a number of studies have focused on healthy subjects, few have actually targeted the more susceptible group of people such as the asthmatics. Malmberg (2001) estimated that there are around 100 to 150 million asthmatic people in the world and that the younger generations are more likely to have asthma for various much-debated reasons. This further implies that in time, more people with asthma will be stepping into the work life. This will substantially influence the productivity level of the workforce, amounting to major monetary loss due to the sub-optimal health condition while at work. Goetzel et al. (2004) estimated that the productivity loss at work is approximately seventy-two US dollars per asthmatic worker per annum, not including the medical costs and loss due to absenteeism triggered by incidences of respiratory problems, allergy and asthma. It is therefore timely to understand the influences and mechanisms through which and to what extent ventilation may also improve the health responses and work performance of asthmatic workers along with their healthy or non-asthmatic counterparts.

This paper reports the recent findings on the effects of ventilation on occupants' responses in the tropics, while identifying the plausible mechanisms that lead to effects on work performance. Preliminary results from a recent study which compares responses of healthy and asthmatic subjects are also included at the end of each section.

2. RESEARCH METHODS

A total of ninety-six (96) and sixty-four (64) subjects were recruited for the two phases of study, respectively, with the later phase involving case-control study on the asthmatics. The subjects were divided equally into groups of sixteen (16) subjects with each group having an equivalent number of male and female participants. The case-control study on the asthmatics involved thirty-two (32) healthy participants and thirty-two (32) participants with history of mild persistence asthma. Before commencing the actual experiment, subjects were given three training sessions to familiarize with the surveys and simulated office tasks.

The experiment was conducted in a Field Environmental Chamber (FEC) where conditioned-air was delivered to the chamber via six concentric air terminal devices with perforated panel at the outlet to ensure uniform air distribution or mixing and minimize the risk of non-uniform turbulence intensity. In controlling the outdoor air supply rate, the supply and exhaust air fan speeds of the air distribution system was locked while the percentage of fresh air intake opening was varied to achieve the target settings. The first phase of the study used three settings, i.e. 4.5, 9.0 and 18.0L/s/p, and the second phase used two settings, i.e. 6.0 and 12.0L/s/p, which were introduced to the subjects following the blind intervention approach. Throughout the interventions, all other indoor environmental parameters were kept constant. Room air temperature was kept between 23.0-24.0°C while relative humidity was maintained between 60.0-65.0%. Each experimental session in the first phase lasted for four (4) hours and the second phase lasted for eight (8) hours including a lunch hour break. It is pertinent to note that only the full exposure effects, i.e. at end of exposure, will be discussed in this paper. During their sessions, subjects stayed in the simulated office and worked on the performance test batteries and series of questionnaire.

The survey consisted of in partial the questions pertaining to perceptual aspects such as acceptability of air quality, levels of irritation to the eyes, nose and throat, the odour intensity, and the Sick Building Syndrome (SBS) symptoms. These subjective responses were obtained using continuous scale. For the scope of this paper, only the results of acceptability of indoor air quality and clusters of predominant SBS symptoms will be reported and discussed. A passive drool salivary sampling procedure

was applied for saliva collection after exposures. Kinetic immunoassay measurement was employed to determine salivary α-amylase concentration in the saliva. A higher concentration of salivary α-Amylase indicates higher activation of the Sympathetic Nervous System (SNS), which is influenced by the olfactory response and is known to be associated with arousal and pleasantness levels. Several mental performances were measured in addition to the simulated office tasks. In this paper, the results of mental arousal and text-typing are reported. Mental arousal was measured using a modified Tsai-partington test. Originally known as Trial Making Test, it was devised for purposes including sequencing ability, mental flexibility, visual search and test of motor function. In this study, subjects were asked to link fifty-five (55) numbers in descending order within two (2) minutes. The total number of links per minute and the number of incorrect links were used as speed and accuracy measures, respectively. Under high arousal, subjects were expected to perform worse due to narrow attention span. The text-typing task was a simple re-typing task of articles. The number of words typed was used as measure of speed while the number of typological error was applied as measure of accuracy.

3. PERCEPTUAL AND SBS SYMPTOMS RESPONSES

Subjects voted the air quality at 18.0L/s/p to be most acceptable, followed by 9.0L/s/p and the least acceptable at 4.5L/s/p ($P<0.001$). There was also significant olfactory adaptation across the time of exposure ($P<0.001$). Further analysis revealed that the predicted percentage dissatisfied and perceived air quality improved monotonically with outdoor air supply rate.

The principal component analysis was used to model the perceptual constructs of the subjective responses obtained from the survey. The cumulative explained variance indicated that 72% of total variance in the survey data was accountable by the extracted subjective factors. The subjective factor that explained most of the

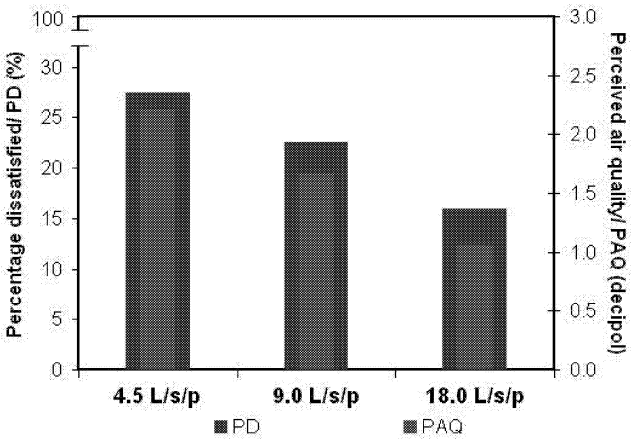

Figure 1. Percentage dissatisfied with air quality and the corresponding perceived air quality at three outdoor air supply rates

variance was the neurobehavioral-related symptoms cluster. These symptoms were apparently more dominant than the thermal-related responses as the result of interventions to the amount of fresh air. The subjective factor was positively loaded with the state of feeling/ mood, level of depression, difficulty to think clearly and difficulty to concentrate, intensity of headache and dizziness, the level of fatigue and depression. Subjects associated symptoms related to the nervous system such as dizziness, headache and abilities to think and concentrate to those of psychological/ behavioural measures such as tension, depression, and mood. Another subjective factor suggested the association between olfaction and chemestesis responses. Increased perceived odour was related to higher intensity of irritation to the eyes, nose and throat. Furthermore, the factor loading of perceived odour indicated that olfactory system was superior over the irritation responses. Principal component analysis also revealed another less dominant symptoms cluster, i.e. the respiratory-related symptoms, which comprised of nose dryness, intensity of blocked nose and flu-like symptoms. The intensity of nose dryness was inversely related to the intensity of blocked nose and flu-like symptoms.

The main effect analysis of outdoor air supply rates on the factor scores of the subjective factor

of neurobehavioural-related symptoms found that increasing outdoor air supply rate from 4.5 to 9.0L/s/p reduced the intensity of neurobehavioral-related symptoms. However, a reversed trend occurred when outdoor air supply rate was further increased to 18.0L/s/p ($P<0.001$). The result highlighted the adverse health-related effect of introducing higher outdoor air supply rate when the increment, in turn, polluted the supply air in the downstream of the used filters. For the perceived odour and irritation, higher outdoor air supply rate was beneficial in reducing these responses with a more pronounced change in factor score occurring between the settings of 9.0 and 18.0L/s/p ($P<0.0001$). The factor score analysis of respiratory-related symptoms cluster suggested that increasing outdoor air supply rate caused reduction to nose dryness symptom ($P<0.04$), which is consistent with the lower nose irritation at higher outdoor air supply rate for the previous subjective factor.

Preliminary results from case-control study on the asthmatics

The levels of acceptability of air quality at both outdoor air supply rates for both subject groups after an eight-hour exposure. The non-asthmatics rated the higher outdoor air supply rate as more acceptable than the lower setting by 8.2% ($P<0.03$, 1-tailed). On the other hand, the asthmatics did not perceived any difference in terms of acceptability of air quality between both settings. Group comparison between both subject groups revealed that the non-asthmatics significantly rated the indoor air quality as more acceptable than the asthmatics ($P<0.01$). Overall, the subjects perceived the indoor air quality of the simulated office environment within the "acceptable" range. The effect of outdoor air supply rate on perceived odour intensity was only significant in the asthmatic group. A higher outdoor air supply rate reduced the perceived odour intensity of the asthmatics by 20.8% even at the lower end of the intensity scale ($P<0.05$).

4. SALIVARY BIOMARKER RESPONSE

Analysis of salivary α-Amylase concentrations showed consistently higher levels after the four-hour exposure across all three outdoor air supply rates ($P<0.0001$). Least activation was observed under the higher outdoor air supply rate at 18.0L/s/p, while more activation (indicated by higher salivary α-Amylase concentration) was seen at 4.5 and 9.0L/s/p. Pair-wise analysis revealed a significantly lower salivary α-Amylase concentration induced by doubling outdoor air supply rate from 9.0 to 18.0L/s/p ($P<0.005$). Based on these results, subjects appeared to have lower arousal at 18.0L/s/p, which is plausibly related to the reduced mental alertness following the elevated neurobehavioral-related symptoms.

Preliminary results from case-control study on the asthmatics

The salivary α-Amylase concentration was found to be higher (20.0%) under exposure to higher outdoor air supply rate only in the non-asthmatic group ($P<0.05$). There seemed to be no exposure effect in the asthmatics as there was only a very marginal increase of salivary α-Amylase concentration. Non-asthmatics also secreted higher α-Amylase levels at both outdoor air supply rates than the asthmatics ($P<0.01$).

5. MENTAL PERFORMANCE AND SIMULATED OFFICE TASK

Figure 2 shows the results of mental arousal test in terms of speed (number of links completed) and accuracy (errors/ incorrect links). Higher speed of work and lower accuracy are indications of an elevated mental arousal. There was no statistically significant effect arising from the outdoor air supply rate interventions. Thus, the physiological effects obtained from the salivary α-Amylase concentrations were not correspondingly reflected through the mental performance test. It seemed that the physiological change was not substantial enough to warrant translational effects on mental work performance.

The mixed model analysis revealed significant differences of typing speed in terms of number of words per minute ($P<0.003$) while no significant difference was associated with text-

typing accuracy (Figure 3). Subjects typed significantly slower at 18.0 L/s/p when compared with speed at 9.0 (P<0.001) and 4.5 L/s/p (P<0.08). The effect of higher outdoor air supply rate on text-typing speed led to a loss of approximately 1.4% of total working time per day. A plausible explanation for this result based on the arousal theory is that subjects were under under-aroused state during exposure to higher ventilation rate and therefore they performed slower at typing task which require an intermediate arousal state for optimum performance (Colman, 2001).

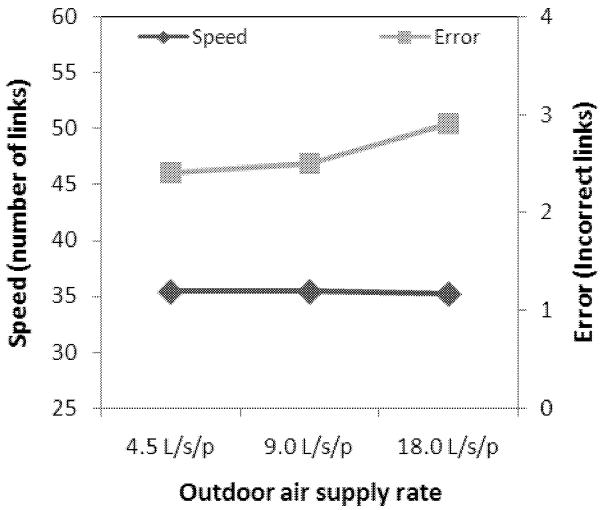

Figure 2. Speed and accuracy results of arousal test at three outdoor air supply rates

Preliminary results from case-control study on the asthmatics

Figures 4 and 5 show the results of the Tsai-partington test, which is used to measure mental arousal level. The result shows that increase in outdoor air supply rate tended to increase the speed of work as shown by the higher number of links completed by both subject groups. There was also an increase of error in completing the test in both subject groups. The results suggest that subjects were likely more aroused when outdoor air supply rate was higher. However, it should be noted that the statistical results was not found to be significant. There was also no statistical difference in terms speed and accuracy between the two subject groups.

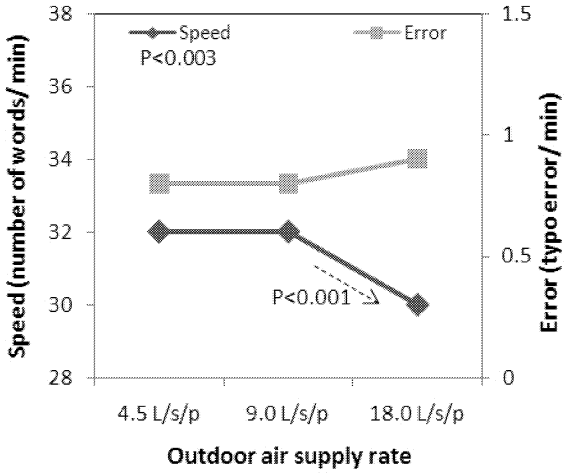

Figure 3. Speed and accuracy results of typing task at three outdoor air supply rates

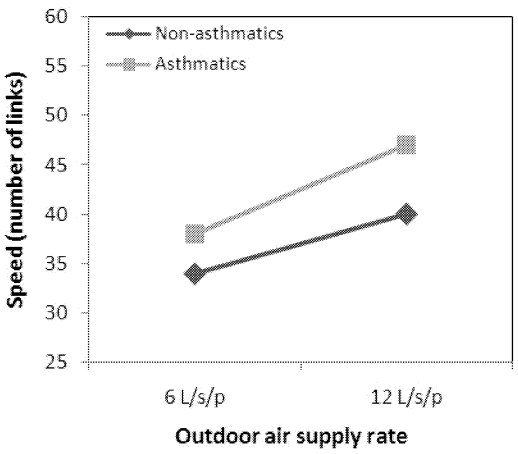

Figure 4. Speed measure (number of links) under exposures to two outdoor air supply rates

6. DISCUSSIONS

The result of perceptual responses indicate that increasing outdoor air supply rates gradually improves the sensory evaluation of indoor air quality by means of reducing perceivable odor and improving acceptability (and thus lowering percentage dissatisfied). The main effect of outdoor air supply rate on the subjective factor comprising the perceived odor and irritation confirms the positive implications of increasing outdoor air supply rate on sensory evaluation. This finding is in parallel with Wargocki et al (2000) who reported the monotonic improvements of perceived air quality and correspondingly the reduction in percentage

dissatisfied with increasing ventilation rate based on subjective assessments of thirty female subjects.

Introducing higher amount of outdoor air supply rates at 18.0L/s/p in conjunction with used ventilation filters seems to increase the risk of elevating the intensity of neurobehavioral-related symptoms and other respiratory-related symptoms. The subjective factor representing the neurobehavioral-related symptoms was significantly higher at 18.0L/s/p, which reflects the observations from the individual symptoms. There could be an increase of particulate at 18.0L/s/p when coupled with used filters that overcomes the benefit of improved sensory responses. This effect has been reported by Clausen (2004) who demonstrated that the presence of used filters in the air conditioning system negatively affects the intensity of SBS symptoms.

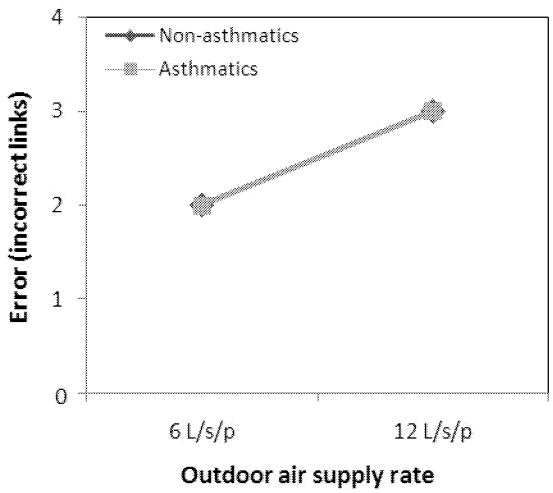

Figure 5. Error measure (number of incorrect links) under exposures to two outdoor air supply rates

Salivary α-Amylase biomarker secretion appears to be influenced by the outdoor air supply rate interventions. There is tendency of higher activation as outdoor air supply rate increases between 4.5 and 9.0L/s/p. However, an effect exclusively related to the indoor air quality at 18.0L/s/p suggests a substantial decrease of activation. This seems to support the adverse effects seen in the neurobehavioural-related symptoms reported earlier and may be an explanation for impaired text-typing performance under exposure to the higher outdoor air supply rate.

Case-control study on the asthmatics

The results reveal the differences between the non-asthmatic and asthmatic subjects in terms of their perceptions of air quality and the biomarker secretion in their body. The hypotheses that higher (doubling of) outdoor air supply rate improves acceptability of air quality by means of reducing perceived odour intensity and that this leads to higher mental arousal or activation are confirmed in the non-asthmatic group, except for the lack of effect on the perceived odour intensity. The non-asthmatic subjects also consistently perceive higher acceptability of air quality and have higher α-Amylase secretion in their saliva compared to the asthmatic subjects.

One plausible factor that may explain the lack of association between the acceptability of air quality and the perceived odor intensity is the olfactory adaptation/ sensitivity. Asthmatics are known to be more sensitive towards odorants (Shim and Williams, 1986) and, in some studies, specific odorants have been shown to trigger asthmatic symptoms and pulmonary function decrements (Kumar et al., 1995). This underlines the ability of the asthmatic group in discerning the odour level as the first protection mechanism even at moderate levels under the two outdoor air supply rate exposures. Nevertheless, these mechanisms seem to have little influence over the evaluation of the indoor air quality by the asthmatics. On the other hand, the non-asthmatic subjects seem to have little perceptual concern over the odour level. After the eight-hour exposure, olfactory adaptation may have affected their evaluation of odour level even after they refresh their sense of smell. This however should not be interpreted as lack of perceptual response from the non-asthmatics as they clearly prefer indoor air quality under a higher outdoor air supply rate setting. The finding supports previous studies conducted on

healthy adult subjects (Wargocki et al, 2000 and Tham and Willem, 2005).

7. CONCLUSIONS

Acceptability of indoor air quality among the young adult subjects working in a simulated office environment improves when outdoor air supply rate is increased. This is not found to be associated with odour intensity or the olfactory sense, which has greater significance to the asthmatic group. Using used ventilation filters in conjunction with high outdoor air supply rate (~18.0L/s/p) seems to elevate the intensity of neurobehavioral-related symptoms, reduce mental activation and decrease text-typing performance. Within the range of outdoor air supply rate of 4.5 to 12.0L/s/p, mental activation increases marginally as shown by the salivary α-Amylase concentration. However, the Tsai-Partington performance test for measuring arousal does not detect the differences in the subjects' arousal level.

REFERENCES

Milton, D.K., Glencross, P.M. and Walters, M.D. (2000). Risk of sick leave associated with outdoor air supply rate, humidification, and occupant complaints. *Indoor Air*, 10(4), 212-221.

Wargocki, P., Wyon, D.P., Sundell, J., Clausen, G. and Fanger, P.O. (2000). The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity. *Indoor Air*, 10, 222-236.

Malmberg, P. (2001). Airway allergy and worklife. *Scandinavian Journal of Work, Environment and Health,* 27(6), 422-425.

Goetzel, R.Z., Long, S.R., Ozminkowski, R.J., Hawkins, K., Wang, S. and Lynch, W. (2004). Health, absence, disability, and presenteeism cost estimates of certain physical and mental health conditions affecting U.S. employers. *Journal of Occupational and Environmental Medicine,* 46(4), 398-412.

Colman, A.M. (2001). *Yerkes-Dodson law.* U.K.: Oxford University Press. Retrieved 28 January 2008 from: http://www.encyclopedia.com/doc/1O87-YerkesDodsonlaw.html

Clausen, G. (2004) Ventilation filters and indoor air quality: A review of research from the International Centre for Indoor Environment and Energy. *Indoor Air*, 14(suppl. 7), 202-207.

Shim, C. and Williams, M.H. (1986) Effect of odors in asthma. *Am J Med*, 80, 18-22.

Kumar, P., Caradonna-Graham, V.M., Gupta, S., Cai, X., Rao, P.N., and Thompson J. (1995) Inhalation challenge effects of perfume scent strips in patients with asthma. *Ann Allergy Asthma Immunol*, 75, 429-433.

K.W. Tham and H.C. Willem (2005) Temperature and ventilation Effects on performance and Neurobehavioral Symptoms of Tropically-Acclimatized Call Centre Operators near Thermal neutrality. *ASHRAE Transactions*, 111(2), DE-05-10-7.

Shusterman, D.J. and Dager, S.R. (1991) Prevention of psychological disability after occupational respiratory exposures. *Occupational Medicine*, 6(1), 11-27.

Bensafi, M., Rouby, C., Farget, V., Bertrand, B., Vigouroux, M., and Holley, A. (2002) Autonomic Nervous System Responses to Odours: the Role of Pleasantness and Arousal. *Chemical Senses*, 27, 703-709.