THE EFFECT OF A PERSONALIZED VENTILATION SYSTEM ON PERCEIVED AIR QUALITY AND SBS SYMPTOMS

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ABSTRACT
Perceived air quality, SBS symptoms and performance were studied with 30 human subjects. Experiments were performed in an office set-up with six workplaces, each equipped with a Personalized Ventilation System (PVS). Each PVS allowed the amount of supply air and its direction to be controlled. Subjects participated in four experiments: (1) PVS supplying outdoor air at 20°C; (2) PVS supplying outdoor air at 23°C; (3) PVS supplying recirculated room air; and (4) mixing ventilation. Room temperature was kept constant at 23°C and relative humidity at 30%. Results showed that the best condition in regard to perceived air quality, perception of freshness and intensity of SBS symptoms was when PVS supplied outdoor air at 20°C. Perceived air quality in this case was significantly better (p<0.01) than with mixing ventilation. Supplying outdoor air by means of the PVS decreased complaints of headache, and improved the ability to think and to concentrate.

INDEX TERMS:
Personalized ventilation, Perceived air quality, SBS symptoms, Improved IAQ, Offices

INTRODUCTION
Numerous studies have associated the quality of indoor air with people’s symptoms and with their performance. It has been shown that poor air quality causes SBS symptoms such as increased prevalence of headache, decreased ability to think, as well as increased dizziness. Providing good air quality, on the other hand, increases occupant’s productivity (Wargocki et al. 1999, Lagercrantz et al. 2000). Furthermore, it has been documented that the quality of inhaled air of low enthalpy (low temperature and humidity) is perceived to be better than when the enthalpy is high (Fang et al. 1988). Mixing ventilation systems dilute pollutants generated indoors by providing clean air and aim to create a uniform quality that is acceptable to persons in the occupied zone. Fanger (2000) suggested instead to supply clean air that is unmixed with polluted ambient air, directly to the breathing zone of each occupant.

Results from a field study (Kroner and Stark-Martin1994) showed that allowing occupants to adjust the parameters of their local environment led to an increase in productivity of 2%. Another study (Bauman et al. 1998) confirmed the positive effect of individual control on overall satisfaction and occupants’ thermal comfort.

The PVS used in the present study combines the benefits achieved from supplying outdoor air with those obtained through individual control of the airflow rate and the direction of the flow from the air supply outlet. The study investigated experimentally the impact of the Personalized Ventilation System on humans when the air was supplied isothermally or cooler than the surrounding, ambient air. The experiment compared the human response to PVS with the response to traditional mixing ventilation.

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METHOD
Thirty human subjects participated in four experimental sessions. There were both male and female students aged 20 –28 years. All but one were healthy, without chronic disease or allergy and were non-smokers. One person reported allergy but the allergen (grass pollen) was not present during the experimental period. Subjects were divided into 5 groups of 6 persons. Each group participated in experiments in the afternoons and was assigned a specific weekday. Experiments were performed in an office set-up with mixing ventilation (Wargocki et al 1999). Six desks with PVS were installed in the office, three desks being placed against two opposite walls. The PVS used in the study consisted of an air supply outlet mounted on a movable arm-duct, thus allowing the position to be changed. Furthermore, the system provided individual control over the airflow rate. Each subject was able continuously to regulate the airflow rate up to 15 L/s. Changes in positioning of the air supply outlet were registered and the preferred airflow rate was recorded continuously. Subjects maintained thermal neutrality by adjusting their clothing. A table was placed in the middle of the office and subjects were asked to be seated around it during breaks.

The conditions during the four experimental sessions were: (1) PVS supplying outdoor air at 20°C; (2) PVS supplying outdoor air at 23°C; (3) PVS supplying recirculated office air; and (4) no PVS, only mixing ventilation. The office space was ventilated with 90 L/s of outdoor air. During sessions 1 and 2 the outdoor air was provided by PVS and mixing ventilation; when a subject chose an airflow rate lower than the designed maximum (15 L/s/person), the complementary amount was supplied to the office by mixing ventilation. Experiment 4 with mixing ventilation was used as a reference. Under all four conditions the room temperature was kept constant at 23°C and relative humidity at 30%. Furthermore, the air quality was modified by introducing a typical pollution source: 64 m² of 20-year-old bouclé carpet that was placed on a rack behind a partition; the carpet was thus hidden from the view of subjects.

Each experimental session lasted 3 hours and 45 minutes. Prior to the four main exposures subjects attended a training session where they were instructed on how to use the PVS and had an opportunity to become acquainted with the experimental procedure. During exposures subjects performed office tasks: first 30 min of proofreading, followed by 35 min of adding numbers on a monitor screen, then 45 min of word processing, 35 min of addition on paper, and finally a second session of 45min word processing. Before and after each task subjects filled in questionnaires displayed on the monitor screen. Questions were related to perceived air quality, thermal comfort, draught sensation and SBS symptoms. Additional paper questionnaires were distributed to assess the air quality in the office, upon first entering the office and during each break. During 5-minute breaks taken in between tasks subjects could drink water or eat digestive biscuits.

Data obtained from subjective measurements were analysed statistically. Normally distributed data were analysed with analysis of variance. Each subject was used as its own control. Furthermore, the Page test for ranking order was performed (Siegel and Castellan 1988).

RESULTS AND DISCUSSION
The acceptability of air as assessed by subjects was transferred into percentage of dissatisfied (PD) using a logit curve fitted to the data obtained by Gunnarsen and Fanger (1992). Table 2 shows the calculated PD with air quality on two occasions: just after entering the office, and at the workstation after approximately 3 min. Due to the pollution source introduced in the office, ca. 50% of subjects were dissatisfied with the air quality upon entering. Adaptation was observed during the first few minutes of occupation. Due exclusively to adaptation PD
dropped in session 4 from 47%, immediately after entering, down to 21.8% after approximately 3 min. With the elapsed time in each experiment further adaptation of the perceived air quality (PAQ) took place. This was observed when subjects moved from their workstation to the middle of the office during breaks between tasks and assessed the air quality at both locations. As a result, the percentage of subjects dissatisfied with the air quality in the office decreased. However, under conditions 1 and 2, subjects were still able throughout the whole experiment to identify the difference between office air and the air they breathed at the workstation. PD was identified as being rather similar for sessions 3 and 4, in which subjects were exposed constantly to office air of the same quality. PD was significantly (p<0.01) lower in sessions 1 and 2 due to the clean outdoor air provided to the breathing zone. PD in session 1 was two times lower than in session 2, due to the temperature of personalized air being 3°C lower. Air was perceived as most fresh in condition 1, then 2, and more stuffy for conditions 3 and 4 (p<0.02). No other factors of generally perceived environment that were investigated, such as noise level or level of illumination differed between conditions.

It was observed that outdoor air provided by PVS at 23°C decreased PD with air quality from ca. 20% (conditions 3 and 4) down to 14.4%. Further improvement in the perception of the air quality and its freshness was obtained by lowering the temperature of the supply air. Outdoor air at the lower temperature of 20°C was perceived as being better than air at 23°C (p<0.01). This finding is in agreement with results obtained by Fang at al. (1998). The intensity of odour perception in the present study, as in the study conducted by Fang, was found independent of the enthalpy of the air. Under all conditions, subject voted their sensation below slight odour.

The results of the present study confirm the conclusions drawn from tests of several air supply devices for PVS performed with a breathing thermal manikin (Melikov et al. 2001), namely that supplying outdoor air directly to the breathing zone substantially increased this fraction in the inhalation air. Therefore potential exists for improving the air quality perceived by occupants.

**Table 2.** Percentage dissatisfied with the air quality.

<table>
<thead>
<tr>
<th>PD, %</th>
<th>Condition</th>
<th>(1) PVS 20°C fresh</th>
<th>(2) PVS 23°C fresh</th>
<th>(3) PVS 23°C recirculated</th>
<th>(4) Mixing ventilation 23°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the office, upon entering</td>
<td>49.1</td>
<td>50.4</td>
<td>51.6</td>
<td>47.0</td>
<td></td>
</tr>
<tr>
<td>At workstation, after ca.3 min</td>
<td>7.3</td>
<td>14.4</td>
<td>19.6</td>
<td>21.8</td>
<td></td>
</tr>
</tbody>
</table>

A better air quality tends to reduce occupants’ complaints regarding SBS symptoms. Thus given tasks are accomplished with less effort and this finally leads to an increase in productivity (Wargocki et al. 1999). This hypothesis was tested on the data obtained with the Page test for ranking order. The same rank of experimental conditions as that for perception of air quality was expected to result for intensity of reported SBS symptoms. The test showed a significant order in the severity of headache (p<0.03) (Figure 2), the ability to think clearly (p<0.01) (Figure 3), and to concentrate (p<0.03) (Figure 5). The same tendency was observed for reported “well being”, subjects felt worst in condition 4 and best in condition 1 (p<0.03) (Figure 4).
The most pronounced symptoms of headache, difficulty to think clearly and to concentrate were reported for mixing ventilation. The intensity of these symptoms was reduced steadily, firstly by providing individual control with PVS in condition 3, secondly by providing outdoor air with PVS in condition 2, and finally by decreasing the temperature of personalized outdoor air in experiment 1. Furthermore, personalized ventilation, by providing occupants with outdoor air and with control over the airflow rate and the direction of the flow, gave rise to greater satisfaction, which was expressed by a better frame of mind – well-being.

**Figure 2.** Reported SBS symptoms. Intensity of headache

**Figure 3.** Reported SBS symptoms. Ability to think clearly

**Figure 4.** Well-being
Subjects also assessed their self-performance. They had to put most effort into fulfilling tasks in the session with mixing ventilation and least in the session with PVS supplying outdoor air at 20°C. This trend was tested and turned out to be significant for two tasks: addition on computer (p<0.04) and the first text typing task (p<0.01). The same tendency was evident, however, for addition on paper (p<0.11) and the second session of text typing (p<0.17).

The page test for expected trend was also applied to the data obtained from performance tests. Learning effect was observed in the text typing tasks and computer addition. However, no such effect was found in the case of addition on paper. In order to eliminate the learning effect, data were normalized by relating each individual score to the group average score. Analyses were based on the normalized score data. Although in subjects’ self-performance the advantages introduced by PVS had a significant positive effect on lowering the effort exerted during tasks, no significant effect on subjects’ performance was observed between conditions studied. It should be taken into account, however, that the subjects were given only one training session with the PVS in order to become familiar with the system. This amount of time was probably insufficient, for subjects spent a substantial part of the time on adjusting the airflow rate and the direction of the flow during experiments with PVS. This has thus delayed their work during the present, quite short, experiments. When people get used to the system such delays are not expected. It should also be considered that only one PVS was investigated. More sophisticated systems with modified air supply outlets need to be developed. Providing occupants with individual control of the supply air temperature should also be considered.

CONCLUSIONS
The present investigation with a personalized ventilation system showed that:

- PVS, when supplied with outdoor air isothermally at 23°C, improved the perceived air quality and decreased SBS symptoms in comparison with mixing ventilation.
- PAQ was further improved and SBS symptoms decreased when the temperature of the personalized air was decreased to 20°C.
- Further studies are recommended with other personalized ventilation systems and with individually controllable temperature of the supply air.

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REFERENCES