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POLLUTION SOURCE CONTROL AND VENTILATION IMPROVE HEALTH, COMFORT AND PRODUCTIVITY

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ABSTRACT

Control of indoor pollution sources and ventilation are both means of improving indoor air quality. Three independent experiments have recently documented that removing a pollution source or increasing the ventilation rate will improve perceived air quality, reduce the intensity of several Sick Building Syndrome (SBS) symptoms and improve the productivity of office workers. In these experiments, the performance of simulated office work (text typing, addition and proof-reading, all typical office tasks requiring concentration) improved monotonically as the proportion dissatisfied with the air quality was reduced by either measure. The quantitative relationship was 1.1% change in performance per 10% dissatisfied, in the range 25-70% dissatisfied, or 0.5% change in performance per 1 decipol (dp), in the range 2-13 dp. Significant performance improvements occurred only when the intensity of general SBS symptoms such as headache and difficulty in thinking clearly were significantly reduced, which implies that this was the mechanism of causation. The performance of simulated office work increased monotonically with decreasing pollution load, a 1.6% increase in performance for each two-fold decrease of pollution load in the range 0.3-2 olf/m^{2}floor, and with increasing outdoor air supply rate, a 1.8% increase in performance for each two-fold increase in the outdoor air supply rate in the range 0.8-5.3 L/s per olf. As these results clearly justify increased initial and operating costs, future developments in HVAC technology may include "personalized air", new ways of improving the quality of supply air (e.g., by filtration), more extensive use of heat recovery from exhaust air and systematic selection of low-polluting building and furnishing materials.

Keywords: Ventilation; Indoor pollution sources; Indoor air quality; SBS; Productivity

INTRODUCTION

It is well documented that thermal conditions within the thermal comfort zone can reduce performance by 5% to 15%, but little is known as regards direct effects of the air quality on human performance in non-industrial environments, especially in offices [1]. Laboratory exposures to toluene (an abundant indoor air pollutant, see Fig. 1 and [2]) at 100 ppm (380 mg/m^3) [3] and to a mixture of 22 common indoor air pollutants at concentrations up to 25 mg/m^3 [4] were shown to reduce the performance of diagnostic psychological tests. However, these two experiments were carried out on selected indoor air pollutants and at concentrations considerably higher than those which typically occur in office buildings [2]. Cross-sectional studies in classrooms in which typical indoor air pollutants from building and furnishing materials and occupants may be presumed to have reached quite high concentrations due to low air change rates that allowed carbon dioxide (CO_2) concentrations to reach levels up to 4000 ppm demonstrated an association between increased CO_2 level and reduced performance of diagnostic psychological tests by pupils >15 years old [5]. The possibility of confounding between classroom air change rates and other factors capable of having caused the observed effects, such as classroom air temperatures or possible socioeconomic differences between the collection areas of different schools, was not addressed. It should also be noted that the dependent variables in all of the above experiments [3,4,5] were diagnostic psychological tests of short duration, which may not predict the performance of typical office work over time. In experiments carried out for the New York State Commission on Ventilation [6] in the 1910's, the performance of simulated office work (including addition and typing) could not be shown to be significantly reduced by low ventilation rates resulting in CO_2 concentrations of 3000-4000 ppm, which were the levels measured in the least well ventilated classrooms in the cross-sectional study cited above [5]. The absence of an effect of low ventilation in the New York experiments could have been due to the presence of sources of pollution in the HVAC system itself, as this would result in a lack of improvement in overall air quality even though CO_2 concentrations and bioeffluents were reduced by the increased ventilation rates used in the control exposures.

It seems reasonable to assume that people who do not feel very well will not work very well. Support for an effect on performance due to the symptoms of distress that are caused by poor air quality is provided by a field investigation in an office building which demonstrated that office workers who had reported any SBS symptoms that day performed significantly less well on diagnostic psychological tests that were administered intermittently throughout the working day by a computer [7], and by the increased SBS symptom intensities that were also associated with high levels of CO_2 in the classroom study cited above [5]. Other possible mechanisms for an effect of poor air quality on performance include distraction by odour, sensory irritation, allergic reactions, or by direct toxicological effects.

The objective of the present paper is to summarize the results obtained in three new and closely related experiments, all of which indicate that poor air quality has a negative effect on the performance of simulated office work and that an increase in the intensity of general SBS symptoms is the causative mechanism, and to discuss the implications of these results for building and HVAC system design.

NEW RESULTS ON THE EFFECTS OF AIR QUALITY ON PERFORMANCE

In three independent field intervention experiments, the air quality in normal offices was altered while the health, comfort and productivity of the occupants were measured [8,9,10]. Air quality was altered by means of one or the other of two types of intervention, either: 1) by decreasing the pollution load, i.e. by physically removing a pollution source without informing the subjects, always maintaining an outdoor air supply rate of 10 L/s per person, which was the intervention used in offices situated in two different countries [8,9]; or 2) by increasing the outdoor air supply rate from 3 to 10 or to 30 L/s per person, thus producing air change rates of 0.6, 2 or 6 per hour in one of these offices, with the same pollution sources always present [10]. A major pollution source in all three studies was the same 20-year-old carpet, present behind a screen in a quantity corresponding to the floor area of the office in which each exposure took place, but the rather innocuous building, floor and furnishing materials, and the bioeffluents emitted by the subjects themselves were of course always present. Although the carpet was taken from a building with a history of SBS problems [11], Fig. 1 shows that the resulting air pollutant concentration levels were typical of those currently found in office buildings worldwide [4]. Temperature, relative humidity, air velocity and noise level were kept constant, independent of the intervention. Ninety female subjects were exposed to different levels of air quality, 30 in each study. They could not see whether the source was present or perceive changes in noise level or air velocity when the ventilation rate was changed, and they remained thermally neutral by adjusting their clothing. In all three studies, subjects performed simulated office work during 4.5-hour exposures to different air quality levels and assessed the perceived air quality and the intensity of their SBS symptoms, in a repeated-measures design balanced for order of presentation. Simulated office work comprised text typing, proof-reading, addition and creative thinking, all being typical office tasks. The performance of these tasks was used to estimate productivity. The perceived air quality in the offices was assessed by asking the subjects to rate the acceptability of the air quality upon entering the office. The intensity of a comprehensive list of specific and general SBS symptoms was indicated by the subjects at intervals throughout each exposure by marking visual-analogue scales (VA-scales).

The main results of the three studies are presented in Figs. 2 and 3. Fig. 2 shows that removing a pollution source from a space or increasing the ventilation rate significantly improved perceived air quality, significantly reduced the intensity of general SBS symptoms such as headaches and difficulty in thinking clearly, and significantly improved the performance of simulated office work (text typing, addition and proof-reading). Fig. 3 shows that increasing the ventilation rate from 3 to 10 L/s per person had a positive effect on creative thinking. Based on the data presented in Fig. 2, the relationships presented in Figs 4, 5 and 6 were derived. They show that improving air quality, either by reducing the pollution load or by increasing the ventilation rate, improves the performance of office tasks. Air quality in Fig. 4 is expressed either as the % dissatisfied with the air quality or in decipol (dp), which is a quantitative measure of perceived air quality based on sensory assessments [13]. The pollution load in Fig. 5 is expressed in olf units: the sensory air pollution source strength in olf is calculated from air quality levels in decipol and the measured ventilation rate, using the comfort model [13]. The ventilation rate in Fig. 6 is calculated as the reciprocal of the perceived air quality expressed in pol (tenfold dp). The quantitative relationships between air quality, sensory pollution load, ventilation rate and the performance of office work are respectively: (1) a 1.1% increase in performance for every 10% reduction in the proportion of dissatisfied with the air quality, in the range 25-70% dissatisfied, or a 0.50% increase in performance for every decrease of 1 dp, in the range 2-13 dp (Fig. 4); (2) a 1.6% increase in performance for every two-fold decrease of pollution load in the range 0.3-2.0 olf/m^{2}floor (Fig. 5) at a ventilation rate of 10 L/s per person; (3) a 1.8% increase in performance for every two-fold increase of ventilation rate in the range 0.8-5.3 L/s per olf (Fig. 6). It is instructive to note that this range of ventilation rate conditions was achieved when outdoor air of high quality was supplied at the rate of 3-30 L/s per person. The difference is due to the presence of other sources of pollution, in addition to people. As it happens, 5.3 L/s per olf was achieved by removing the extra pollution source while supplying outdoor air at the rate of 10 L/s per person, not by supplying 30 L/s per person with the extra

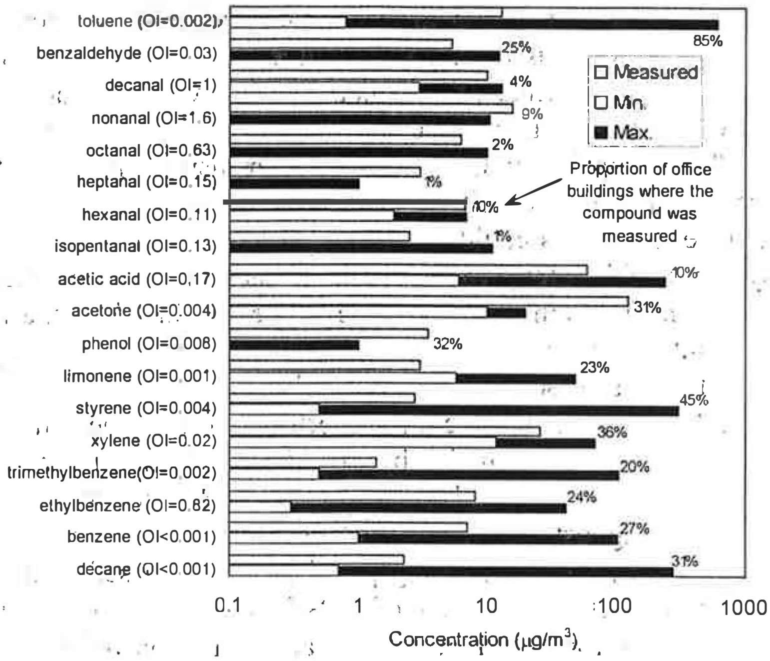

Fig. 1. Comparison of concentrations of chemicals measured in the office with pollution source present [8] with the range of oconcentrations (min.-max.) measured in 22 studies in 209 office buildings when the chemical was detected [2]. Odour index (OI), the ratio of the concentration measured in the experiment to the odour detection threshold concentration [12], is given in brackets for each chemical

pollution source present.

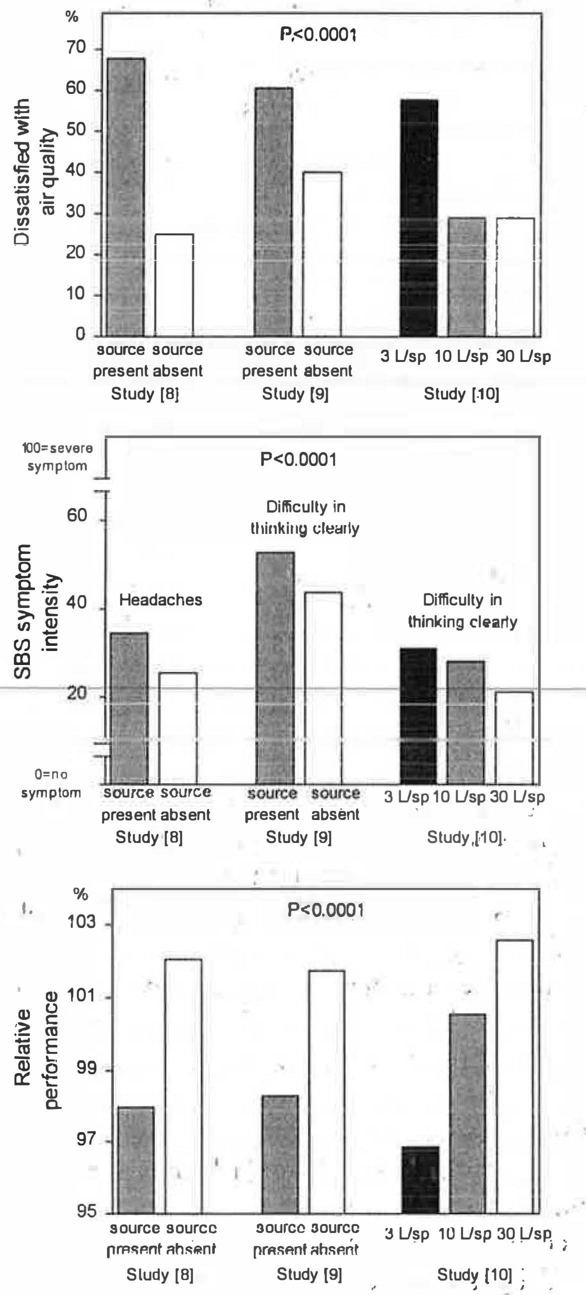

Fig 2. Perceived air quality, intensity of general SBS symptoms and relative performance of office tasks as a function of the presence or absence of the pollution source, or the outdoor air supply rate

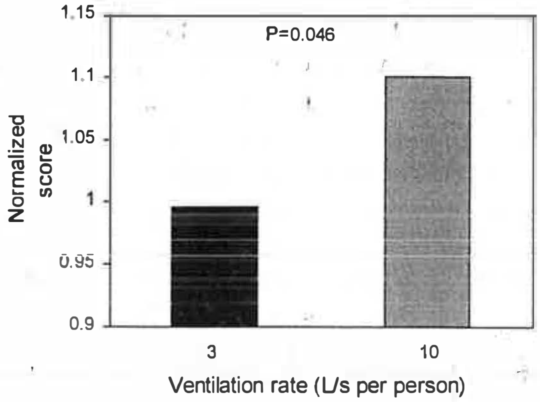

Fig 3. Normalized score on the originality-weighted test of creative or open-ended thinking, as a function of the outdoor air supply rate [10]

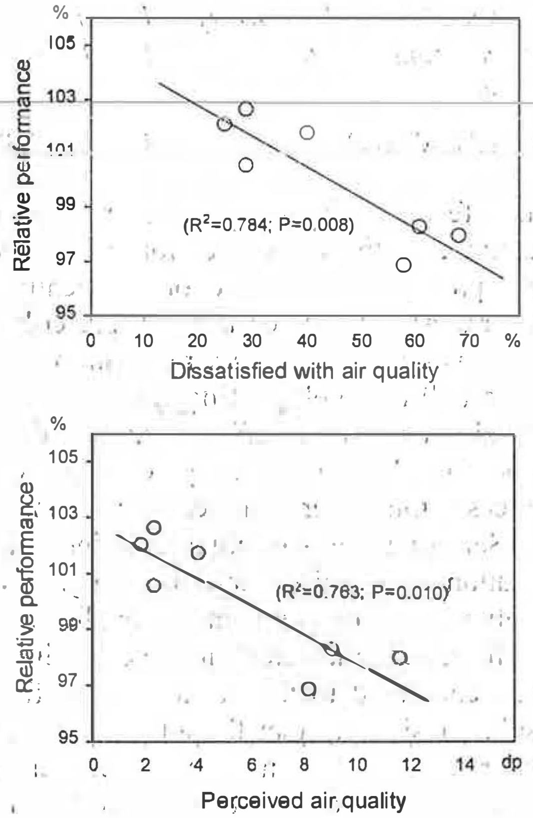

Fig 4. Relative performance of office tasks as a function of the air quality

Figs 2 to 6 indicate that improving air quality by either reducing the pollution load in a space or increasing the outdoor air supply rate has a positive effect on health, comfort and productivity. The possible mechanism of the observed results is indicated in Fig. 2: poor air quality increased the reported intensity of general SBS symptoms (headaches, difficulty in thinking clearly), effects which are expected to reduce the performance of any kind of mental work. Fig. 1 indicates that aldehydes, organic acids and ethylbenzene were present and had odour indices close to 1, i.e. they were present in perceptible concentrations. It is reasonable to assume that these pollutants may be responsible for the observed decrease in perceived air quality when the pollution load was increased. However, as only the 25 VOCs with the highest concentrations were measured, and neither particles nor microorganisms were quantified, this does not amount to support for the hypothesis that SBS symptom intensity and performance were exclusively mediated by odour perception, as other non-perceptible and non-measured pollutants may have contributed to cause the observed effects.

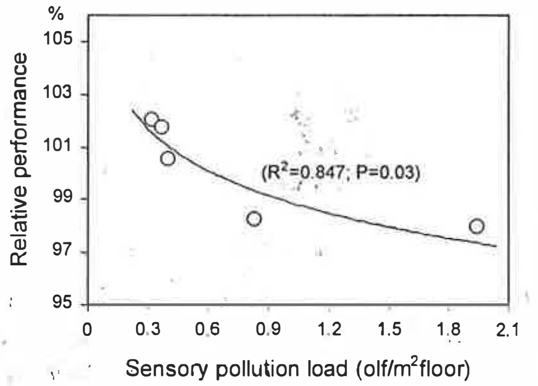

Fig. 5. Relative performance of office tasks as a function of the sensory pollution load at a constant ventilation rate of 10 L/s per person

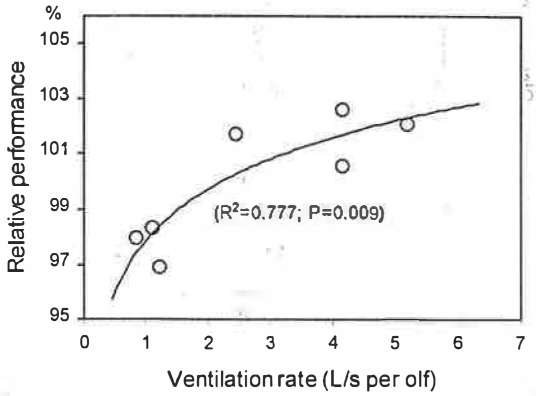

Fig. 6. Relative performance of office tasks as a function of the outdoor air supply rate

IMPLICATIONS FOR BUILDING AND HVAC SYSTEM DESIGN

The effects of air quality on human performance [8,9,10] presented above are similar in magnitude to those observed for the effects of thermal conditions on human performance [1]. They provide a strong economic incentive for designing indoor environments with air of a higher quality than the minimum prescribed by the present ventilation standards. High levels of air quality will not only result in improved productivity but will also promote health and comfort. With intelligent design of the building envelope and the HVAC system, and with careful selection of building and furnishing materials, the provision of good air quality indoors need not necessarily cost more or require more energy. Reducing indoor pollution sources is thus a very efficient way of improving indoor air quality.

Selecting low-polluting building and furnishing materials will result in decreased pollution load. This method is strongly recommended by CEN CR 1752 [14] as it need not involve extra costs, especially if applied at the building design stage.

Increasing the ventilation rate will incur extra costs. However, the additional costs will be small compared to the economic benefits obtained by the increased productivity that will result, considering that the total operating costs for HVAC are normally well under 1% of labour costs. Efficient energy recovery systems can often minimize the extra energy consumption used to increase ventilation rates. High quality of the breathing air can even be obtained at low ventilation rates by using "personalized air" systems [15,16] instead of traditional HVAC systems which aim to achieve full mixing. In such systems small amounts of fresh and cooled air are supplied directly to the breathing zone of the occupants so that a high quality of inhaled air is obtained. High quality of breathing air can only be achieved by assuring high quality of air supplied by HVAC systems, which sometimes in themselves can be a source of pollution [17,18,19]. Effective maintenance and cleaning of HVAC systems is thus essential. New developments in HVAC technology should include innovative ways of filtering room and supply air and new methods of air-conditioning.

CONCLUSIONS

- The performance of office work has been shown experimentally to be a function of air quality. This effect appears to be mediated by effects on the subjectively reported intensity of general rather than specific SBS symptoms.
- Improving air quality by pollution source control or increased ventilation is economically justified since it is beneficial for human health, comfort and productivity. Consequently, future buildings should be low-energy and low-polluting. This goal can be achieved by proper selection of building and furnishing materials, new ways of filtering the air supplied by HVAC systems, personalized air systems, and efficient heat recovery from exhaust air.

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