Multifunctional analysis of health problems in office spaces

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Objectives Because more than half of the employees in the offices of a new building complained of conditions attributed to the work environment, a case study was carried out to determine the possible cause.
Methods The building in which the study was carried out was constructed in accordance with the most up-to-date expertise in ecological construction. A survey of the employees produced frequent mention of the following complaints: headache, tiredness, complaints concerning the ear, complaints concerning the nose and throat area, bronchitis, skin and eye irritation, and tension in the neck. The measured air exchange did not meet the recommended value of 1.4 l/hour. High concentrations of volatile organic compounds (VOC) and carbon dioxide were measured.
Results The results of measurements of the concentration of ultrafine particles were unusual. The source of VOC was the cleaning agent, and the high level of carbon dioxide was caused by insufficient ventilation.
Conclusions Mechanical ventilation appears to be essential for tight buildings. Noise reduction measures in open-plan offices are necessary.

Key terms case study; noise; open-plan office; ultrafine particles; ventilation; volatile organic compounds.

This is a case study carried out in the offices of a new building where more than half of the employees complained of conditions attributed to the work environment. The building was constructed in accordance with the most up-to-date expertise in ecological construction and was naturally ventilated. For safety reasons, the ceiling-high windows could only be opened slightly. A polyurethane adhesive was used for bonding. Only low-emission and, to some extent, certified materials were used for the interior design (eg, dividing walls, carpets, and paints). Certificates were available for the furniture. They confirmed that the furniture met European standards and directives (ie, that it was free of formaldehyde emissions). The open-plan offices were linked by a passageway, where copiers and printers were located. The passageway can be shut off on both sides by sliding doors.

Communication strategy and inspection

In conjunction with the employees, industrial medical experts, and safety personnel, a basic survey was conducted using the graded-modular measuring and assessment concept and checklists of the German Federation of Institutions for Statutory Accident Insurance and Prevention (1). When the building was inspected, evaluations of the building status, fixtures, hazardous substances, and ergonomic modules were carried out, complaints from employees were analyzed, and existing certificates and datasheets were checked. Altogether 65% of the affected people took part in the survey.

Determining indoor-air parameters

It was decided to measure air quality, noise, total volatile organic compounds (TVOC), carbon dioxide, aldehydes, air exchange, particle number concentration, and particle mass concentration. In Germany, guideline or target values are available as recommendations for interiors for some of these parameters. The rooms were not ventilated for 24 hours prior to the samples being taken. In accordance with the VDI 4300 guideline (2), samples of volatile organic compounds (VOC) were collected using NIOSH (National Institute for Occupational Safety and Health)-type activated carbon tubes for nonpolar components, and NIOSH-type silica gel tubes for polar components. Air samples for the measurement of aldehydes were collected on treated silica gel cartridges (Waters

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Corporation, Milford, MA, USA). Carbon dioxide was measured with a two-beam infrared spectrometer. The particles were collected using a controlled pump with a flow rate of 4 m³/hour, and the particle mass concentration was determined gravimetrically. The number of ultrafine particles in a size range from 10 nm up to around 1000 nm was calculated using a TSI-model 3007 condensation particle counter (TSI Incorporated, Shoreview, MN, USA). In one of the two open-plan offices, the air-exchange rate was calculated when the windows were open and again when they were closed. The calculation involved introducing a defined volume of sulfur hexafluoride into the room and continuously measuring the fall in concentration at various points in the room. In line with provisions from VDI guideline 4300, all of the rooms were ventilated normally on the day before the measurements, then the windows were closed over the night and were not opened while the samples were taken.

Survey of employees

The survey of the employees produced frequent mention of the following complaints: headache, tiredness, complaints concerning the ear, complaints concerning the nose and throat area, bronchitis, skin and eye irritation, and tension in the neck. The symptoms occurred weekly during workhours after the workers moved into the offices in the new building and disappeared on weekends and while on vacation. Disturbance from noise was more frequently mentioned than disturbance from air quality or odors. The results are shown in figure 1. The symptoms with a high percentage of mention, such as headache and eye irritation, frequently occur with problems indoors. More than 50% of the respondents reported high levels of work strain without mentioning changes in the structure of the work or responsibility. Work stress can also be caused by noise exposure, which leads to reduced concentration and thus also to higher work strain.

Evaluation of ergonomic parameters

Noise measurements produced a value of 73 dB (A) because parts of the dividing walls had been replaced by cupboards and the opposite side of the room was taken up by ceiling-high windows. There were no noise reduction devices in the room. Background noise in offices is recommended to be 30–45 dB (A) (3).

Disturbance from air quality or odors appeared to be low.

Hazardous substances and dust

Carbon dioxide is produced in interiors by people breathing. The concentration varies according to the location, number of people, and time of day. It usually rises during the day and is an indication of the efficiency of the ventilation. In the current example, values of up to 1540 ppm were measured in all of the office spaces when the windows were closed. The carbon dioxide concentration increased only slightly during the entire measurement period, as shown in figure 2. After the windows were opened, it fell to around 400 ppm. It is generally believed that the guideline value should be a maximum concentration of 1000 ppm (4). VOC were found in all

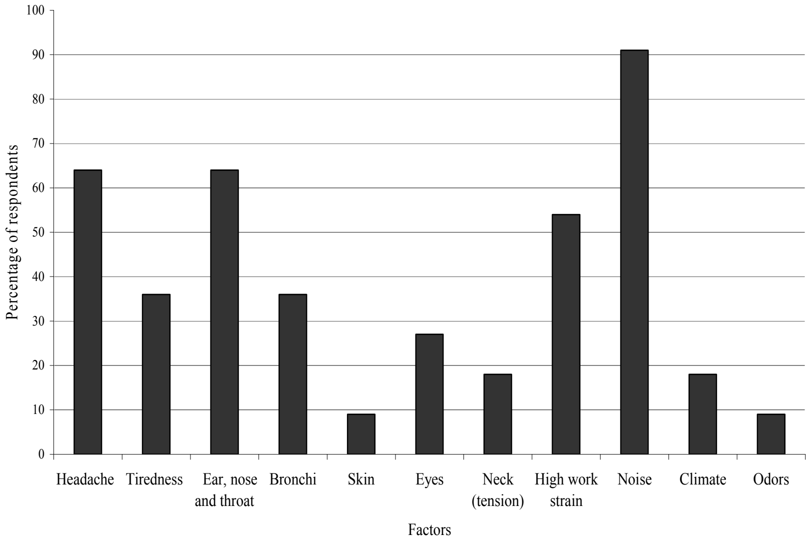

Figure 1. Results of the evaluation of the individual survey of employees (values above 50% mention indicate a problem building).

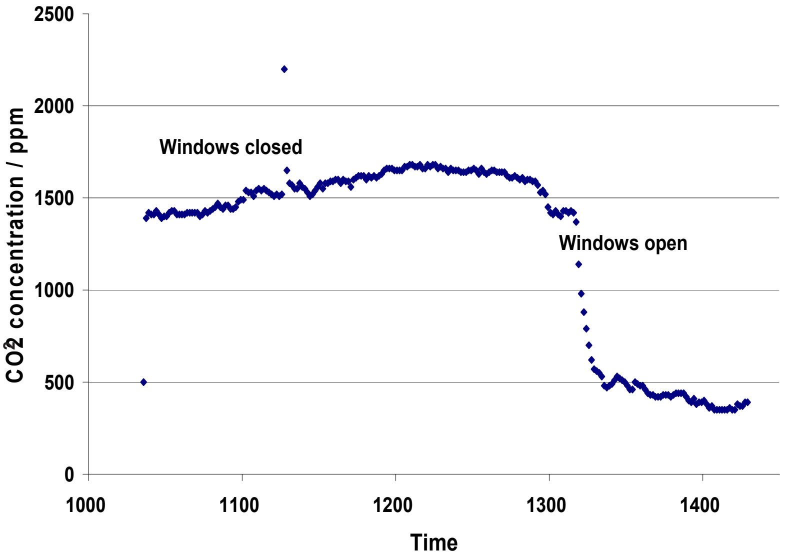

Figure 2. Progress of carbon dioxide (CO_2) concentration when the windows were closed.

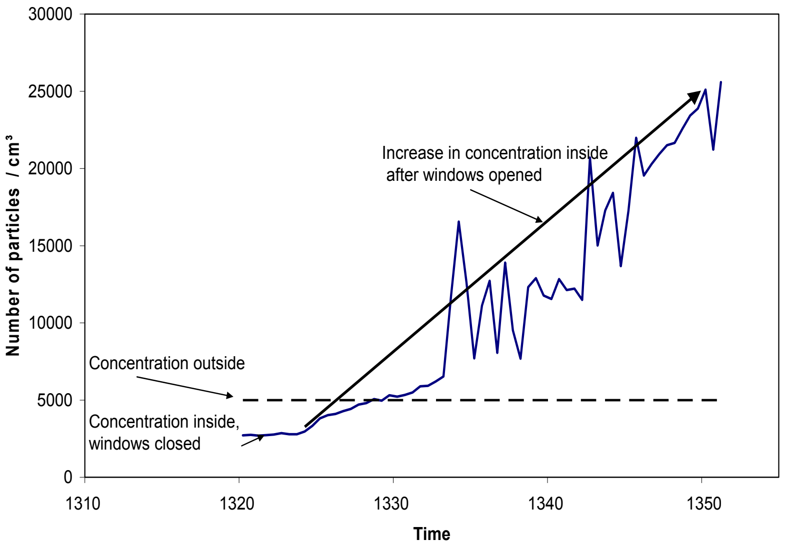

Figure 3. Particle concentration before and after ventilation.

of the office areas in a concentration range from 840 to 975 µg/m. The concentration of analyzed aldehydes was 350 µg/m³. Formaldehyde (mean value 0.055 ppm) and acetaldehyde were the main constituents. Formaldehyde is normally found in office buildings at a concentration of 0.01 to 0.03 ppm.

WHO recommends a maximum formaldehyde concentration of 0.1 ppm (5) for interiors.

High concentrations of alkanes (n-methylbutane), siloxanes (decamethylcyclopentasiloxane), terpenes, and alcohols indicate that cleaning agents are the sources. After the cleaning agent being used was examined, it was discovered that a cleaning agent for the sanitary facilities was wrongly used in the office areas. After the cleaning agent was no longer used, the room users' well-being improved. The concentration of respirable dust was under 60 µg/m³ and thus in the normal range.

Notable problems occurred regarding the concentration of ultrafine particles (<1 µm). There were around 3000 particles/cm³ when the windows were closed, and this level represents a normal value. The concentration outdoors was 5000 particles/cm³. After the windows were opened, the concentration in the room slowly rose to 30 000 particles/cm³ (figure 3). Examination by means of a portable condensation particle counter showed a formation of particles inside the room near the slightly opened windows. No other particle sources could be found. This effect was reproduced in a later measurement. We assume that, by bringing together ozone (outside air concentration 70 µg/m³) with the outside air, chemical reactions occur with, for example, limonene, pinene, carene (concentration 30 µg/m³), or other compounds, such as ionene, terpineols, and esters of acetic acid, which were constituent parts of the used cleaning agent. However, it is unclear whether the observed particle formation effect was connected to the health complaints. These effects have been reported by several authors (6–9), but we have not examined them in more detail.

Wolkoff et al (6) reported that ozone reacts with certain VOC to form gaseous oxidation products and secondary aerosols, which may contribute to sensory irritation. Sarwar et al (7) reported that reactive oxidation products attach themselves to ultrafine dust particles; such attachment can result in larger measurable secondary particles. The simultaneous cooling of indoor air by cooler outside air appears to accelerate this process. Baltensperger et al (8) recorded polymerization and oligomerization reactions in the air. Secondary organic aerosol (SOA) formation from the photooxidation of an anthropogenic (1,3,5-trimethyl-benzene) and a biogenic (a-pinene) precursor was investigated in a new smog chamber at the Paul Scherrer Institute (Villingen, Switzerland). Stridh et al (9) found a sudden increase in the number of particles belonging to the smallest classes in Swedish buildings.

Ventilation and air exchange

Ventilation and air exchange are also key factors in indoor climate. The high carbon dioxide concentration (figure 2) already showed that the air exchange was insufficient. The measurements with sulfur hexafluoride when the windows were closed produced air exchange figures of 0.47 l/hour and 0.36 l/hour. Air is exchanged with neighboring rooms to a certain extent at least. Effective air exchange with outside air is even lower. The windows can only be partly opened due to architectural requirements. With windows opened as wide as possible, an air exchange value of 3.8 l/hour was recorded. However, this value depends on temperature conditions and outdoor wind speed. During the measurement, the outdoor wind speed was below 1 m/s, the temperature was 14°C. When the wind is still, lower values are also possible. The target for the offices is an air exchange of 1.4 l/hour. This air exchange does not take into account building-related emissions of pollutants. To achieve the necessary air exchange, the windows in the office areas studied should be kept at least half-open during workhours.

Concluding remarks

Using low-emission building materials and ecological, energy-saving construction can lead to health problems in office spaces if not all possible factors are taken into account. Mechanical ventilation appears essential for buildings with a high level of insulation even though studies show that a rise in the sick building syndrome can be observed for air-conditioned or mechanically ventilated rooms. Constant ventilation using windows is not possible, particularly at cold times of the year, and can lead to noise pollution from traffic and industrial and aircraft noise. Cleaning agents are a constantly recurring and frequently unrecognized source of VOC. Incorrectly used or unsuitable cleaning agents can lead to problems in office spaces. In some cases, cleaning agents contain allergenic ingredients that can accumulate in office spaces. For office spaces, the use of low-emission cleaning agents is recommended. Noise-reduction measures in open-plan offices are essential.

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