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# EUROPEAN AUDIT STUDY IN 56 OFFICE BUILDINGS: CONCLUSIONS AND RECOMMENDATIONS

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## INTRODUCTION

Fifty six office buildings in nine European countries were audited during the heating season of 1993-1994 (1). The audits were performed according to a standard procedure, within the frame of the "European Audit project to optimize indoor air quality and energy consumption in office buildings", sponsored by the European Community through the Joule II programme. The main aim of this EC-Audit was to develop assessment procedures and guidance on ventilation and source control, which help to assure indoor air quality and optimize energy use in office buildings. 15 institutes from 11 countries (The Netherlands, Denmark, France, Belgium, United Kingdom, Greece, Switzerland, Finland, Norway, Germany and Portugal) participated.

By determining the pollution load (chemically and sensory), the ventilation performance and the energy consumption, and by identifying the pollution sources, recommendations can be made to avoid excessive energy consumption and ensure air quality by source control and ventilation. A common agreed Europe-wide method to investigate indoor air quality in office buildings, including a common agreed European questionnaire and walk-through survey checklist were developed (2).

This paper presents the general results and recommendations of the audit in 56 buildings in Europe. Detailed results and discussions can be found in the final report (1).

## PROCEDURE

In nine countries, six or more office buildings were selected. Measurements were performed at five selected locations in each building. The buildings were studied while normally occupied and ventilated to identify the pollution sources in the spaces and to quantify the total pollution load caused by the occupants and their activities and the ventilation systems. The investigation included physical and chemical measurements, assessment of the perceived air quality in the spaces by a trained sensory panel, and measurement of the outdoor air supply to the spaces. The physical and chemical measurements in the spaces included measurements of noise, concentrations of carbon dioxide ($CO_2$), carbon monoxide (CO), total volatile organic compounds (TVOC), and the thermal parameters: operative temperature, air temperature, relative humidity and air velocity. Airflows between the selected spaces and adjacent spaces were measured when necessary. Additional measurements in the adjacent spaces included measurements of CO, $CO_2$ and TVOC and assessments of the perceived air quality. In the mechanically ventilated buildings the perceived air quality of the supply air in the five selected spaces were assessed by the sensory panel. At one of the five selected locations of each building the measurement further comprised measurement of individual volatile organic compounds (VOC), and of airborne particulate matter. All chemical measurements were also performed outdoors. A questionnaire for evaluating retrospective and immediate symptoms and perceptions was given to the occupants of the buildings. The building characteristics were described by use of a check-list. The annual energy consumption of the buildings and the weather conditions were registered.

## GENERAL RESULTS

### *Indoor air quality and energy consumption*

No contradiction between low energy consumption and good indoor air quality was found. Hence, a potential exists for optimizing indoor air quality without consuming more energy.

No correlation between energy consumption and outdoor airflow rate was found. This indicates that in general energy is mostly used for other purposes than ventilation.

No systematic regional differences were found in Europe concerning IAQ parameters, occupant responses or energy consumption.

### *Indoor air quality*

The outdoor air change rate of the audited rooms averaged 2.5 $h^{-1}$. The average outdoor airflow rate was 1.9 $l/s.m^2$ or 25 l/s.person. The average TVOC concentration in $\mu g/m^3$ toluene was 337, the mean particulate matter concentration was 111 $\mu g/m^3$, the $CO_2$ concentration 700 ppm and the CO concentration below 1 ppm. These values meet the requirements in existing national standards and European guidelines (3).

27% of the occupants found the indoor air quality not acceptable at the time of the building audit and 32% found the indoor air quality not acceptable during the month preceding the audit. In all buildings the air was found to be dry by the occupants. In half of the buildings the air was perceived to be on the stuffy side. The indoor air was not perceived as strongly odorous by the occupants. (The average response rate of all occupants in the 56 audited buildings for the questionnaires was 79%).

On the day of the building audit the three most prevalent building-related symptoms were dry skin (32%), blocked or stuffy nose (31%), and lethargy or tiredness (31%). The three most prevalent building-related symptoms for the month preceding the building audit were lethargy or tiredness (52%), headache (42%), and dry eyes (39%).

The mean number of building-related symptoms on the day of the audit was approximately two out of a list of twelve symptoms, whereas the mean number of building-related symptoms for the month preceding the audit was approximately three out of the same list of twelve symptoms.

The mean perceived air quality assessed by trained sensory panels in the selected spaces was approximately 6 decipol for office air, 4 decipol for supply air and 2 decipol for outdoor air.

The most important pollution sources in the audited buildings were the materials and furnishing in the offices and the ventilation system in the buildings. The occupants were less significant pollution sources. The mean total sensory pollution load for the offices (including buildings materials, ventilation systems, occupants and previous and present smoking), was 0.7 olf/m$^2$. The occupants corresponded to 0.1 olf/m$^2$ and 0.3 olf/m$^2$ came from the ventilation systems (including in some cases previous smoking through recirculation). The total mean chemical pollution load for the offices (including buildings materials, offices, occupants, ventilation systems and previous and present smoking) was 0.3 µg TVOC/s·m$^2$.

No relation was found between sensory and chemical pollution loads or perceived air quality and TVOC-levels. Some specific components (VOCs) have a high sensory effect, while others have not. Total volatile organic compounds might therefore not correlate with the sensory evaluations as is also the case for semi-volatile compounds or particulate matter and attached compounds, which were not characterized in this study.

Identified pollution sources comprised materials and furnishing in the office environment, ventilation system, occupants, tobacco smoking and outdoor pollution. The following contributors were suggested: flooring, glues, paints, wax, office machines, cleaning agents, filters, humidifiers, heat exchangers, ducts, present and previous tobacco smoking, consumer products, outdoor traffic and industrial pollution.

The mean perceived air quality showed significant correlation with the measured ventilation rates, which implies that buildings with high ventilation rates had better perceived air quality than other buildings.

The mean perceived air quality assessed by sensory panels giving the unadapted impression of the air quality did not show correlation with occupants' health and their acceptability of the air quality. For this the following should be considered: the perceived air quality is the initial impression of a guest visiting the building, whereas the occupants' perception is adapted to the environment. Differences in population make a comparison between buildings difficult. The perceived air quality was measured at five locations whereas occupant responses were related to the whole building. Furthermore, a relation between the perceived air quality and the building-related symptoms at the time of the audit was not necessarily expected, since most odorous pollutants are not necessarily a health risk and most individual measured and identified compounds were far below the health risk limits. Poor indoor air quality is not necessarily a hazard to the occupants' health.

The measured operative temperature (22.5°C) and air velocities (mean 0.08 m/s) met in general recommendations in the thermal comfort standard (CEN 27730) (4) and recommendations in prENV 1752 (5). In general the occupants felt slightly warmer than neutral. The operative temperature found neutral by the occupants was 21.8°C, which agrees accurately with the 22.0°C predicted by the PMV-model for winter conditions in offices. The average noise level was 47 dB(A).

The measurements performed within this project showed that the mean outdoor air supply was 25 l/s.person, which in general meets the recommendations in the CEN prENV 1752 pre-standard (5). However, the figures in the pre-standard assume that new buildings are designed using low-pollution materials and furnishing, and fresh air from outdoor and from the ventilation system.

*Energy consumption*

The mean energy consumption per gross heated floor area was 1100 MJ/m$^2$ per year. The yearly energy consumption per gross heated floor area varied by a factor 7 for the least energy consuming building to the most energy consuming building which shows a large theoretical economy potential as well as a great diversity of conditions for the different buildings within each country and for the different countries.

One half of the energy was used on electricity, the other on fuel divided equally between district heating, heating oil and natural gas.

Energy data were often difficult to obtain from the building management because the energy consumption was not known in details. This indicates that energy consumption is often of less importance to management and only represent a minor part of the running costs of the building.

Energy consumption of the buildings audited in the North European countries was not higher than in the buildings audited in the other European countries, which seems to indicate that energy consumption has been adapted to national standards and outdoor conditions.

Energy consumption varied strongly from building to building. In practice, it depends more on planning, construction, and management than on climate, building type or HVAC systems. It is hence possible to make low-energy buildings with different architectures and various HVAC systems.

## DISCUSSION AND RECOMMENDATIONS

*Energy and IAQ*

One of the challenges for this study was to relate energy consumption and the indoor air quality, and to investigate the possibility of optimizing both parameters at the same time. The energy consumption varied substantially from building to building. The indoor air quality measured as perceived air quality, TVOC concentration and occupants' responses also varied significantly from building to building. No contradiction between energy consumption and IAQ was found, in fact some of the audited buildings showed both good indoor air quality and low energy consumption which demonstrates a significant potential for improved indoor air quality without consuming more energy. Good building design, including ventilation systems, and source control to reduce the strength of pollution sources and the decrement of heating/cooling loads are the key words.

*Source control*

The audited European office buildings in general showed rather poor indoor air quality, as perceived by the sensory panels, with some dissatisfaction among the occupants in spite of the high ventilation rates compared with existing national European (and North American) standards. These ventilation standards and guidelines have considered the occupants to be the only source of pollution in the indoor environment. However, this study clearly shows that the occupants are a less dominant pollution source and that sources of pollution in the audited European office buildings comprised mostly building materials and components in the ventilation systems. It is therefore necessary to acknowledge the building including the ventilation system as a pollution source. To improve indoor air quality without consuming more energy, source control should be applied to the materials, the systems and activities (e.g. smoking).

Source control is the first priority instead of dilution of pollutants by ventilation or by cleaning the air. By reducing pollution sources, e.g. by selection of low-polluting floor covering, indoor air quality may be maintained or even improved at lower ventilation rates. Manufacturers of building materials and furnishing should be encouraged to provide information on their products so engineers and architects more easily can select low-polluting materials. Designers of systems, manufacturers of components and maintenance professionals must be aware of the importance of systems as a potential source of pollution. A reduction or elimination of environmental tobacco smoke, for instance by regulation of the smoking policy in office buildings, can improve indoor air quality or allow lower ventilation rates.

The most recent proposal for ventilation standards is the prENV 1752 (5), now under public enquiry within CEN. The proposed recommendations are based on maximum allowed percentage of dissatisfied by first olfactory impression of the indoor air quality. From the present study, made on "normal" (not sick) office buildings, it appears that in nearly all buildings, the ventilation rates are large enough to maintain bioeffluents below the proposed limits. However, when recommendations on perceived indoor air quality are considered, this is not the case. The audited buildings were surely not clean, in that sense that the main pollution source was the building itself in most cases. However, the majority of the occupants were satisfied with the indoor air quality, and in most of the locations, recommendations given in prENV 1752 can not be satisfied without outdoor air cleaning. The challenge for the future is to propose a standard for existing buildings.

*Outdoor air*

When ventilation procedures are discussed and ventilation rates compared, the quality of the outdoor air used for ventilation must be considered. Outside some of the audited European buildings the perceived air quality was found to be poor. In some cases even poorer than the perceived air quality indoors. In such cases increased ventilation with outdoor air would not help to improve the indoor air quality. Furthermore, the TVOC concentration inside was affected by the outdoor air. It was shown that the TVOC concentration in the offices was directly correlated with the TVOC concentration of the outdoor air. The location of the air intakes is therefore also important. Development for improved methods to clean outdoor air is recommended.

*Individual control*

Large variations between the occupants' perceptions within the same building were registered. With sensitivity differing from person to person an obvious way to satisfy individual requirements is to establish individual control of environmental parameters. The control of the office environment, especially the ventilation, was generally rated low by the occupants in the audited buildings. An easy alternative in some cases would be to allow the occupants to open the windows. In approximately half of the audited buildings the occupants could not, or were not allowed to, open the windows. Adverse perceptions and building related symptoms are expected to be improved by individual control. Development of workstations with individual control especially in landscaped offices could be a possibility in the future.

*Maintenance*

Both the sensory and the chemical measurements showed that the ventilation system is often a significant pollution source in itself. Especially the filters in the ventilation system were frequently suggested as a pollution source during the walk-through survey. The HVAC system including filters, ducts, humidifiers, heat-exchangers, induction units should be properly maintained and cleaned. One of the identified pollution sources in the European buildings was cleaning agents, so selection of proper materials for cleaning should also be considered. The office cleaning as a part of the building maintenance should improve, not deteriorate the indoor air quality.

*Methods and future audits*

The present procedure with a one-day building audit was successfully carried out in all buildings by 9 teams, in 9 countries. The audit method, including equipment, is described in the Research Manual (2) and thoroughly discussed in chapter 5 of the final report (1). In future building audits the method could be used and compared with the results from the present Europe-wide survey. Some improvements of the procedure could be adapted (see chapter 5 of final report). The database with occupants' responses, measured IAQ-parameters and energy consumption is now available as a standard of reference.

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