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Indoor Air Quality in a New Office Building

L.E. Ekberg

ABSTRACT

The goal of this IAQ project is to determine how levels of indoor air contaminants vary in a new office building during the first year of occupancy. The study is based on field monitoring carried out both as short-term measurements and continuous monitoring. The contaminants studied include volatile organic compounds (VOC), formaldehyde, carbon dioxide, carbon monoxide, and particles. In the construction of the office building studied, standard materials and common construction methods were used. It is, in all respects, a typical modern office building. VOC and formaldehyde concentrations decreased drastically during the first months of occupancy. Concentrations of the contaminants studied are, after one year of occupancy, well within established guidelines and recommendations.

INTRODUCTION

The office building investigated is located in the city of Malmö in southern Sweden. The building has been occupied since September 1989. It is a four-story building with approximately 4,100 m^2 floor area. The building is occupied by approximately 140 office workers. The main type of room is an office of 11 m^2 floor area designed for single occupancy. There are two variable-air-volume HVAC systems serving the building. The HVAC systems are equipped with rotary heat exchangers and heating and cooling coils. Maximum capacity is 5.4 m^3/s for each HVAC system. Each office is supplied with airflows between 15 L/s and 60 L/s. Today the flow rate is controlled by room temperature. Future tests will include control by other parameters, for example, carbon dioxide.

This IAQ study is part of a project where thermal comfort and energy for heat and electricity are also matters of great importance. The work is a cooperative effort of Chalmers University of Technology and the Swedish National Testing Institute.

METHODOLOGY AND TEST DESIGN

The concentration of VOC has been detected by active sampling using sorbent tubes (2,6-diphenyl-p-phenylene oxide), analyzed with GC/MS technique. This procedure allows quantitative detection of VOCs with a boiling temperature between approximately 70°C and 290°C. VOC samples have repeatedly been collected from (1) two rooms representative of the building, (2) the exhaust air from the entire building, and (3) outdoor air. In order to examine VOC transfer in the HVAC system, sorbent tube samples have been taken from return, exhaust, outdoor, and supply air in parallel.

Formaldehyde sampling also has been carried out frequently, both from the outdoor air and indoor air. Formaldehyde has been detected by using passive sampling, which gives mean values for six- to eight-hour periods. The formaldehyde samples have been analyzed with high performance liquid chromatography (HPLC). Sampling intervals between one week and several months have been used.

Continuous measurements have been carried out, using photoacoustic spectroscopy (PAS), with a multipoint sampling device. This technique is used to make a more detailed comparison between contaminant concentrations in indoor, outdoor, supply, and exhaust air. The contaminants studied by the PAS technique are carbon dioxide, carbon monoxide, and volatile organic compounds. The lower detection limit for VOC is 0.02 ppm.

When the PAS technique is used, the total VOC concentration includes even very volatile organic compounds. When using sorbent tubes analyzed with GC/MS, several of the organics with a boiling temperature below approximately 70°C will be excluded or only partly included in the concentration result. PAS results refer to methane, while the GC/MS analysis presents VOC concentrations as hexane equivalents. Results from the two methods are, therefore, not directly comparable. However, the PAS technique provides the opportunity to make continuous monitoring at several locations during the same period of time. (Calibrating the GC/MS with hexane is a standard procedure at the laboratory that made these analyses.)

Particle concentrations have been measured with an optical particle counter, operating with white light. There are five particle size groups recorded between 0.5 and 15 micrometers. Particle monitoring has been used in three different types of tests: (1) filter efficiency tests, (2) particle concentrations in supply and indoor air relating to flow rate and occupancy, and (3) indoor air particle concentrations vs. time. Optical particle counter results are given in number concentrations, while standards and guidelines use mass concentrations. Accurate conversion between these two units requires a detailed analysis of the particle composition and is, therefore, not carried out here.

RESULTS

The following paragraph describes results obtained by GC/MS analyses. Figure 1 shows the total VOC concentration

Lars E. Ekberg is a postgraduate student in the Department of Building Services Engineering, Chalmers University of Technology, Gothenburg, Sweden.

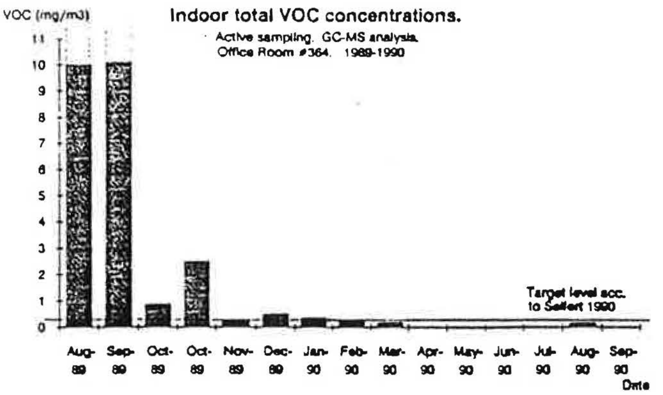

Figure 1 Indoor VOC concentrations during the first year

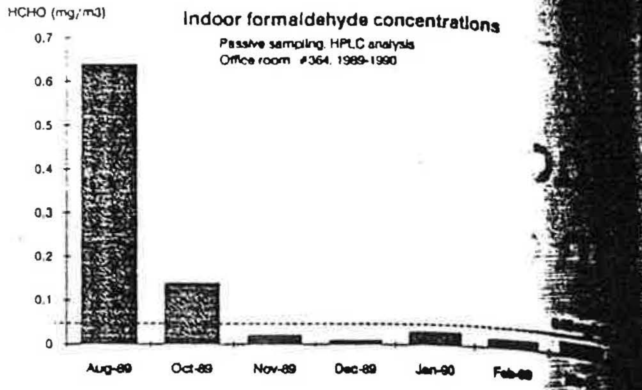

Figure 2 Indoor formaldehyde concentrations during the first seven months

vs. time in one of the two rooms mentioned previously. Results from these two rooms were in agreement, which is why only one of the rooms will be discussed here. During pre-occupancy and the moving-in period, indoor air concentration of total VOC reached values above 10 mg/m^3. Construction of the HVAC system had not been completed at this time; therefore, no mechanical ventilation was in operation. After one week of occupancy, fans started to run. During the first weeks of occupancy, the total VOC concentration decreased drastically and, after four months, levels never exceeded 0.4 mg/m^3. After one year, total VOC concentrations were found to be below 0.3 mg/m^3. Outdoor concentrations detected during this period were between 0.05 mg/m^3 and 0.11 mg/m^3, which indicates that internal sources of VOC are still active after one year. Some of the compounds detected with the GC/MS technique were found among the construction materials. Other measurements, carried out by the Swedish National Testing Institute, which also made the GC/MS analyses in this study, show that a "normal" total VOC concentration in indoor air is about 0,3-0,4 mg/m^3.

Formaldehyde concentrations reached levels near 0.7 mg/m^3 during the initial period but decreased rapidly within a few weeks. After four weeks of occupancy, formaldehyde concentration in the indoor air was equal to the outdoor concentration; therefore, there is no evidence of any significant indoor formaldehyde emission. Formaldehyde concentrations during the first seven months are shown in Figure 2.

Some of the volatile organic compounds have been identified among the construction materials, for example:

Compound	**Material**
toluene	carpet glue
texanol	paint (water based)
alcohols	glue, paint
formaldehyde	glue, filler

The chromatograms indicate that toluene is a major indoor air contaminant (in relation to other contaminants). Even after one year, exhaust air toluene concentrations of 22 μg/m^3 were detected. Outdoor concentrations were 6 μg/m^3 at the same time.

GC/MS measurements showed that VOC concentration increased from 47 μg/m^3 in outdoor air to 104 μg/m^3 in the supply air. The concentration in the exhaust air at this time was 182 μg/m^3. This transfer, (from exhaust to supply air) is a result of adsorption of VOC on the surface of the rotary heat exchanger wheel. The heat wheel is equipped with a purge section, and the transfer is not a result of air leakage, which was proved by tracer gas monitoring. The tracer gas monitoring showed an air leakage of about 5% to 10% from supply to exhaust air, due to higher static pressure in the supply air duct than in the ex[haust] air duct.

PAS monitoring of exhaust air shows that the conc[entra]tion of carbon dioxide seldom reaches levels above 600 ppm [as] building average. Figure 3 shows an example of carbon di[oxide] concentrations in exhaust air vs. time. With a minimum [flow] rate of 15 L/s in one office occupied by one person, carbon d[iox]ide concentration was about 750 ppm. However, when the [room] is occupied, the system is normally operated at flow rates [higher] than the minimum of 15 L/s. When the flow rate increased [to a] maximum of 60 L/s, carbon dioxide concentration stabilized [at] approximately 510 ppm. During these measurements, the [sup]ply air contained 400 ppm carbon dioxide.

Continuous PAS monitoring over several two-week peri[ods] showed that carbon monoxide concentration in the exhaust [air] was in close agreement with the content in the outdoor air. Typi[cally], the background outdoor carbon monoxide level was [...] ppm during weekends. During the daytime, Monday to Friday, carbon monoxide concentration increased to 2-3 ppm bo[th] indoors and outdoors. Continuous PAS detection also indicate[d] considerable variations of indoor air VOC concentrations. Out[door] air VOC content showed the same pattern of variation. Indoor concentrations were, however, 0.2-0.4 ppm higher than outdoor concentrations. Indoor VOC concentrations at night time and during weekends seldom reached levels above 1.5 ppm. During weekdays, several peaks above 2.5 ppm were record[ed]. Figure 4 shows one week of indoor and outdoor VOC concen[trations] vs. time.

Figure 5 shows the results from several short-term measure[ments] of indoor air particle concentrations during the fir[st] seven months. A major increase of particle concentrations [in] the size range from 0.5 to 15 micrometers was recorded wh[en]

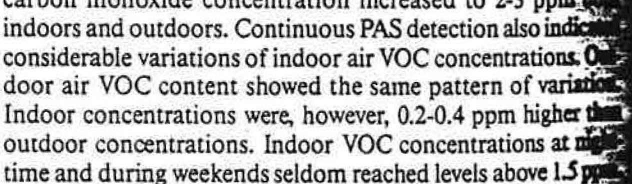

Figure 3 Carbon dioxide concentrations in exhaust air

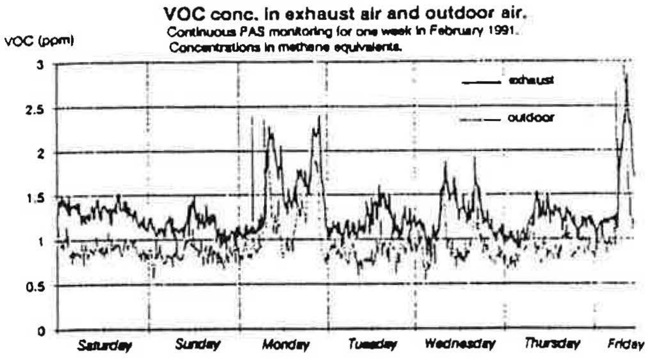

Figure 4 *VOC concentrations in exhaust air and outdoor air during one week*

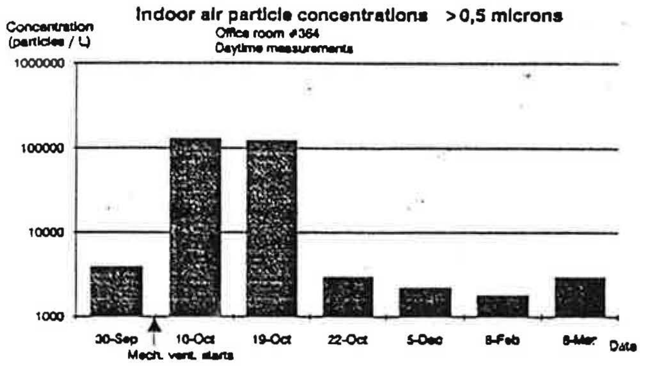

Figure 5 *Daytime measurements of indoor air particle concentrations during the first seven months*

HVAC fans started to operate. Particle filtration units were, however, installed all the time; therefore, a probable explanation could be that dust from the construction period had contaminated the supply air ducts. When mechanical ventilation started, the ducts were cleaned by the supply airflow. After two weeks of HVAC fan operation, particle levels decreased by a factor of approximately 30. The concentrations of particles between 0.5 and 1.5 micrometers showed little daily variation. Particles greater than 1.5 micrometers had more pronounced variation in correlation with occupation and human activity.

Particle monitoring up- and downstream from the filtration units showed that 36% of the particles greater than 0.5 micrometers, 75% of the particles greater than 1.5 micrometers, and 99% of the particles greater than 3 micrometers were collected. This is in approximate accordance with the manufacturer's data for these filtration units.

DISCUSSION AND CONCLUSIONS

This IAQ study was carried out in order to document how indoor air contaminants vary in a new office building during the initial year of occupancy. Conclusions about design, construction, and operation parameters that affect the indoor air quality are important parts of the work.

Construction of the HVAC system had not been completed prior to occupation. As a result, occupants were exposed for a few weeks to VOC levels above 10 mg/m^3 and formaldehyde concentrations of approximately 0.7 mg/m^3. Both formaldehyde and VOC concentrations decreased drastically during the first weeks of HVAC fan operation. After two weeks, there was no evidence of any indoor formaldehyde emission. However, after one year, there was still a significant indoor VOC emission. This seems to be a result of outgassing from the construction materials used in the building. VOC concentrations after one year were, however, less than 0-3 mg/m^3, which is the proposed target level according to Seifert (1990).

Dust from the construction period had probably contaminated the supply air ducts. When HVAC fans started to operate, indoor air concentration of particles greater than 0.5 μm increased dramatically. After a few weeks of fan operation, concentrations decreased and stabilized. During normal operation, human activity was found to have a major influence on concentrations of particles greater than 1.5 fm.

Carbon dioxide concentrations seldom reached levels above 600 ppm, as a building average. This indicates that the ventilation system is able to take care of human-related compounds and odors in a satisfactory way. Complaints have been reported in other studies when levels exceed 600 ppm. The ASHRAE standard proposes a maximum CO_2 concentration of 1000 ppm (ASHRAE 1989).

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