*Indoor Air 1997; 7: 116–120*


INDOOR AIR
*ISSN 0905-6947*

# The Influence of Area-Specific Ventilation Rate on the Emissions from Construction Products

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**Abstract** Experiments were performed using small-scale climate chambers, including the new Chamber for Laboratory Investigations of Materials Pollution and Air Quality (CLIMPAQ), to gain knowledge about the influence of ventilation rate per plane specimen area (specific ventilation rate) on emission rates. Emissions from pieces of linoleum, waterborne acrylic paint, nylon carpet, and sealant were quantified at different specific ventilation rates. A trained sensory panel used the decipol scale and chemical analysis quantified some major Volatile Organic Compounds (VOCs) after the specimens had been conditioned in the chambers for six days. The results showed that the specific ventilation rate (L/s m2) may influence the emission rates. In both sensory and chemical terms, emission rates increased when ventilation was increased. At low specific ventilation rates the emission rate was proportional to the specific ventilation rate. For higher ventilation rates the emission rates stabilized and became independent of ventilation. The chemical measurements showed that only the emissions from the tested paint were influenced by ventilation rates above those comparable to 0.5 $h^{-1}$ in a typical room. The emissions quantified by the sensory panel continued, however, to be influenced by ventilation even at rates higher than 5 $h^{-1}$.

**Key words** Emissions from construction products; Perceived air quality; VOC, Ventilation rate; Environmental parameters.

*Received 5 July 1993. Accepted for publication 27 February 1994.*


## Introduction

Emissions from building materials depend on several use- and environment-related parameters: temperature, time after manufacture (Girman, 1989), air velocity, moisture content in air and material, maintenance activities and emissions from other sources (e.g. tobacco smoking) adsorbed on materials (Nielsen, 1988; Wolkoff et al., 1991a). Tichenor and Guo (1991) have demonstrated a vapor pressure effect or influence of concentration of pollution in the air for some wet wood finishing products a few hours after application. Increased specific ventilation rate for a constant source would reduce the concentration of air pollution, but the findings of Tichenor and Guo suggest that the sources may respond to the reduced concentration by increasing their emission rates and in this way counteract the intention to improve air quality by increased ventilation in buildings.

Indoor air often contains a complex mixture of pollutants influenced differently by the environmental parameters. A better understanding of the basic processes controlling emission rates may give a better basis for controlling air pollution sources in buildings.

Cost-effective ventilation requires answers to a number of questions. These are: When and how is ventilation most efficient? How are construction products conditioned best before buildings are occupied? Which air pollution sources are important when buildings are new and which are important after some years? We need more information on the influence of the interactions between emission rates and environment- and use-related parameters.

In an occupied building, the air exchange rate is seldom allowed to be lower than 0.5 $h^{-1}$ and it is often higher. Some office buildings have air exchange rates up to approximately 5 $h^{-1}$ (Ekberg et al., 1995). With a room height of 2.5 m, these air exchange rates compare to 0.35–3.5 L $s^{-1}$ $m^{-2}$ (area referring to the floor). Emission testing of construction products should, when necessary, relate to these rates in order to be relevant for buildings.

The purpose of this study was to investigate the influence of ventilation rate per surface area on emission rates from typical construction products.

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## Materials and Methods

The following products, also used in Gunnarsen et al. (1994), were tested:

*Carpet* Polyamide fibers on a latex foam backing, tested and preconditioned while hanging, fixed back-to-back with metal staplers and exposing only the tufted side and edges.

*Linoleum* Oxidized mixture of linseed oil, wood flours and pine resins on a jute backing, tested and preconditioned while hanging, fixed back-to-back with metal staplers and exposing only the smooth side and edges.

*Paint* Waterborne acrylic paint on both sides of 0.7 mm aluminum plates, two coats applied with roller using 0.1 L $m^{-2}$ for each coat.

*Sealant* Silicone-based sealant for indoor use, tested in u-shaped aluminum profiles; inner width and depth were 10 mm and 12 mm.

All products were new. A few days after they were received from the manufacturers they were cut to size and stapled or applied to test frames of correct sizes. The carpet and linoleum were then wrapped in aluminum foil. The sealant and paint were left in a well ventilated room for one week to harden and were then wrapped. After two to four weeks in aluminum wrapping, specimens were hung up in a well ventilated room for seven days and then placed in the chambers, one product at a time.

Five test chambers of the new CLIMPAQ type (Gunnarsen et al., 1994) were used together with three field and laboratory emission cells, FLECs (Wolkoff et al., 1991b) and two jar-like 3-liter glass chambers, 3-l-C (Bluyssen and Fanger, 1991). The main parameters during tests are summarized in Table 1. The mean air velocity was measured with an anemometer in the actual space for materials in the CLIMPAQs. For the FLEC it was calculated based on air supply and geometry, and it was measured with an anemometer in the space for materials in the 3-l-C. The measured velocity in the 3-l-C was uncertain because of the small size of the chamber compared to the probe and complex airflow patterns. All chambers were kept at a temperature of 22±1°C. The air supply was at the same temperature. The FLEC and the CLIMPAQ with low air supply received humidified air of 50% RH (relative humidity) treated with an activated carbon filter. The other chambers received their air supply from the surrounding chamber. A high ventilation rate in the surrounding chamber with tempered and particle-filtered outdoor air assured a sufficiently clean air supply of approximately 35% RH.

The chambers were cleaned with acetone and flushed with distilled water before each test. Thereafter temperatures in the empty chambers were raised to 40°C for 12 h. The FLEC was cleaned according to its protocol (Wolkoff et al., 1991b) including a low pressure bake-out at more than 100°C. Samples of each material were tested simultaneously in the different chambers. After six days VOCs were sampled on Tenax TA and the sensory panel assessed the air quality. The tests were performed at ventilation rates comparable to typical buildings and at some extreme values. The three VOCs having the higher concentrations were quantified by a flame ionization detector after thermal desorption and gas chromatography (Wolkoff et al., 1991b). Concentration measurements were transformed to emission rates based on plane specimen area and air change rate measurements with tracer gas at each test. Background concentrations were subtracted.

A panel of 15 trained persons assessed the perceived air quality in decipol (Pejtersen and Mayer, 1993). Each panel member assessed each test condition twice ac-

**Table 1** Test facilities used in the experiment

| | Volume L | Air supply rate L/s | Mean air velocity m/s | Specimen area $m^2$ | |
|---|---|---|---|---|---|
| CLIMPAQ 1 | 50.9 | 0.0069 | 0.15 | Linoleum: | 0.61 |
| CLIMPAQ 2 | | 0.5 | | Carpet: | 0.61 |
| CLIMPAQ 3 and CLIMPAQ 4 | | 0.86 | | Paint: | 1.82 |
| CLIMPAQ 5 | | | | Sealant: | 0.018 |
| FLEC 1 | 0.035 | 0.00167 | 0.0035 | Linoleum: | 0.018 |
| FLEC 2 | | 0.00333 | 0.007 | Carpet: | 0.018 |
| FLEC 3 | | | 0.014 | Paint: | 0.018 |
| | | | | Sealant: | 0.00072 |
| | | | 0.43 | Linoleum: | 0.18 |
| 3-1-C 1 | 3.0 | 0.86 | (Uncertain value) | Carpet: | 0.12 |
| | | | | Paint: | 0.28 |
| | | | | Sealant: | 0.018 |
| | 3.0 | 0.86 | 0.43 | Linoleum: | 0.061 |
| 3-1-C 2 | | | (Uncertain value) | Carpet: | 0.031 |

cording to a randomized and blinded plan. Minor corrections were made according to known concentrations of acetone simultaneously assessed in the test. Sensory assessments were not made at airflows below 0.5 L/s in order to avoid exposure of panelists to concentrations that depended on sniffing behavior (Knudsen, 1994).

## Results

Due to the higher ventilation rates, many of the chemical measurements were below detection limits of typically 2 $\mu g/m^3$, but the sensory evaluations had sufficient signals under most test conditions.

The emission rates in each chamber are presented in sensory terms in Figure 1 and in chemical terms in Figure 2. Only the one VOC measured in highest concentration in CLIMPAQ 3 has been selected for presentation for each specimen.

In a typical room of 28.5 $m^3$ with a height of 2.5 m and a square floor, the area ratio between floor, wall and sealant is 1:3.0:0.030 if sealant is used along all

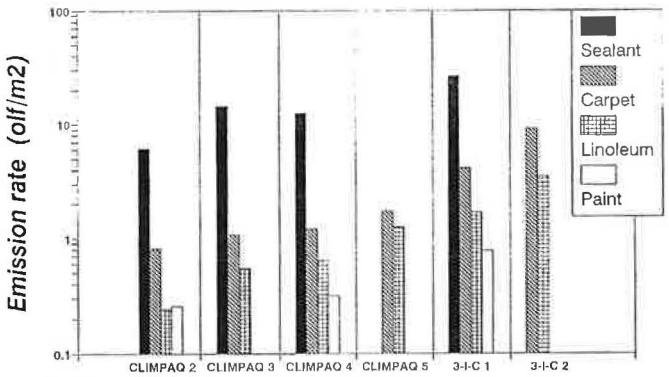


**Fig. 1** The calculated emission rates per specimen area (olf/m2) in the chambers based on the initially perceived air quality assessed by the sensory panel after six days in the chambers. Missing bars indicate missing data.

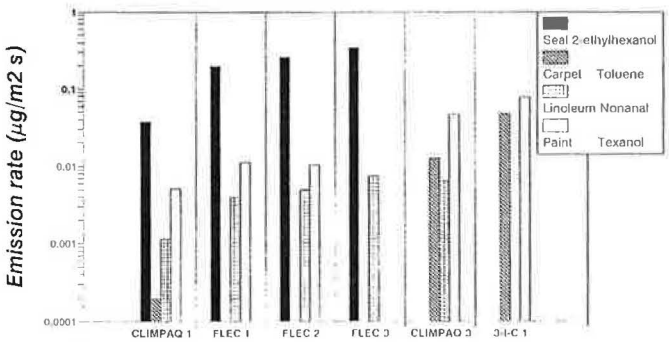


**Fig. 2** The calculated emission rates of selected VOCs per specimen area ($\mu g/m^2$ s) in the chambers based on chemical measurements after six days in the chambers. Missing bars indicate measurements below detection limits.

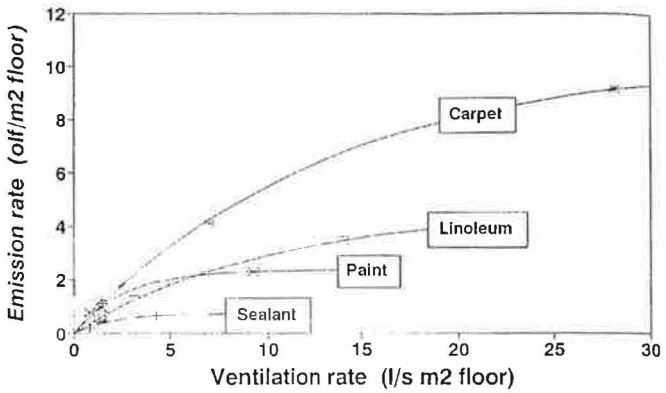


**Fig. 3** The emission rates per floor area in a typical room based on perceived air quality in relation to ventilation rate per floor area after six days in the chambers.

corners. Based on these relations and Figures 1 and 2, the emission rates per floor area in such a room may be calculated.

Figures 3 and 4 were made by converting air supply to ventilation rate per floor area in a typical room according to the above relationship. Emission rates are seen to depend significantly on the ventilation rate at lower ventilation rates.

For visual clarification, an empirical model has been fitted using nonlinear regression to the observed data in the form:

$$E = K_1(1 - e^{-k2\ V})$$

E: Specific emission rate ($\mu g/s\ m^2$ floor)
V: Specific ventilation rate ($L/s\ m^2$ floor)
K1 and K2: Constants.

Some measurements of other VOCs in the FLEC did not fit the model in Figure 4. The model gives a good fit for the VOCs chosen. Emission rates are shown to increase from 0 up to a stable level for increasing specific ventilation rates. The model reflects that when there is no ventilation, partial pressures of VOCs in the source and in the air reach equilibrium and no emission takes place. With increasing ventilation, emission increases. Initially, emissions will be controlled by the resistance to evaporation from the surface of the source. As ventilation increases, the emissions increase less and less, probably because resistance to diffusion within the source becomes more important. This model is expected to fit only during short experiments not very much longer than the six days used for conditioning in this study where the remaining emitable mass is not reduced significantly during the experiment.

Emissions in sensory terms are seen to stabilize at high ventilation rates of 3–30 $L/s\ m^2$ floor, while they stabilize at lower rates of 0.2–7 $L/s\ m^2$ floor according to the chemical measurements. Texanol from paint sta-

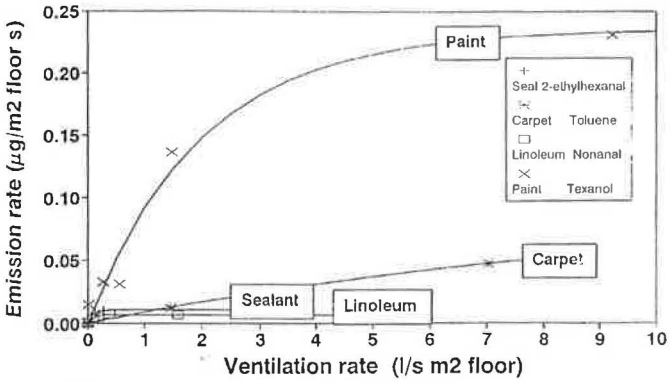


Fig. 4 The emission rates per floor area in a typical room based on chemical measurements in relation to ventilation rate per floor area after six days in the chambers.

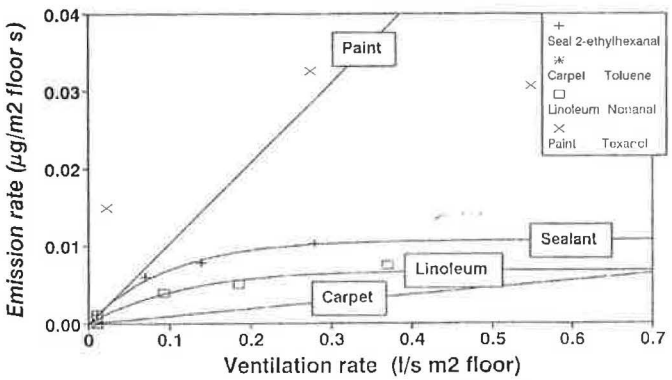


**Fig. 4a** Section of Figure 4 giving more details at the low ventilation rates.

bilizes at a high rate of 7 L/s $m^2$ floor, and toluene from carpet does not seem to stabilize at the studied rates. For clarification for the two other VOCs, a section of Figure 4 at lower rates is shown in Figure 4A.

## Discussion

The results are in good agreement with previous findings on thin layers of wood-finishing products a few hours after their application (Tichenor and Guo, 1991). From no ventilation up to a certain stabilizing level the emission rates depend on the ventilation rate. It is noteworthy, however, that emission rates depend on ventilation rates even for the older products used in this experiment and at the higher ventilation rates used here.

As ventilation increases from low rates where evaporation controls emission, resistance to diffusion in the materials becomes more and more important and emission rates become less influenced by ventilation at the higher rates. Apparently both emission and evaporation control of emission rates are seen, depending on ventilation rate, for all the tested materials. The emission rates may be considered almost proportional to ventilation rates at the lower ventilation rates. Therefore the concentration of air pollutants changes very little when ventilation rates are changed for short periods since concentration (under stable conditions) is equivalent to emission rate divided by ventilation rate.

The different ventilation rates may have caused differences in remaining emitable mass between chambers. Considering the previous conditioning period outside the chambers, these differences are deliberately kept relatively small. The effect of reduced emitable mass or exhaustion of the source in an environment favoring emissions would be the opposite of the increased emission rate found at increased ventilation rates.

At ventilation rates below the level where emissions stabilize, the main effect of a slightly increased ventilation rate may be to shorten the time before aging reduces the emission rates. Building installations are often operated on a diurnal basis with mechanical ventilation halted during unoccupied periods at night. With these 8–12 hour diurnal increases of ventilation rates, the effect of increased ventilation may be small. Emissions are expected to increase when ventilation is high, and the time with increased ventilation may not be sufficient to significantly reduce emitable mass in the sources. For many large area sources, the main effect of increased ventilation may be a faster reduction of emission rates during the first months after installation due to a faster exhaust of sources.

It is unlikely that pollutants in the air supply have caused the calculated increased emission rates at higher ventilation rates since we compensated for the background concentrations; if this compensation was not successful, we would not see emission rates stabilize as ventilation is increased.

Absorbed pollutants on chamber surfaces probably did not influence our findings significantly since we cleaned the chambers carefully before use, and during the six-day conditioning period in the chambers the concentrations were approximately constant.

The relatively higher level for stabilized emission rates seen with the sensory assessments may be caused by the different properties expected among the compounds responsible for the sensory perceptions compared to the single VOCs measured chemically. The recent findings of Henrik Knudsen (1994) contribute to the explanation for these differences. He compared the relationship between perceived air pollution (decipol) and concentrations of human bioeffluents and the emissions from three different construction products. The relationship for human bioeffluents had the greatest slope. In the present investigation, we as-

sumed that these relationships were the same. If this assumption is not valid, as indicated by Knudsen's work, and the products used had lower slopes for their dose response curves, the calculated emission rates would be expected to stabilize at somewhat higher levels than when using individual dose response curves for each product.

Many air pollution sources indoors are, however, ventilated at very high specific ventilation rates compared to the primary surface materials such as paint, sealant, linoleum and carpet. Products introduced during minor renovations, furniture and office machines are examples of air pollution sources which may be highly ventilated per surface area. Consequently they may be considered to be diffusion-controlled pollution sources and emitting at rates independent of room ventilation.

## Conclusion

In both sensory and chemical terms, the emission rates from large area sources increased when ventilation was increased for less than approximately one week. For low ventilation rates, the influence of ventilation rate on emission rates may be important. For higher ventilation rates, the emission rates become independent of ventilation.

For initially low ventilation rates and moderate increases of ventilation rates during less than approximately one week, the resulting concentration of air pollution from some primary surface materials may be higher than expected from a model with constant emission sources.

If the influence of ventilation rate on emission rate is unknown, it is recommended to test construction products at ventilation rates comparable to the relevant rates in buildings. Lower ventilation rates during testing may underestimate the relevant emission rates.

## Acknowledgements

This study was supported by the National Agency of Industry and Trade, Denmark.

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