THE INFLUENCE OF NOCTURNAL VENTILATION REDUCTION ON INDOOR AIR QUALITY

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ABSTRACT

The energy saving practice of stopping ventilation systems at night may reduce the daytime air quality. Sorption phenomena where pollutants absorbed at night are reemitted during the day and the general slower removal of pollutants at the reduced average ventilation rates will contribute to the deterioration of air quality at intermittent running systems. The purpose of the study was to investigate the impact on construction product emission during the day from reduced ventilation rates at night. Experiments were performed in three small-scale chambers of Climpaq type with dilution systems. An untrained panel of approximately 45 human subjects assessed the air quality in terms of acceptability. It was found that the intermittent ventilation reduces the daytime air quality significantly for the investigated new surface materials. If the ventilation is stopped 12 hours every night, the increase in ventilation rates required to maintain the same air quality as for continuous ventilation may be more than 100%.

INTRODUCTION

The necessity to improve the air quality within dwellings, public buildings and non-industrial workplaces has increased during the last decade. This necessity was sustained by the common aspiration to have better quality of air both at home and at work and the awareness of the running and installation costs of the systems providing healthy air to occupants. Many studies have documented that the building products are important polluters of the indoor environment with VOCs (1). These findings are supported by studies indicating significant sensory impact of buildings and installations (2) and limited sensory adaptation to emissions from many construction products (3). Increased prevalence of eye and airway irritation may also be caused by less adequate choice of construction products and ventilation (4). Several parameters may affect the emission rates from materials: e.g. temperature, air velocity, moisture content in air and material, their age and the pollution levels in surrounding air (5). Little knowledge exists on the air quality effects of transients in these parameters. Energy will be saved if ventilation is reduced at night but a few studies have indicated that one unintended cost may be reduced air quality during the occupied period (6). Recently the experimental complication of the different exposure-response relations for emissions from different sources have been overcome by the development of a useful dilution system for efficient sensory assessments at ranges of emission concentrations (7). By these relationships, it may be possible to predict changes in ventilation requirements based on changes in sensory impact.

The objective of this study was to compare the daytime acceptability of air when the ventilation had been interrupted at nights with the case of continuous ventilation. Furthermore, the aim was to quantify the difference in terms of required increase in ventilation rates at intermittent ventilation to maintain the acceptability of the air.

METHOD

Facilities

The experimental set-up is shown in Figure 1. Three small-scale chambers of a modified Climpaq type (8) were used. The chambers were made of steel with a volume of 54.6 l. Their lids were made of glass. Chamber surfaces were chromed to reduce sorption effects. Each chamber was equipped with an internal fan recirculating air over the test samples and driving the supply of air.

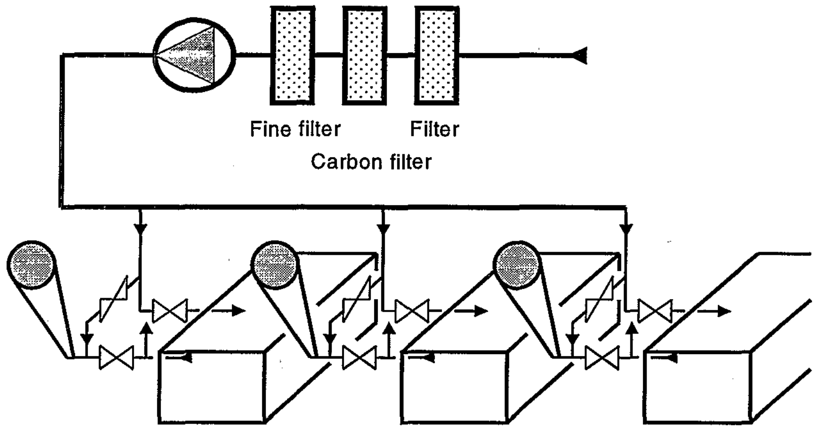

Figure 1. The experimental set-up.

The chambers were placed in a laboratory with a high supply rate of conditioned outdoor air. The air inlets of the test chambers were connected to an air supply system taking air from the laboratory. Supply air was filtered first through a prefilter designed to remove larger particles and then an activated carbon filter that removed most common VOCs. Finally, the air passed a HEPA filter to remove at least 99.97% of all particles bigger than 0.3 μm. The exhaust air from each test chamber was led through a dilution system before part of it reached the diffuser specially designed for sensory assessments. The air temperature and relative humidity in the test chambers were 21±1°C and 43±5%RH. The flow rate of supply air to the test chambers and in the diffusers was kept at 0.9 l/s. During the experiment, the chambers were covered with aluminum foil to hide the tested materials from the view of the sensory panel.

Sensory panel

Untrained panels comprising 50, 42 and 29 subjects performed the sensory assessments. The subjects were mainly university students. 19 panelists participated in all assessments, 30 participated in two sessions while the rest only participated once. Data for all the participants are shown in Table 1

Table 1. Data for the participating subjects.

Number of Subjects	Range of ages Years	Mean age years	Males %	Smokers %
72	21-43	32	72	21

The panel assessed the immediate acceptability of air from the diffuser by marking on the acceptability scale shown in Figure 2. The scale was used as shown. In the following data-analyses, numbers were assigned to the markings. "Clearly not acceptable" was assigned –10, "Clearly acceptable" was assigned 10, the midpoint 0 and numbers in between was considered belonging to a linear scale.

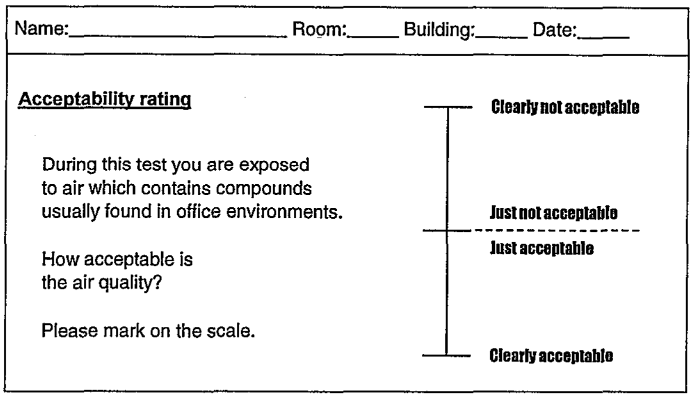

Figure 2. Acceptability scale and the accompanying question

Before the assessments, the panel was carefully instructed on how to use the scale. It was pointed out that focus should be on the initial perception, that no communication what so ever on air quality was allowed during voting procedures, and that the scale should be considered continuous without categories. The panel members were asked to breathe the laboratory air for at least three minutes between assessments and their exposure to polluted air was in general kept limited. The assessments were done in random order.

Materials

The three building products used in this study were selected to represent major groups of building products often used indoors. The building products were:

- 1.5 mm thick sheet of soft PVC on a cardboard backing
- 8 mm thick nylon carpet on a rubber backing
- White waterborne acrylic wall paint applied twice with roll using 0.1 l/m^2 per time on both sides of 13mm gypsum board.

All products were new and bought at the same time at consumer stores. Immediately upon purchase the materials were cut to sizes fitting the chambers and wrapped in aluminum foil where they stayed some days or weeks before they were placed in the test chambers. The flooring materials were stapled together, back to back to reduce emissions from their backsides. They were placed vertically at equal spacing, in parallel with the airflow in the test chambers, while samples of wall paint on gypsum board were placed horizontally along the airflow at equal spacing.

The sizes of the test samples were determined so that the area-specific ventilation rates corresponded to the typical application of the building products in a room when the ventilation was running. This model room was imagined to be 3.2m long, 2.2m wide and having a free height of 2.4m (17 m3). The surface area of the tested materials and the area specific airflow rate in the model room and the corresponding airflow rate and samples area in the test chambers are shown in Table 2.

Table 2. Conditions in the chambers based on a model room with an air change rate of 2h^{-1}

Material	Model room		Test chamber		
	Surface area m^2	Area specific airflow rate m^3/h/m^2	Sample area m^2	Airflow rate Vent.on l/s	Airflow rate Vent.off l/s
Paint	24	1.42	2.24	0.91	0.0072
Carpet	7	4.85	0.65	0.91	0.0065
PVC	7	4.85	0.65	0.89	0.0066

Procedure

Three rounds of sensory testing were carried out. Continuous and intermittent ventilation were tested as well as the impact of diluting the emissions for the case of continuous ventilation. The three test chambers were carefully cleaned before each installing of samples. First hot water with a neutral detergent added was used, then they were rinsed with hot water and finally rinsed with distilled water. New samples were placed in the chambers six days before the sensory assessments of both continuous and intermittent ventilation strategies and another set of new samples were placed only three days before assessments of the impact of dilution. Fans in the chambers and supply system were running either continuously or in periods with 12 hours operation followed by 12 hours of no operation. Assessments were made around noon on the last day. This was four to eight hours after the onset of fans at 6 AM in the intermittent case. Dilution was established by leading various fractions of the exhaust air to the diffuser. Excess chamber air was exhausted before the diffusers and additional supply air was lead to the diffusers to assure a constant airflow through diffusers as well as chambers.

RESULTS

Figure 3 shows the mean acceptability votes for the air quality assessed by the sensory panels at continuous and intermittent ventilation. Mean acceptability votes were calculated using simple arithmetic means. The standard deviation on the mean votes were in the range of 0.5-0.7 and differences are significant for $P< 0.05$ for carpet and paint and for $P<0.1$ for PVC. Differences are not significant for supply.

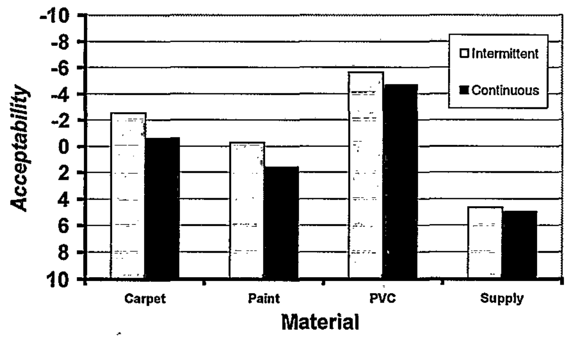

Figure 3. Mean acceptability votes at continuous and intermittent ventilation. For the case of continuous ventilation, the panel comprised 50 subject and for intermittent ventilation, the panel had 42 members.

Figure 4 show mean acceptability when chamber exhausts are diluted and ventilation is running continuously. Values at dilution = 1 (undiluted) are repetitions of the assessments for continuous ventilation in Figure 3 but with samples only conditioned in the chambers during three days. Values are seen to bee in good agreement with a tendency for the values during dilution to be less acceptable caused by the shorter conditioning period. The dashed line for the empty chamber is estimated based on the leveling of the curves at this level. The straight lines for the material samples are based on least square regression of all observations for PVC and the three least diluted observations for Carpet and Paint. The horizontal line for supply represents the mean of the observations. Observations for the materials were fitted to this model.

$$ACC = K_1 + K_2 \log(DIL) \qquad \ldots(1)$$

Where ACC is acceptability, K1 and K2 are constants and log(DIL) is the logarithm of the dilution factor.

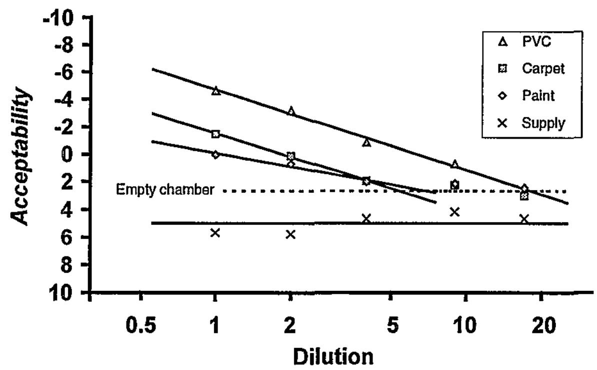

Figure 4. Mean acceptability when chamber exhausts are diluted. Dilution is the ratio between total flow and chamber exhausts in the diffuser. Each value is the mean of 30 votes. It is not possible to achieve dilutions below 1 in the experimental set up but extrapolation is shown for calculation purposes.

DISCUSSION

Stopping the ventilation when buildings are not occupied is widely applied. By proper timing of the start up of systems, temperatures may be restored when occupants enter. This energy saving practice may however as shown have a strong negative impact on air quality in the occupied periods. The effects may be seen as the combined effect of several mechanisms. The following may be the most important. Most surface materials will adsorb air pollutants when air concentrations are high for later desorption to the air when concentrations are reduced after systems have been turned on. Average removal of pollutants from a building may be reduced. Concentration gradients may be reduced in building materials at night giving higher emissions initially after ventilation systems, are turned on.

Table 2 shows the assessments at intermittent and continuous ventilation. Figure 4 was used to convert these values to required dilution of emissions for the achieved acceptability according to the slightly less aged materials used here. More ventilation will be required at intermittent ventilation to maintain acceptability at the level of continuous ventilation. The ratios between these dilutions have an average of 2.5. This means for intermittent ventilation, that the materials in average would require 2.5 times more ventilation than for continuous ventilation to compensate for the lowered ventilation rates at night.

Table 2. Acceptability assessments at intermittent and continuous ventilation along with required dilutions according to Figure 4 to achieve these values.

Material	Acceptability, Intermittent Ventilation	Acceptability, Continuous Ventilation	Required Dil. to match intermittent v.	Required Dil. to match continuous v.	Ratio between dilutions
PVC	-5.65	-4.69	0.7	1.0	1.5
Carpet	-2.55	-0.61	0.7	1.4	2.2
Paint	-0.27	1.61	0.9	3.3	3.8

CONCLUSION

- Stopping the ventilation at night may lower the air quality in the daytime when the ventilation again is turned on
- For ventilation rates, based on criteria for acceptable air quality, the effect of stopping the ventilation half the time may be a doubling or more of the daytime ventilation requirements.
- These small-scale experiments should be validated in buildings with ventilation systems.

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