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The effect of using low-polluting building materials on perceived air quality and ventilation requirements in real rooms

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SUMMARY

Source control is acknowledged as a means of achieving good indoor air quality. Labelling and classification schemes have been introduced that require specific criteria to the odour intensity or perceived quality of the emissions from building materials to be met when tested in small-scale test chambers in a laboratory. The objective of the experiments described in this paper was to study, how building materials tested in small-scale test chambers in a laboratory setting and classified as low-polluting affect the perceived air quality when applied in real rooms. The exposure-response relationship, i.e. the relationship between ventilation rate and perceived indoor air quality, was established for each of a series of materials tested in ventilated small-scale glass chambers in the laboratory and in real full-scale rooms furnished with combinations of the same materials. The results suggest that the perceived air quality in rooms can be improved considerably when polluting building materials are substituted with less polluting materials. Therefore, selecting low-polluting materials can result in considerable energy savings as a result of reducing the ventilation rate required to achieve a certain level of perceived air quality. To fully benefit from the lower required ventilation rates, attention should be paid to other parameters that may determine the need for ventilation, like heating or cooling of rooms with supply air.

KEYWORDS

Building materials, Exposure-response relationship, Odour, Perceived air quality, Ventilation

INTRODUCTION

Good perceived indoor air quality can be obtained by a combination of source control and adequate ventilation. Among indoor pollution sources, focus has centred on building materials for which different kinds of labelling schemes for emissions have been developed in some European countries (ECA-IAQ, 2005). The main purpose of labelling is to protect consumers from exposure to chemical pollutants and resulting adverse health effects or annoyance caused by bad odours. EU experts agreed a decade ago that odour evaluations should be part of a labelling scheme (ECA-IAQ, 1997). Work was initiated, but until now no consensus has been reached on which specific sensory method should be applied in labelling schemes (ECA-IAQ, 1999). As a consequence, different odour evaluations are included in the Danish "Indoor Climate Label", the Finish "M1- Emission classification of Building Materials" and in the French "CESAT - Evaluation of environmental and health-based properties of building products" (optional to evaluate odour). The intention is also to introduce an odour evaluation in the German AgBB scheme.

One thing that the schemes have in common is that odour evaluations of building materials are performed using ventilated small-scale test chambers in a laboratory setting. The schemes are based on the assumption that reducing the odour intensity or perceived quality of the emissions from a building material, as documented by a test in a small-scale test chamber, will also improve the perceived air quality in a real full-scale room where the material is applied. There are, however, only few experimental data supporting this assumption (e.g. van Beuningen et al., 1994).

Previously several studies investigated the relationship between perceived air quality and ventilation rate for pollution emitted from building materials either in small-scale chambers or in full-scale rooms (Knudsen, 2006). However, there is a lack of systematic experiments linking results from small-scale tests with the perceived air quality in real full-scale rooms where the materials are used.

It would be desirable if it was possible on the basis of small-scale testing of materials in a laboratory to predict the perceived air quality in a full-scale real room, where the materials are used. But a series of factors are believed to make such a prediction impossible at present. For example, factors related to the sensory panel doing assessments such as status of adaptation, psychological factors like context in which assessments are made (in laboratory vs. in real buildings), expectations and previous familiarity and experience with odours and not least perception of complex odour mixtures. Recently, it was demonstrated that the information given about tested materials affects assessments of perceived air quality (Wilkins, 2007). Moreover, it is a challenge to understand how the often high number of different pollution sources in a room interacts, e.g. with respect to secondary processes like adsorbed and desorbed pollution and reactive chemistry, e.g. when odorous secondary emissions are formed in reactions with ozone.

Rather than trying to understand all relevant links between small-scale testing of materials and full-scale real rooms, a pragmatic approach needs to be used. The objective of the experiments described in this paper was to study, how building materials classified as low-polluting when tested in small-scale test chambers in a laboratory setting affect the perceived air quality when applied in real rooms.

METHODS

A sensory panel assessed the air quality in full-scale test rooms ventilated with three different outdoor air supply rates and polluted by typical building materials including wall, floor and ceiling materials; the materials were carefully selected to range from high to low polluting. The relationships between the perceived air quality and ventilation rate were examined for different combinations of materials to assess the impact of using low-polluting materials and/or increased ventilation rate on the perceived air quality.

The assessments took place in three similar test rooms with a floor area of 18 m^2 and a volume of 57.6 m^3, each constituting an independent unit. The test rooms were served by a HVAC system supplying outdoor air to each room through a duct system and ceiling diffusers; the air was exhausted through wall-mounted grills. There was no recirculation of air. Outdoor air was supplied to the test rooms by an air handling unit with a fan and was conditioned by an electric pre-heater; no filter was installed. The temperature of the supplied air was independently controlled for each test room by electric heaters mounted upstream of the ceiling diffusers. The rate at which outdoor air was supplied to the rooms was controlled by IRIS dampers with motorized shut-off dampers independently for each test room. The air was exhausted directly outdoors by duct fans. The exhaust rate of the air was determined by a pre-defined overpressure in the test rooms (relative to adjacent spaces), which was controlled by motorized dampers. The test rooms were fully refurbished a few months prior to the experiments: the ceiling and flooring materials were changed, walls were painted and sliding doors of laminated wood were installed, so that one large room could be turned into three separate test rooms. The HVAC system was completed in the week prior to the experiments. A cabinet in which pollution sources were hidden was mounted in each test room, so that the sources were hidden from sight. Room air entered the cabinet through a slot close to the floor and was pulled through the cabinet by an axial fan mounted at the top, where the air was exhausted into the room air. The cabinet also contained ultrasonic humidifiers that were mounted on the rails above the space for the pollution sources, immediately upstream of the axial fan; the humidifiers were used to control relative humidity in the test rooms. The air circulation through the cabinets ensured that the air in the test rooms was well mixed. The cabinets were completed the week prior to the experiments.

Nine different building materials were used (Table 1 and Figure 1). They were carefully selected based on the results of a preliminary experiment in which 20 building materials were screened individually in small-scale glass chambers, in accordance with the principles of the Nordtest methods (Nordtest, 1990, 1998). These 20 materials were in turn selected on the basis of a review of studies reporting the relationships between ventilation rate and the perceived quality of air polluted by building materials (Knudsen et al., 2006). The aim was to select wall, floor and ceiling materials that could be ranked in a range from high to low polluting. The nine materials were tested individually in small-scale glass chambers of the CLIMPAQ type (Nordtest, 1998), following the procedure used in the preliminary tests outlined above. For that purpose eight glass chambers were placed in a 26.8 m^3 stainless steel chamber (Albrechtsen, 1988) and ventilated with an outdoor air change rate of 57 h^{-1}. Then a sensory panel assessed the air quality in the glass chambers. The temperature in the chamber was kept constant at 22±0.1^oC; the relative humidity was not controlled and averaged 31±6%. Each material was tested at three different area-specific ventilation rates, i.e. the ratio between outdoor air supply rate and the area of material. Different area-specific ventilation rates were obtained by varying the surface area of materials and keeping the ventilation rate through glass chambers constant at 0.9 L/s. The area-specific ventilation rates for the materials in the glass chambers were kept as in the test rooms ventilated with 1, 3 and 9 h^{-1} for floor and ceiling materials and 1.3, 4 and 12 h^{-1} for wall materials (Table 1); the higher air change rates for wall materials were due to limitations on the material loading that could be placed in a glass chamber. The sensory panel also assessed the air quality in empty glass chambers. The materials were purchased about two months prior to the start of sensory assessments. The specimens of materials to be used in test rooms and glass chambers were prepared (cut and/or painted) 4-6 weeks prior to the beginning of experiments; the specimens were stored in a ventilated hall. During sensory assessments, the specimens of materials used in test rooms were hung on trolleys, which were placed in the cabinets, while other specimens of the materials were placed in glass chambers; the backside of materials was not exposed. The materials were set up in test rooms and glass chambers about 21 hours prior to the sensory assessments. The sensory panel could not see the material specimens, which were hidden in the cabinets in the test rooms or under aluminium screens in the glass chambers.

Nine different combinations of the nine carefully selected materials were placed in the full-scale test rooms (see Figures 2 and 3 for the combinations). In order to resemble a typical indoor setting, each combination consisted of a ceiling, floor and wall material, and included both high- and low-polluting materials. The amount of materials set up in the test rooms corresponded to the actual area of ceiling, walls and floor in the test room (Table 1). A sensory panel assessed the air quality in the test rooms polluted by the combinations of materials and ventilated with three different outdoor air supply rates corresponding to outdoor air change rates of 1.3±0.1, 2.8±0.1 and 6.4±0.2 h^{-1}. The sensory panel also assessed the air quality in empty test rooms, i.e. without any of the nine materials set up in test rooms. During all assessments, the temperature in test rooms was kept constant at 22.2±0.3°C; the relative humidity was not controlled and averaged 36±5%.

Table 1. Area of building materials used in the full-scale and small-scale experiments.

Material		Area of material (m^2)			
Acronym	Description	Full-scale test room	Small-scale glass chamber, CLIMPAQ		
Ceiling 2	10 mm plain gypsum board covered with plastic coated material	18	0.113	0.338	1.013
Wood	14 mm beech wood parquets, untreated	18	0.126	0.372	1.106
Carpet 1 Linoleum 2 PVC Polyolefine	6.4 mm tufted loop polyamide carpet with supporting layer of polypropylene web and polypropylene backing 2.5 mm linseed-oil-based flooring, 52 % wood meal 2.0 mm homogenous single layered vinyl flooring, reinforced with polyurethane 2.0 mm homogenous polyolefine-based resilient flooring, reinforced with polyurethane	18	0.113	0.338	1.013
Gypsum board Paint 1 Paint 2	13 mm plain gypsum board lined with cardboard Gypsum board painted with one coat (0.14 l/m^2) of water-based acrylic wall paint Gypsum board painted with one coat (0.14 l/m^2) of water-based wall paint with linseed oil	52	0.243	0.730	2.187

The sensory panel consisted of 38 subjects recruited from 50 applicants. The subjects were students, aged on average 24 years; 42 % were females and 21 % were smokers. Ten subjects had previously participated in similar experiments, where sensory assessments of air quality were made. Subjects received written and oral instructions concerning the sensory assessments. The subjects assessed air quality by using the continuous acceptability scale, see caption of Figure 1. Sensory measurements were made on 15 days in three consecutive weeks, each day both in full-scale test rooms and small-scale glass chambers. Exposures were randomly assigned to subjects in a design balanced for order of presentation. Each substitution with low-polluting material was always tested at three different ventilation rates in the same room to minimize the impact of the possible differences in air quality between empty test rooms. The three different area-specific ventilation rates of the same material established in glass chambers were always tested on the same day of the experiment. The assessments in tests rooms were made immediately when reaching a marked spot on the floor, about 2 m from the door. This procedure was used to standardise the position in the middle of the room and the approximate time spend in the test room prior to assessment of the air quality. The doors to the test rooms were closed during assessments. The subjects entered the tests rooms, one at a time. The assessments in glass chambers were made by taking one inhalation of polluted air exhausted from the chamber through a diffuser. A break of at least two minutes was made between assessments in glass chambers and test rooms. The break was taken in a well-ventilated hall adjacent to test rooms and the chamber with the glass chambers. The mean votes of acceptability were plotted against the logarithm of air change rate (for the ratings performed in test rooms) or the logarithm of area-specific ventilation rate (for the ratings performed in glass chambers).

RESULTS

Figure 1 shows the mean assessments of acceptability of air quality for individual materials in small-scale glass-chambers at different area-specific ventilation rates. The results show that the selection of the materials turned out well, since the materials covered a range from low to high acceptability (from high- to low-polluting materials). The materials can be ranked in the following order, starting with the highest-polluting material: Paint 2, Wood, Carpet 1, Linoleum 2, Paint 1, Gypsum board, Ceiling 2, PVC and Polyolefine.

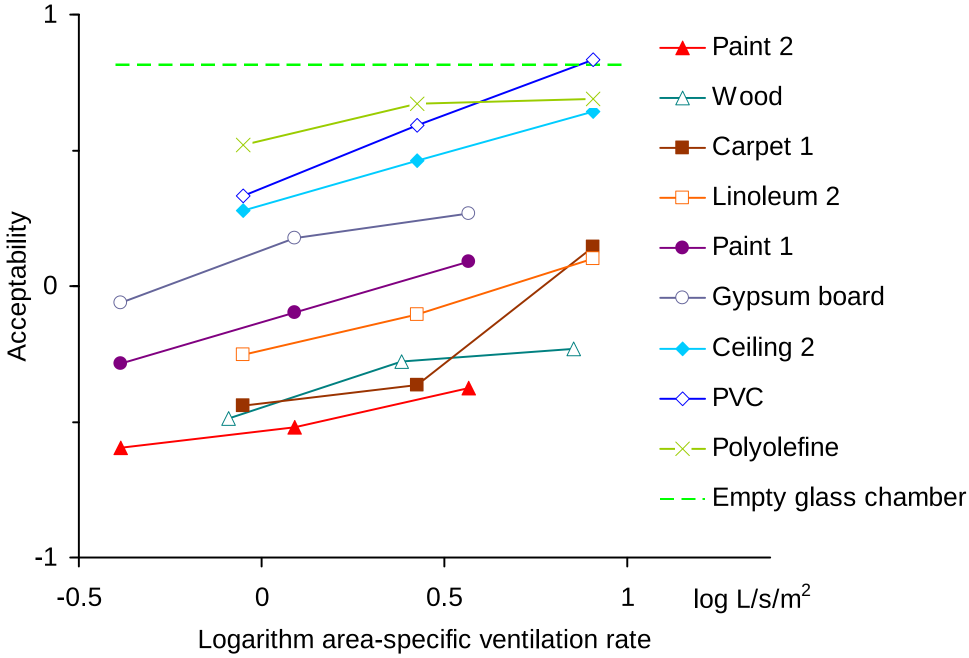

Figure 1. Mean acceptability of air quality as a function of the area-specific ventilation rate in small glass chambers containing the nine individual building materials that were examined in combinations in test rooms. The scale coding was as follows: -1=clearly not acceptable; 0=just not acceptable/just acceptable; +1=clearly acceptable.

Figures 2 and 3 show the mean assessments of acceptability of air quality in test rooms at three different outdoor air change rates when the test rooms were empty and in the test rooms with different combinations of the nine building materials including both high- and lower-polluting wall and floor materials; ceiling material was unchanged and always the same in all test rooms. The acceptability of air quality in the empty test rooms was lower than in empty glass chambers, probably because the test rooms had undergone a renovation only a few months prior to the experiments and primary emissions were still affecting the perceived air quality. Figure 2 left shows that substituting high polluting Wood with lower-polluting Linoleum 2 or Polyolefine did not improve the assessments of acceptability of air quality when combinations of materials included the highest-polluting Paint 2. On the other hand, when the combinations included lower-polluting Paint 1 (Figure 2 right), substituting high-polluting Carpet 1 or Wood with lower-polluting PVC improved the assessments of acceptability of air quality. Figure 3 shows that the assessments of acceptability of air quality improved when the highest-polluting Paint 2 was substituted with lower-polluting Paint 1 and it improved further when substituting with unpainted Gypsum board, independently of whether the combinations of materials included the high-polluting Wood (left) or lower-polluting Polyolefine (right). However, the improvement seems to be somewhat greater in the latter case (Figure 3, right). Figures 2 and 3 also show that increasing the ventilation rate improved the assessments of acceptability of air quality in the test rooms with different combinations of building materials. This effect was, however, small for the combinations of materials including high-polluting Paint 2.

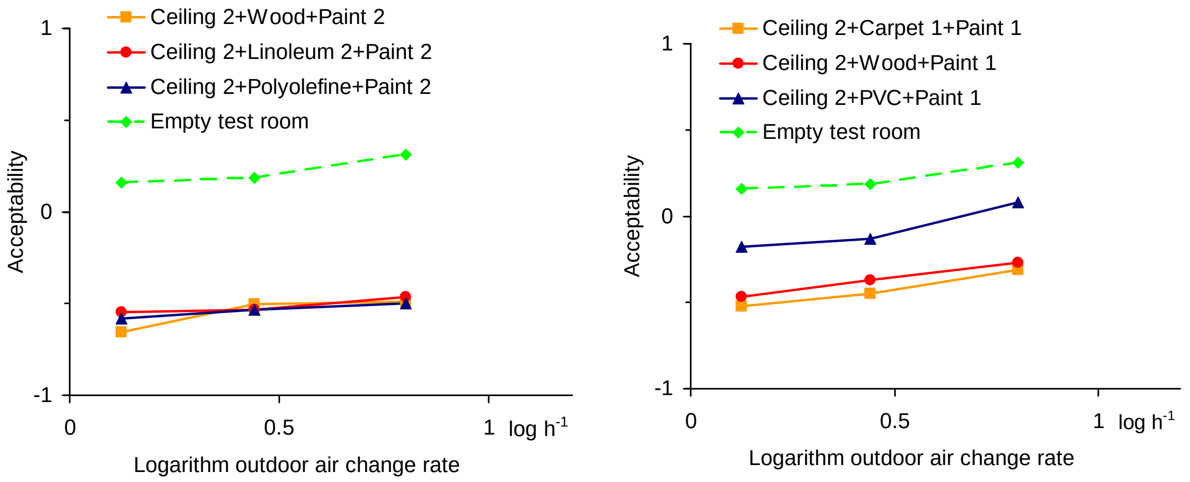

Figure 2. The effect of substituting high-polluting floor materials with lower-polluting materials on the mean acceptability of air quality in the tests rooms ventilated with different outdoor air change rates, when the combinations of materials included high-polluting (left) or lower polluting (right) wall materials; ceiling material was unchanged.

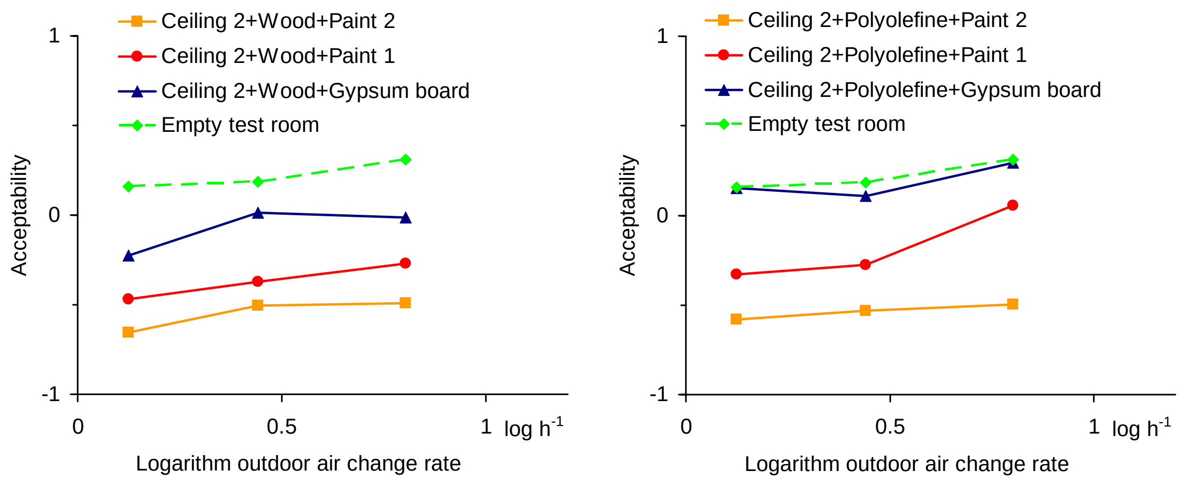

Figure 3. The effect of substituting high-polluting wall materials with lower-polluting materials on the mean acceptability of air quality in the tests rooms ventilated with different outdoor air change rates, when the combinations of materials included high-polluting (left) or lower-polluting (right) floor material; ceiling material was unchanged.

DISCUSSION

Substituting pollution sources by selecting lower-polluting building materials, based on sensory assessments made in small-scale glass chambers, improves the perceived air quality in full-scale rooms where these materials are used. The improvement is more pronounced than that achieved by a realistic increase of the outdoor air supply rate. For example, a sevenfold increase of the outdoor air supply rate improved acceptability of quality of air polluted by a combination of materials including Ceiling 2, Polyolefine and Paint 1 less than substituting Paint 1 in this combination with the lower-polluting Gypsum board (Figure 3, left). Similar results can be provided for nearly all substitutions with the lower-polluting building materials examined. The only exception was the substitution of high-polluting floor material with lower-polluting materials when the room air was still polluted by the highest-polluting Paint 2

(Figure 2, left). In this case, the perceived air quality did not improve, probably because the strongest pollution source, Paint 2, is so dominating that it determines the perceived air quality in a room polluted by different materials. Figure 3, right, suggests a possible air cleaning effect, where the acceptability of quality of air polluted by Ceiling 2, Polyolefine and Gypsum board is similar to the acceptability of air in the empty test room. The results show that a rational way of improving the perceived air quality in a room is to substitute the highest polluting material with a low-polluting alternative. For that purpose a ranking of materials is suitable for estimating the relative effects on perceived air quality in real rooms, e.g. by using sensory assessments of air quality in small-scale glass chambers.

Worldwide there is a need for reducing energy consumption. One initiative for reaching this goal is the EU Directive 2002/91/EC Energy Performance of Buildings (2002) that makes it obligatory to reduce energy consumption in buildings while taking into account the indoor environment. For many buildings this can only be achieved if the energy used for ventilation is also reduced, as it constitutes about 20-30 % of the total energy consumed in buildings today. This may lead to reduced ventilation rates and increased levels of air pollution from buildings, people and their activities, and thus to a poorer indoor air quality, which contradicts the requirements of the EU Directive. The obvious solution for this contradiction would be to reduce the pollution sources indoors. This study shows this to be an effective measure. The effect of using low-polluting building materials and changing outdoor air supply rates on the perceived air quality were studied by examining the relationships between acceptability of air quality and ventilation rate, Figures 1-3. Such an approach has also been shown to be useful in previous studies (Knudsen et al., 2006, 1998), where these effects have been studied. The relationships can be useful for specifying the requirements for criteria used in labelling schemes on odour intensity or perceived quality of the emissions from building materials and for specifying levels of required ventilation rates in ventilation standards. For considerations on the potential of reducing energy used for ventilating buildings by using low-polluting building materials, see Wargocki and Knudsen (2008). The potential energy savings from using low-polluting building materials are limited by the extent to which ventilation is used to control the thermal environment in rooms by heating and/or cooling the supplied outdoor air.

Even though it is not possible at present to predict the perceived air quality in a building directly from data obtained in small-scale test chambers in the laboratory, it is strongly advised to test building products in the laboratory for the purpose of labelling or ranking building materials. With the appropriate acceptance criteria in a labelling scheme this study has demonstrated that the use of low-polluting materials can help to ensure an acceptable perceived air quality at the lowest required ventilation rate. The present labelling schemes are typically voluntary for the manufacturers. In spite of a trend towards European harmonisation, most of the labelling schemes are mainly focused on national markets. Test methods are basically the same but the evaluation of the emission test results vary from scheme to scheme. There is a need for a harmonised system for material emission labelling in Europe in order to take full advantage of the potential to improve the perceived air quality at a low ventilation rate. The obvious connection between labelling schemes of material emissions and standards on ventilation requirements should be further studied.

CONCLUSIONS

- Substituting building materials with materials shown in small-scale chamber tests to be lower-polluting improved the perceived air quality in full-scale test rooms. The effect was most pronounced when the highest polluting material was replaced by a lower polluting material.

- The improvement of the perceived air quality by using lower-polluting materials was more pronounced than the improvement obtained by a realistic increase of the outdoor air supply rate.
- The use of lower-polluting materials was showed to reduce the ventilation rate required to achieve a given level of perceived air quality and hence allow a reduction in energy used for ventilation.

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