

Effect of using low-polluting building materials and increasing ventilation on perceived indoor air quality

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SUMMARY

The potential of improving perceived air quality indoors was quantified when low-polluting materials are used and when building ventilation is increased. This was done by studying the relationships between ventilation rate and the perceived indoor air quality. A sensory panel assessed the air quality in test rooms ventilated with realistic outdoor air supply rates, where combinations of high- and low-polluting wall, floor and ceiling materials were set up. These materials were ranked as high- and low-polluting using sensory assessments of air quality in small-scale glass chambers, where they were tested individually. Substituting materials ranked as high-polluting with materials ranked as lower-polluting improved the perceived air quality in the test rooms. This improvement was greater than what was achieved by a realistic increase of the ventilation rate in the test rooms. Thus reducing pollution emitted from building materials that affects the perceived air quality has a considerable potential of limiting the energy for ventilation without compromising indoor air quality.

INTRODUCTION

There is a need for reducing the energy consumption worldwide. One initiative to reach this goal is the EU Directive 2002/91/EC Energy Performance of Buildings [1] that makes it obligatory to reduce energy consumption in buildings while taking into account the indoor environment. For most 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 however may lead to reduced ventilation rates and increased levels of air pollution from buildings, people and their activities, and thus to poorer indoor air quality, which contradicts the requirements of the EU Directive. The obvious solution for these apparently opposing requirements would be to reduce the pollution sources indoors.

Several studies have previously investigated the effects of pollution emitted by building materials on the indoor air quality and related these effects to ventilation requirements [2]. However, there is a lack of systematic experiments, in which building materials are first ranked according to their pollution strength, e.g. by using methods applied in labelling schemes [3], and then the effect on the indoor air quality of using these materials in real rooms is examined. Such studies would make it possible to quantify to what extent using low-polluting building materials would reduce the energy used for ventilation of buildings without compromising indoor air quality. The main objective of an ongoing research project is to quantify this energy saving potential based on the effects on the perceived air quality. The specific objective of the experiments described in this paper is to systematically study, how

the selection of low-polluting building materials affects the perceived air quality and to compare this effect with the effects of increased outdoor air supply rate on the perceived air quality.

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 ranged 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 increasing ventilation rate on the perceived air quality.

The assessments took place in three similar test rooms with a floor area of 18 m² and a volume of 57.6 m³, each constituting an independent unit. The test rooms are served by a HVAC system supplying outdoor air to each room through a duct system and ceiling diffusers; the air is exhausted through wall-mounted grills. There is no recirculation. Outdoor air is supplied to the test rooms by an air handling unit with a fan and is conditioned by an electric pre-heater; no filter is installed. The temperature of the supplied air is independently controlled for each test room by electric heaters mounted upstream of the ceiling diffusers. The rate at which outdoor air is supplied to the rooms is controlled by IRIS dampers with motorized shut-off dampers independently for each test room. The air is exhausted directly outdoors by duct fans. The rate at which the air is exhausted is determined by a pre-defined overpressure in the test rooms (relative to adjacent spaces) which is 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 larger space could be turned into three separate test rooms. The HVAC system was completed in the week prior to the experiments.

A special cabinet is mounted in each test room. In this cabinet pollution sources can be hidden, so that the exposure conditions are not revealed. Room air enters the cabinet through a slot close to the floor and is pulled through the cabinet by an axial fan mounted at the top, where the air is exhausted to the room air. The cabinet also contains ultrasonic humidifiers that are mounted on the rails above the space for the pollution sources, immediately upstream of the axial fan; the humidifiers are used to control relative humidity in the test rooms. The air circulation through cabinets ensures that the air in test rooms is well mixed. The cabinets were completed in the week prior to the experiments.

Nine different building materials were used (Table 1 and Figure 1). They were selected using the results of preliminary experiments in which 20 building materials were screened individually in small-scale glass chambers, following the principles of the Nordtest methods [4,5]. The 20 materials were selected based on a review of studies reporting the relationships between ventilation rate and the perceived quality of air polluted by building materials [2]. The aim was to select wall, floor and ceiling materials that can be ranked in a range from high- to low-polluting. The nine materials were tested individually in small-scale glass chambers, CLIMPAQs [4], following the procedures used in preliminary tests outlined above. For that purpose eight glass chambers were placed in a 26.8 m³ stainless steel chamber [6] ventilated with an outdoor air change rate of 57 h⁻¹, and the sensory panel assessed the air quality in the glass chambers. The temperature in the chamber was kept constant at 22±0.1°C; the relative humidity was not controlled and averaged 31±6%. Each material was tested at 3

different area-specific ventilation rates, i.e. the ratio between outdoor air supply rate to the area of material. Different area-specific ventilation rates were obtained by changing the surface area of materials and keeping the ventilation rate through glass chamber constant at 0.9 L/s. The area of materials tested in glass chambers were selected according to the principles of the Nordtest methods [4,5] - the area-specific ventilation rates in glass chambers were kept the same 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.

Nine different combinations of the selected 9 materials were tested in full-scale test rooms (Figures 2 and 3). In order to resemble 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 the outdoor air change rate 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 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. 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 | 6.4 mm tufted loop polyamide carpet with supporting layer of polypropylene web and polypropylene backing | 18 | 0.113 | 0.338 | 1.013 |
| Linoleum 2 | 2.5 mm linseed-oil-based flooring, 52 % wood meal | | | | |
| PVC | 2.0 mm homogenous single layered vinyl flooring, reinforced with polyurethane | | | | |
| Polyolefine | 2.0 mm homogenous polyolefine-based resilient flooring, reinforced with polyurethane | | | | |
| Gypsum board | 13 mm plain gypsum board lined with cardboard | 52 | 0.243 | 0.730 | 2.187 |
| Paint 1 | Gypsum board painted with one coat (0.14 l/m ²) of water-based acrylic wall paint | | | | |
| Paint 2 | Gypsum board painted with one coat (0.14 l/m ²) of water-based wall paint with linseed oil | | | | |

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 the specimens of materials were placed in the glass chambers using a special supporting system; 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 materials

hidden in the cabinets in tests rooms or the materials in glass chambers, which were covered with aluminium screens.

The sensory panel of 38 subjects was recruited from among 50 applicants. The subjects were students at the Technical University of Denmark, 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. These person-related data were collected via a questionnaire filled in by applicants upon recruitment. Subjects received written and oral instructions concerning sensory assessments. The first day of experiments was a practice session, but this was not communicated to the subjects; the assessments collected during this day were discarded. The subjects assessed air quality, using continuous acceptability scale [7] printed on paper. To test whether the sensory assessments were drifting/stable, on each day of experiments the subjects assessed the air quality in two glass chambers, where the loading of Carpet 1 and Ceiling 2 was the highest (Table 1) and kept unchanged during the whole course of the experiment. No drift was observed.

Sensory measurements were made on 15 days in three consecutive weeks during November/December 2006, 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 upon 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 tests rooms one at a time. The assessments in glass chambers were made upon 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 stainless steel chamber with the glass chambers.

The ratings made on paper questionnaires were digitized; 10 % of the ratings were digitized twice for quality control. The acceptability scale was coded as follows: Clearly not acceptable = -1; Just not acceptable/Just acceptable = 0; Clearly acceptable = 1. Using individual ratings made by the subjects means were calculated separately for each condition assessed in the tests rooms and in 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) [8]. This was done to examine the relationship between the perceived air quality and ventilation rates [2,9,10], which was then used to assess the effect of changing ventilation on perceived air quality and compare it with the effect of using low-polluting materials.

RESULTS

Figure 1 shows the mean assessments of acceptability of air quality in glass-chambers at different area-specific ventilation rates when the building materials were placed individually in glass chambers. The results show that the selection of the materials used in the combinations examined in the test rooms turned out well, because both high- and low-

polluting materials were included. These 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. The least polluting was the empty glass chamber, for which the acceptability of air quality was assessed to be the highest.

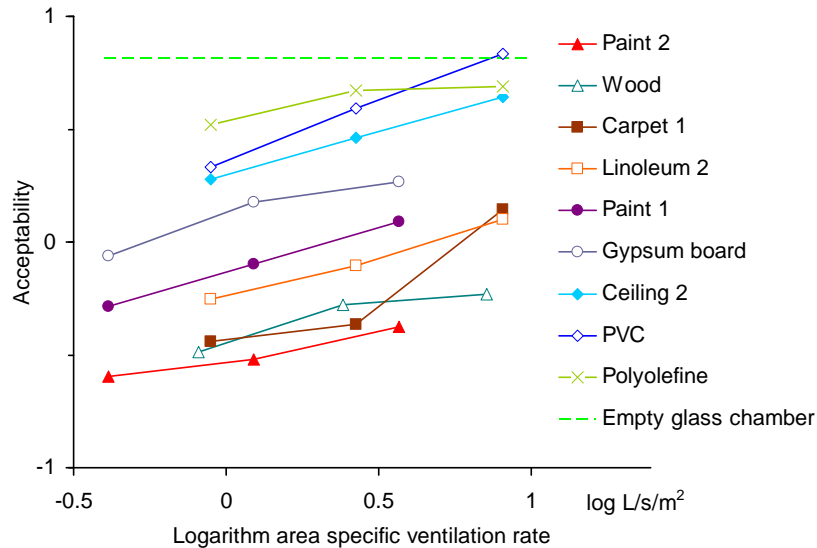


Figure 1. Acceptability of air quality as a function of the area-specific ventilation rate in small glass chambers containing the individual building materials that were examined in combinations in test rooms.

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 building materials including both high- and lower-polluting wall and floor materials, ranked by means of sensory assessments made in small-scale glass chambers; ceiling material was unchanged and always the same in all combinations examined in test rooms. The acceptability of air quality in empty test rooms was lower than in empty glass chambers, probably because the test rooms had undergone a renovation only a few month prior to the experiments and primary emissions were still affecting the perceived air quality.

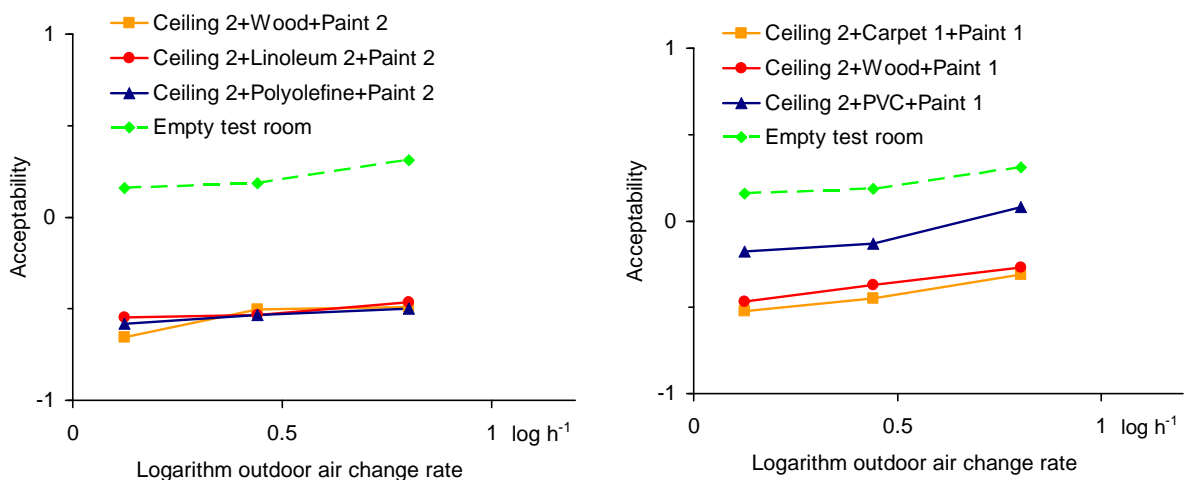


Figure 2. The effect of substituting high-polluting floor materials with lower-polluting materials on the acceptability of air quality in the tests rooms ventilated with different outdoor air change rates, when the combinations of materials included high-polluting (left) or lower-polluting (right) wall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

Figure 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 high-polluting Paint 2. When on the other hand 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.

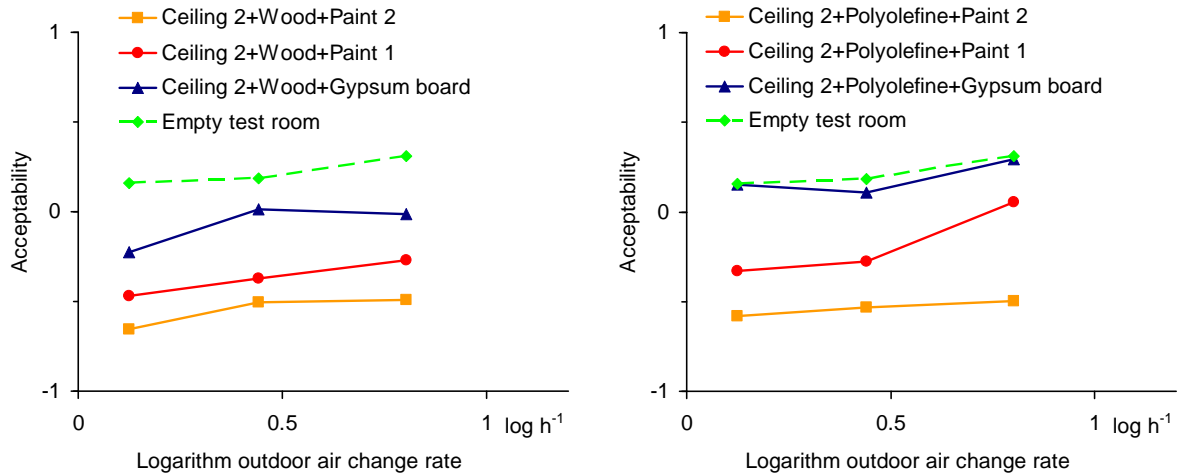


Figure 3. The effect of substituting high-polluting wall materials with lower-polluting materials on the acceptability of air quality in the tests rooms ventilated with different outdoor air change rates, when the combinations of materials included high-polluting (left) or lower-polluting (right) floor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

Figure 3 shows that the assessments of acceptability of air quality improved when the high polluting Paint 2 was substituted with lower-polluting Paint 1 or unpainted Gypsum board, independent of whether the combinations of materials included 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.

DISCUSSION

The study shows that reducing pollution sources by selecting lower-polluting building materials, ranked by means of 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 greater than what was achieved by increasing the outdoor air supply rate in a realistic range. 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 lower-polluting Gypsum board (Figure 3, left). Such results can be provided for nearly all substitutions with 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 high-polluting wall paint, Paint 2 (Figure 2, left). In this case the perceived air quality did not improve, probably because the strongest pollution source, in this case Paint 2, determines the perceived air quality in a room polluted by different materials. This phenomenon has also

been observed for mixtures of odorous compounds [11] and is further illustrated in Figure 4, which combines the results of sensory assessments of air quality in test rooms and small-scale glass chambers in one chart. Combining both data was possible because the area of materials tested individually in glass chambers was calculated using the area-specific ventilation rates estimated using the actual dimensions and outdoor air change rates in the test rooms. Figure 4 shows that the assessments of acceptability of air quality in rooms polluted by different combinations of building materials were similar to the assessments for the material that was the strongest pollution source in the combination according to the ranking made by means of sensory assessments made in small-scale glass chambers: Paint 2 in the combination including Ceiling 2, Wood and Paint 2, and Wood in the combination including Ceiling 2, Wood and Paint 1. The exception was the combination of Ceiling 2, Wood and Gypsum board. In this case the air quality was assessed to be more acceptable than the assessments of air quality polluted individually by Wood, the strongest pollution source in this combination, suggesting an air cleaning effect, probably due to adsorption on Gypsum board which is known to be a strong sink [12]. A similar air cleaning effect is also observed in Figure 3, right, 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 the decision, which materials to substitute with low-polluting alternatives, should be based on ranking of materials depending on their pollution strength; the highest polluting materials should be substituted first. Such ranking can be made, e.g. using sensory assessments of air quality in small-scale glass chambers, which as shown in the present experiments, is suitable for estimating the relative effects on perceived air quality in real rooms.

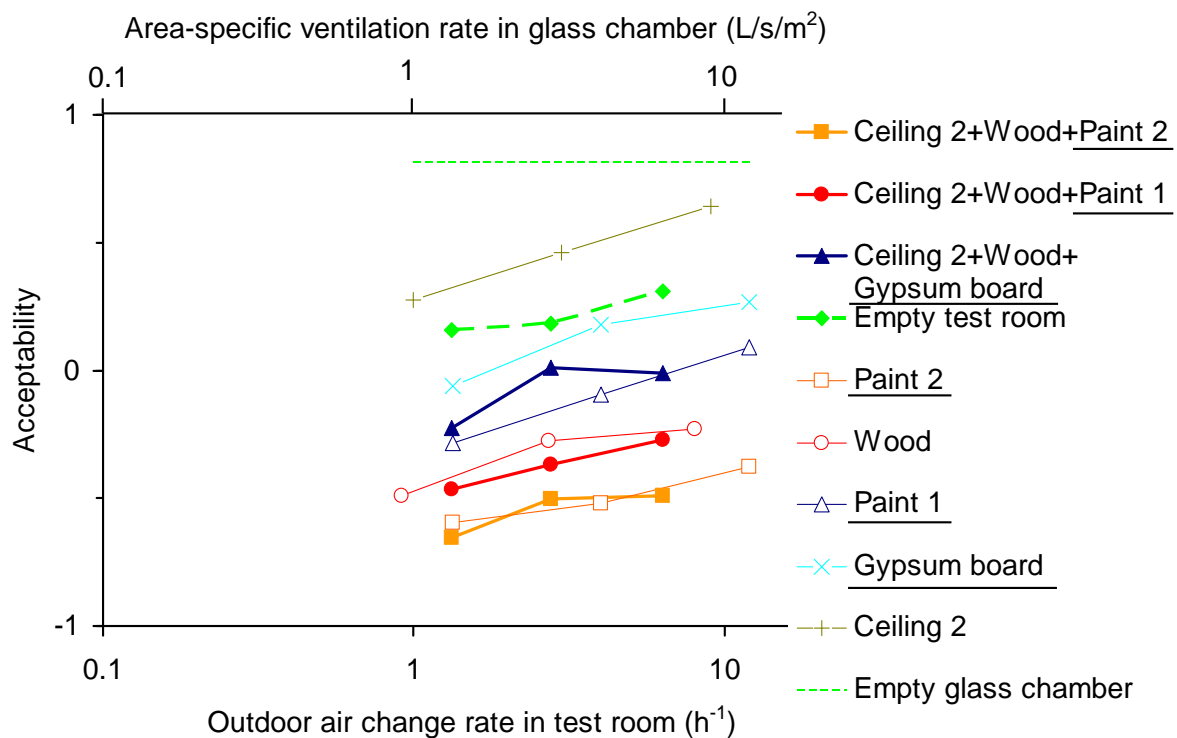


Figure 4. Assessments of acceptability of air quality as a function of the outdoor air change rate for the combinations of materials examined in the test rooms (thick lines) or the area-specific ventilation rate for individual materials tested in glass chambers (thin lines). The materials that were substituted are underlined. Note, the logarithmic scale on the abscissa.

The effect of using low-polluting building materials and increasing outdoor air supply rates on the perceived air quality were studied by examining the relationships between acceptability of air quality and ventilation rate, Figures 1-4. Such an approach has also been shown to be very useful in previous studies [2,9,10] when these effects have been quantified. These relationships can be used to assess to what extent a reduction in ventilation requirements in buildings will contribute to comply with the EU Directive 2002/91/EU [1] that requires reduction of energy use without negative consequences for the indoor environmental quality. They can also be used for specifying the requirements for emissions from building materials, e.g. by labelling schemes for building materials or ventilation standards.

The effects on perceived air quality were examined in rooms polluted only by building materials. Indoor air is however normally polluted also by human bioeffluents. The relationship between perceived air quality and ventilation rate for human bioeffluents was established in the 1980's [13]. However, the assessments were made by a sensory panel on a dichotomous (yes/no) acceptability scale that can not be directly compared with the relationships for building materials examined in this study. Future studies should investigate how the presence of bioeffluents in rooms with otherwise low-polluting building materials will influence the perceived air quality, and consequently ventilation requirements and energy use.

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 improvement of the perceived air quality was greater than the improvement obtained by increasing the outdoor air supply rate within a range that was realistic for indoor settings.

- The perceived air quality in a room polluted by building materials was improved when the highest-polluting material was substituted with a lower-polluting material.
- The greatest improvement of the perceived air quality is obtained when all high-polluting materials are substituted with low-polluting materials.

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REFERENCES

1. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.
2. Knudsen, H.N., Wargocki, P. and Vondruskova, J. 2006. Effect of ventilation on perceived quality of air polluted by building materials – a summary of reported data. *Proceedings of Healthy Buildings 2006* Vol. 1, pp 57-62.
3. Danish Indoor Climate Labelling (DICL): <http://www.danishtechnology.dk/13268>
4. Nordtest. 1998. Nordtest Method 1216-95, Building materials: Emission testing by CLIMPAQ chamber. Esbo, Finland: Nordtest.
5. Nordtest. 1990. NT Build 358, Building materials: Emission of volatile compounds, chamber methods. Esbo, Finland: Nordtest.
6. Albrechtsen, O. 1988. Twin climatic chambers to study sick and healthy building. *Proceedings of Healthy Buildings'88* Vol. 3, pp 25-30.

7. Wargocki P. 2004. Sensory pollution sources in buildings, *Indoor Air*, 14 (Suppl 7), 82-91.
8. Cain, W.S. and Moskowitz, H.R. 1974. Psychophysical scaling of odor. *Human Responses to Environmental Odors*, New York, Academic Press, 1-32.
9. Knudsen, H.N., Valbjørn, O. and Nielsen, P.A. 1998. Determination of Exposure-Response Relationships for Emissions from Building Products. *Indoor Air* 8, 264-275.
10. Wargocki, P., Sabikova, J., Lagercrantz, L. et al. 2002. Comparison between full- and small-scale sensory assessments of air quality”, *Proceedings of Indoor Air 2002 Vol. 2*, pp. 566-571.
11. Cain, W.S., Schiet, F.T, Olsson, M.J. and Wijk, R.A. 1995. Comparison of models of odor interaction. *Chemical Senses* 20, 625-637.
12. Sakr, W., Weschler, C.J. and Fanger, P.O. 2006. The impact of sorption on perceived indoor air quality. *Indoor Air* 16, 98-110.
13. Fanger, P.O. 1988. Introduction of the olf and decipol units to quantify air pollution perceived by humans indoors and outdoors. *Energy and Buildings* 12, 1-6.