Strategy for good perceived air quality in sustainable buildings

Knudsen, Henrik Nellemose; Wargocki, Pawel

Published in:
Proceedings of Clima 2010

Publication date:
2010

Document Version
Early version, also known as pre-print

Strategy for good perceived air quality in sustainable buildings

Henrik N. Knudsen[1] and Pawel Wargocki[2]

[1]Danish Building Research Institute, Aalborg University, Hørsholm, Denmark
[2]ICIEE, DTU Civil Engineering, Technical University of Denmark, Denmark

Corresponding email: hnk@sbi.dk

SUMMARY

Source control has been shown to be an effective strategy for improving air quality. The objective of the present study was to investigate and compare the potential for achieving an improved perceived indoor air quality by selecting less-polluting building materials or by increasing the ventilation rate in real rooms. Relationships between ventilation rate and perceived indoor air quality were established for differently polluting materials in real rooms. The results showed that the use of low-polluting materials reduced the ventilation rate required to achieve an acceptable level of perceived air quality and thereby prevented unnecessary use of energy for ventilation. For some high-polluting materials it will not be realistic in practice to provide enough ventilation to achieve an acceptable level of perceived air quality. Therefore, the use of low-polluting materials should be part of a strategy for good perceived air quality in sustainable buildings.

INTRODUCTION

In sustainable buildings it is necessary, among many other issues, to consider the energy used for ventilation with outdoor air to dilute emissions from people-related, activity-related, and building-related pollution sources indoors to a concentration level that provides an acceptable indoor air quality (IAQ). Acceptable IAQ with respect to comfort, health and productivity should be achieved at the lowest possible ventilation rate to prevent unnecessary use of primary energy. In addition, for a building to be sustainable, it is important to satisfy the needs of building users to prevent unnecessary use of resources, e.g. for rebuilding, replacement of HVAC equipment or even demolition earlier than expected. This paper focuses on perceived air quality (PAQ), one aspect of IAQ.

For the purpose of setting up a strategy for good PAQ in sustainable buildings, it would be useful to quantify and compare in real rooms the effect on PAQ of the two alternative strategies for improving PAQ: (i) source control and (ii) increased ventilation.

It is well established that an effective strategy for achieving good IAQ is source control. Building materials are important indoor pollution sources affecting IAQ. Therefore, different kinds of labelling schemes for emissions from building materials have been developed in various European countries [1]. The main purpose of labelling is to protect consumers from exposure to chemical pollutants and resulting adverse health effects and annoyance caused by unpleasant odours. EU experts have agreed that odour evaluations should be part of a labelling scheme [2, 3] to control for good perceived indoor air quality. The schemes share the approach that emissions from building materials are assessed by using ventilated small-scale test chambers in a laboratory setting. The schemes are based on the assumption that by increasing the perceived quality of the emissions from a building material, as documented by a test in a small-scale test chamber, the PAQ will also improve in a real full-scale room where the material is applied.

Previously studies have investigated the relationship between PAQ and the ventilation rate for pollution emitted from building materials either in small-scale chambers or in full-scale rooms [4, 5]. However, there is a lack of systematic experiments linking results from small-scale tests with the PAQ in real full-scale rooms where the materials are used.

The objective of the present study was to investigate and compare the potential for achieving a better PAQ by selecting less-polluting materials or by increasing the ventilation rate 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 in the range from high- to low-polluting. The relationships between ventilation rate and perceived indoor air quality, the so-called exposure-response relationships [4], were established to assess the impact of using less-polluting materials and/or an increased ventilation rate on the PAQ.

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 independently controlled for each test room by IRIS dampers with motorised shut-off dampers. 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 motorised 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 to hide the sources 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 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 [6, 7]. 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 [5]. 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 [7], 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 [8] and ventilated with an outdoor air change rate of 57 h^{-1}. Then a sensory panel assessed the quality of air exhausted from 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 three different area-specific ventilation rates, i.e. the ratio between the outdoor air supply rate and the area of material (Table 1). Different area-specific ventilation rates were obtained by varying the surface area of materials and keeping the ventilation rate through the glass chambers constant at 0.9 l/s. The area-specific ventilation rates were similar in the glass chambers and in the ventilated test rooms corresponding to air changes of 1, 3 and 9 h^{-1} for floor and ceiling materials and 1.3, 4 and 12 h^{-1} for wall materials; the higher air change rates for wall materials were due to limitations on the amount of material 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 beginning the experiments; the specimens were stored in a well-ventilated hall. During sensory assessments, specimens of materials used in test rooms were hung on trolleys placed in the cabinets, while other specimens were placed in glass chambers; the reverse side 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 specimens, which were hidden in cabinets in the test rooms or behind aluminium screens in the glass chambers.

Table 1. Area of building materials in the full-scale rooms and in the small-scale chambers

<table>
<tr><th colspan="2">Material</th><th colspan="4">Area of material (m^2)</th></tr>
<tr><th>Type</th><th>Description</th><th>Full-scale test room</th><th colspan="3">Small-scale glass chamber, CLIMPAQ</th></tr>
<tr><td>Ceiling 2</td><td>10 mm plain gypsum board covered with plastic coated material</td><td>18</td><td>0.113</td><td>0.338</td><td>1.013</td></tr>
<tr><td>Wood</td><td>14 mm beech wood parquets, untreated</td><td>18</td><td>0.126</td><td>0.372</td><td>1.106</td></tr>
<tr><td>Carpet 1</td><td>6.4 mm tufted loop polyamide carpet with supporting layer of polypropylene web and polypropylene backing</td><td rowspan="4">18</td><td rowspan="4">0.113</td><td rowspan="4">0.338</td><td rowspan="4">1.013</td></tr>
<tr><td>Linoleum 2</td><td>2.5 mm linseed-oil-based flooring, 52% wood meal</td></tr>
<tr><td>PVC</td><td>2.0 mm homogenous single layered vinyl flooring, reinforced with polyurethane</td></tr>
<tr><td>Polyolefine</td><td>2.0 mm homogenous polyolefine-based resilient flooring, reinforced with polyurethane</td></tr>
<tr><td>Gypsum board</td><td>13 mm plain gypsum board lined with cardboard</td><td rowspan="3">52</td><td rowspan="3">0.243</td><td rowspan="3">0.730</td><td rowspan="3">2.187</td></tr>
<tr><td>Paint 1</td><td>Gypsum board painted with one coat (0.14 l/m^2) of water-based acrylic wall paint</td></tr>
<tr><td>Paint 2</td><td>Gypsum board painted with one coat (0.14 l/m^2) of water-based wall paint with linseed oil</td></tr>
</table>

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). For it 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 rooms (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 the test rooms was kept constant at 22.2±0.3 ^{o}C; the relative humidity was not controlled and averaged 36±5%.

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 new combination of lower-polluting materials was always tested at three different ventilation rates in the same room to minimise 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 spent 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 the area-specific ventilation rate (for the ratings performed in glass chambers).

RESULTS

Figure 1 shows the mean assessments of acceptability of air quality for nine individual materials in small-scale glass-chambers at different area-specific ventilation rates. It is seen that the selection of the materials turned out well, since the materials covered a range from low to high acceptability (i.e. 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.

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 with different combinations of the nine building materials including both higher- and lower-polluting wall and floor materials; the ceiling material was unchanged and always the same in all test rooms.

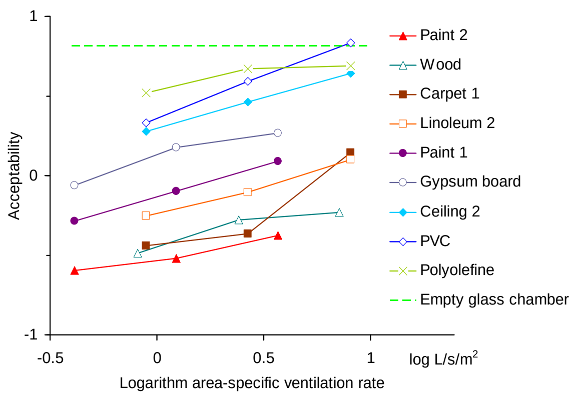

Figure 1. Mean acceptability of air quality as a function of the area-specific ventilation rate in small glass chambers containing the nine individual building materials that were examined in combinations in test rooms. The scale coding was as follows: -1=clearly not acceptable; 0=just not acceptable/just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

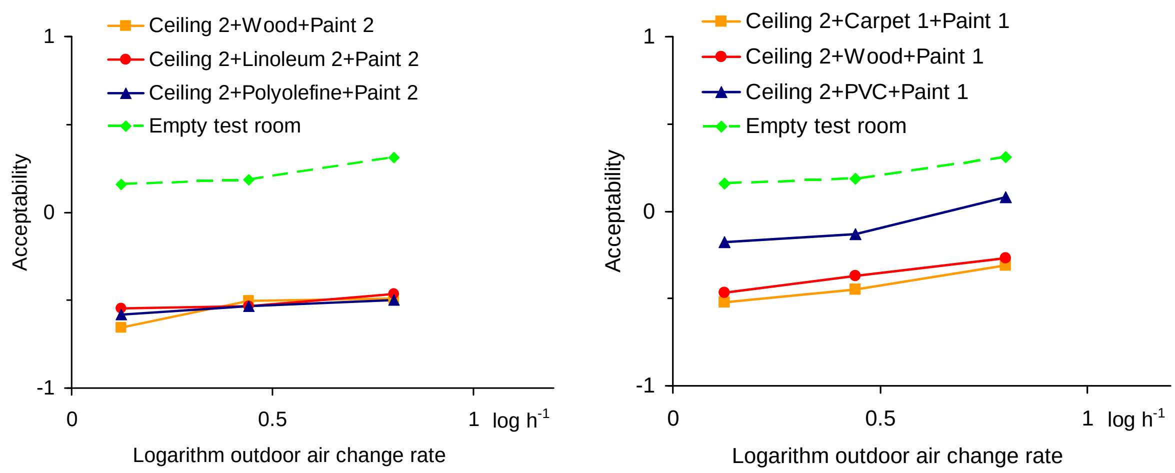

Figure 2. The effect of substituting high-polluting floor materials with less-polluting materials on the mean acceptability of air quality in the tests rooms ventilated with different outdoor air change rates, when the combinations of materials included high-polluting (left) or less-polluting (right)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

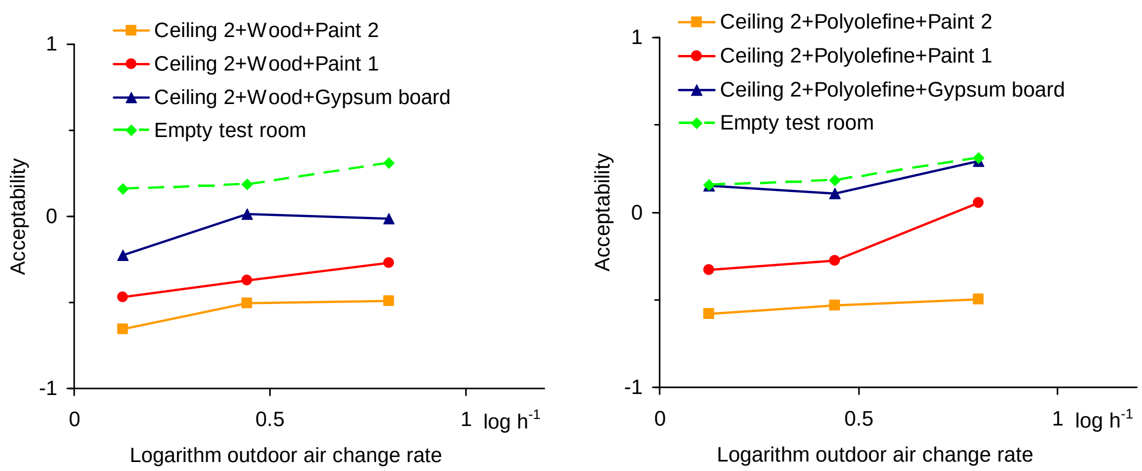

Figure 3. The effect of substituting high-polluting wall materials with less-polluting materials on the mean acceptability of air quality in the tests rooms ventilated with different outdoor air change rates, when the combinations of materials included high-polluting (left) or less-polluting (right)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

The acceptability of air quality in the empty test rooms was lower than in the 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 PAQ. Figure 2 left shows that substituting the higher-polluting Wood with less-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 less-polluting Paint 1 (Figure 2 right), substituting higher-polluting Carpet 1 or Wood with less-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 the less-polluting Paint 1 and it improved further when substituted with unpainted Gypsum board, independently of whether the combinations of materials included the high-polluting Wood (left) or less-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, however, was generally small compared with the effect of substituting higher-polluting materials with less-polluting materials.

DISCUSSION

Substituting building materials with materials shown in small-scale chamber tests to be less-polluting generally improved the PAQ in full-scale test rooms. The effect was most pronounced when the most polluting material was replaced by a less polluting material. This improvement was more pronounced than that achieved by a realistic increase of the outdoor air supply rate. For example, the fivefold increase of the outdoor air supply rate improved the acceptability of the quality of air polluted by the combination of Ceiling 2, Polyolefine and Paint 1 less than when substituting Paint 1 in this combination with the less-polluting Gypsum board (Figure 3, right). Similar results can be seen for nearly all substitutions with less-polluting materials. The only exception was the substitution of high-polluting floor material with less-polluting materials when the room air was still polluted by the most-polluting Paint 2 (Figure 2, left). In this case, the PAQ did not improve, probably because the strongest pollution source, Paint 2, was so dominating that it determined the poor PAQ in the room. For the high-polluting materials it was seen that, even at the highest ventilation rate at 6.4 h^{-1}, it was far from possible to achieve an acceptable level of perceived air quality.

Figure 3, right, shows that it was possible to install the low-polluting materials Ceiling 2, Polyolefine and Gypsum board in the empty test room without lowering the acceptability of quality of air. For some materials a possible air cleaning effect may be seen.

The results showed that a rational way of improving the PAQ in a room was to substitute the most polluting material with a less polluting alternative. For that purpose a ranking of materials by using sensory assessments of air quality in small-scale glass chambers as seen in Figure 1, is suitable for estimating the relative effects on PAQ in real rooms.

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 [9] which 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 normally constitutes about 20-30% of the total energy consumed in buildings today. This could 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 disagrees with the requirements of the EU Directive. The obvious solution for this conflict would be to reduce the emission from pollution sources indoors, as indicated in the present study.

Even though it is not possible at present to predict the PAQ in a building directly from data obtained in small-scale test chambers in the laboratory, it is strongly recommended to test building products in the laboratory for the purpose of labelling or ranking building materials. This study demonstrates that with the appropriate acceptance criteria in a labelling scheme the use of low-polluting materials can help to ensure an acceptable level of PAQ at a low ventilation rate and thereby prevent unnecessary use of energy for ventilation. The present labelling schemes are typically voluntary for the manufacturers. In spite of a trend towards European harmonisation, most labelling schemes focus mainly on national markets. Test methods are basically the same but the evaluation of emission test results vary from scheme to scheme. A harmonised system for material emission labelling in Europe is called for in order to take full advantage of the potential to improve the PAQ at a low ventilation rate. The connection between the criteria of labelling schemes of material emissions and standards on ventilation requirements should be further studied. This knowledge is also relevant for inclusion of source control and assessment of energy consumption in sustainable building certification and rating programs like e.g. BREEAM or LEED.

To ensure good PAQ, a practical approach is needed since all relevant information may not be available. A practical strategy for good PAQ in sustainable buildings is outlined in the following. Two relevant situations could be considered: (i) the design stage and (ii) an PAQ problem in an existing building.

At the design stage the minimum required ventilation rate is determined based on regulations, standards and guidelines. Effective ventilation systems should be used, e.g. use of local exhaust for known concentrated sources (chemicals and moisture). Then the main sources of pollutants should be identified and eliminated or decreased as much as possible. Such source control, however, is not a straightforward process since the emission may not be known for many products. One way of tackling the selection of products, which does not necessarily ensure that the lowest-polluting products on the market are used, would be to search for and use indoor-labelled products. If project economy and time allow, it may be relevant to make emission testing of relevant but non-labelled products e.g. in accordance with the procedures in the labelling schemes. Finally, use of common sense and experience from previous projects are valuable for careful selection of products that do not cause odour problems.

Eliminating an existing PAQ problem is often not a straight forward process either. It may require advice from experts with experience of odour from various indoor sources. If it is not obvious straight away what causes the odour problem, a first step would be to make sure that the ventilation rate is sufficient according to regulations, guidelines and standards. If the PAQ problem persists, it is necessary to try to identify the strongest odour source(s) and then eliminate/remove/substitute/seal it/them.

If no precautions are taken, the ventilation rate required to achieve a given level of perceived air quality, if possible at all, may be considerable and require unnecessary use of energy. The required ventilation rate may of course be determined by other parameters than odour like e.g. the need for heating or cooling of rooms with supply air, health-related chemicals like formaldehyde or humidity sources. Although source control is a very effective strategy for improving air quality it should be recognised that some sources of indoor air pollution cannot be removed, e.g. bioeffluents.

CONCLUSIONS

- The use of low-polluting materials should be part of a strategy for good perceived air quality in sustainable buildings.
- The use of low-polluting materials reduces the ventilation rate required to achieve an acceptable level of perceived air quality and thereby prevents unnecessary use of energy for ventilation.
- For some high-polluting materials, it will not be realistic in practice to provide enough ventilation to achieve an acceptable level of perceived air quality.

ACKNOWLEDGEMENT

The work was supported by the Danish Energy Authority through an EFP-05 project "Reduced energy use for ventilation in buildings through selection of low-polluting building materials and furniture", contract #33031-0048. The authors wish to thank Jana Vondruskova and Pawel Zuczek, who acted as research assistants in the laboratory experiments and gave an account of them in their M.Sc. theses. Thanks also to Gunnar Holm, SBi and Peter Simonsen, DTU for technical assistance during experimental work and to Birgit Markfoged, SBi for assisting in recruiting the sensory panel.

REFERENCES

1. ECA-IAQ (European Collaborative Action, Urban Air, Indoor Environment and Human Exposure), 2005. Harmonisation of indoor material emissions labelling systems in the EU Inventory of existing schemes, Report No 24. EUR 21891 EN. Luxembourg: Office for Official Publications of the European Communities.
2. ECA-IAQ (European Collaborative Action ''Indoor Air Quality and its Impact on Man'') 1997. Evaluation of VOC Emissions from Building Products – Solid Flooring Materials, Luxembourg, Office for Publications of the European Communities (Report No. 18 (EUR 17334 EN)).
3. ECA-IAQ (European Collabortive Action "Indoor air quality and its impact on man"), 1999. Sensory evaluation of indoor air quality. Report No. 20. EUR 18676 EN. Luxembourg: Office for official publications of the European communities.
4. 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.
5. 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.
6. Nordtest. 1990. NT Build 358, Building materials: Emission of volatile compounds, chamber methods. Esbo, Finland: Nordtest.
7. Nordtest. 1998. Nordtest Method 1216-95, Building materials: Emission testing by CLIMPAQ chamber. Esbo, Finland: Nordtest.
8. Albrechtsen, O. 1988. Twin climatic chambers to study sick and healthy building. Proceedings of Healthy Buildings'88 Vol. 3, pp 25-30.
9. Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.