Saving energy for ventilation by careful selection of building materials

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SUMMARY:
The main objective of the research project described in this paper was to study the potential of reducing energy used for ventilating buildings by using low-polluting building materials, without compromising indoor air quality. To quantify this potential, the exposure-response relationships, i.e. the relationships between ventilation rate and the perceived indoor air quality (indoor air quality perceived by humans as opposed to indoor air quality evaluated by chemical measurements), were established for rooms furnished with different more or less polluting materials. Based on these results, simulations of energy used for ventilation were carried out for selected building scenarios. The results show that the exposure-response relationships vary between different building materials. Consequently, the ventilation required to achieve a certain level of perceived indoor air quality varies according to which building materials are used. Furthermore, the results show that the perceived air quality in rooms can be considerably improved when low-polluting building materials are selected and that the improvement is greater than a realistic increase of the ventilation rate. The energy simulations show that selecting low-polluting materials will result in a considerable energy saving as a result of reducing the ventilation rates without compromising indoor air quality. Halving the ventilation rate, which seem to be realistic when low-polluting building materials are used, can reduce the energy used for ventilation by up to 50%. However, the energy savings from using low-polluting building materials are limited by the extent to which ventilation is used to control the thermal environment, i.e. heating and/or cooling the supplied outdoor air.

1. Introduction

There is a need to reduce energy consumption worldwide. One initiative to reach 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 most buildings this can only be achieved if the energy used for ventilation is also reduced, because 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.

This paper describes the results of the research project called “Reduced energy use in buildings through selection of low-polluting building materials and furniture”. The main objective of the project was to quantify the extent to which reducing pollution sources indoors by selecting low-polluting building materials would reduce the energy used for ventilation of buildings, without compromising indoor air quality as it is perceived by humans and not as it is defined by the concentration of air pollutants measured using chemical methods. This objective was achieved by summarizing the existing data on the effects of emissions from building materials on perceived air quality, by carrying out experiments in which the effects of using low-polluting building materials on the perceived air quality were examined and related to ventilation requirements, and by performing energy simulations examining the extent to which reducing ventilation rates, as a consequence of using low-polluting building materials, will affect energy use.

2. The effects of using low-polluting materials on ventilation

Several studies have previously investigated the effects of pollution emitted by building materials on indoor air quality as it is perceived by people, and related these effects to ventilation requirements. In these studies, perceived air quality was generally measured by a group of untrained persons who were exposed to air polluted by emissions from building materials and /or rooms and assessed the quality of air immediately upon exposure by rating whether the air quality was acceptable or not acceptable. To examine the effect of ventilation on the perceived air quality when different building materials are selected, the exposure-response relationships between the acceptability of air quality and the dilution achieved by changing the ventilation are created by log-linear regression (Cain and Moskowitz 1974, Knudsen et al. 1998).

The data obtained in previous experiments was summarized and systematized by Knudsen et al. (2006). They concluded that the effect of changing the ventilation rate on the perceived quality of air polluted by different building materials can vary considerably. Consequently there are relatively large differences in the ventilation requirements needed to obtain a certain level of perceived air quality for emissions from different building products. There could be a number of factors causing the observed differences and may for example include: the type of pollution source; psychological factors such as context in which assessments are made (in laboratory vs. in real buildings); expectations and previous experience with odours; the information given concerning the pollution sources before assessments; physiological factors such as more or less adaptation to air pollution; perception of complex odour mixtures from e.g. combinations of building products; chemical/physical factors, e.g. how products interact when air pollution is adsorbed and/or desorbed on material surfaces; and reactive chemistry, e.g. when odorous secondary emissions are formed in reactions with for example ozone. All these factors should be taken into account when investigating the effects of using low-polluting materials on perceived air quality and ventilation requirements.

The summary of Knudsen et al. (2006) showed in addition that 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 (Witterseh 2002) and then the effect on the indoor air quality of using these materials in real rooms is examined. Experiments were carried out to fill this gap (Wargocki et al. 2007). In these experiments a sensory panel assessed the air quality in full-scale test rooms ventilated with three different outdoor air supply rates and polluted by nine combinations of typical building materials including wall, floor and ceiling materials; the materials ranged from high- to low-polluting, and were ranked in this range using sensory assessments of air quality in small-scale glass chambers where they were tested individually following the principles of the Nordtest methods (Nordtest 1990, 1998). The results of this testing are shown in Figure 1 confirming that both high- and low-polluting materials were selected.

The materials tested individually in small-scale glass chambers were examined in combinations in the test rooms. The results of these experiments confirm 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. This is exemplified in Figure 2. It shows that the air quality improved when the high-polluting paint on gypsum board (Paint 2) was substituted with lower-polluting paint on gypsum board (Paint 1) or unpainted gypsum board (Gypsum board). The improvement was greater than that achieved by increasing the outdoor air supply rate in a realistic range: a sevenfold increase of the outdoor air supply rate improved acceptability of quality of air polluted by a combination of materials including plastic-coated gypsum ceiling (Ceiling 2), polyolefine flooring (Polyolefine) and paint on gypsum board (Paint 1) less than substituting Paint 1 in this combination with lower-polluting gypsum board (Gypsum board). Similar results were obtained for nearly all other substitutions with the lower-polluting building materials examined (Wargocki et al. 2007).

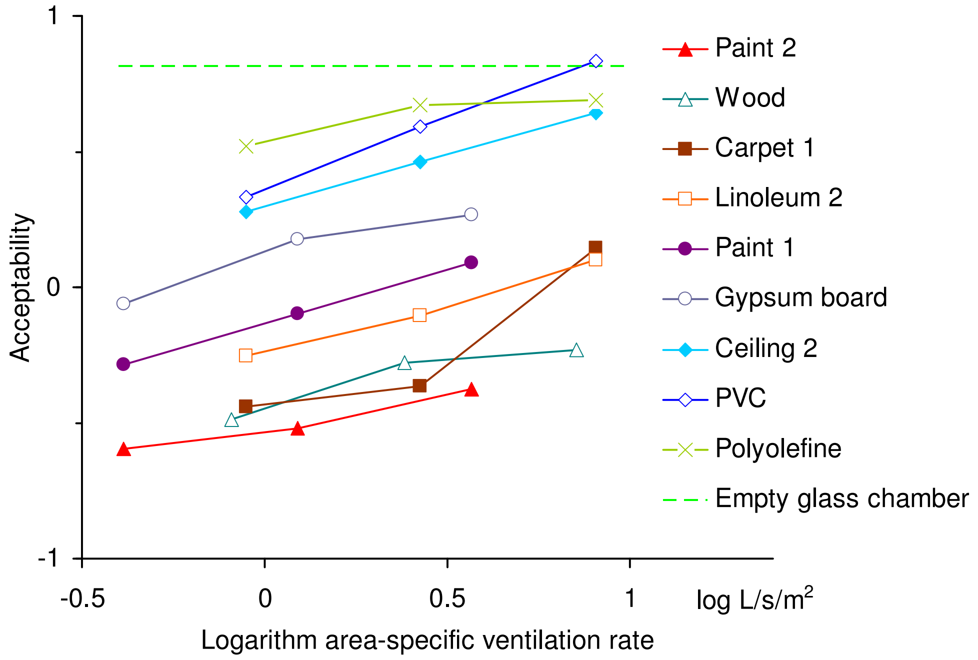

FIG 1: Acceptability of air quality as a function of the area-specific ventilation rate in small glass chambers containing the individual building materials that were examined in combinations in test rooms (Wargocki et al. 2007); the scale coding was as follows: -1=clearly not acceptable; 0=just not acceptable/just acceptable; +1=clearly acceptable

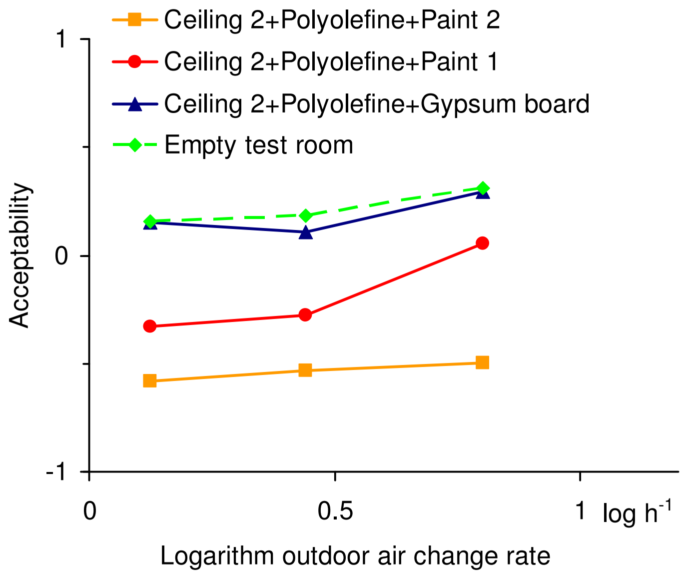

FIG 2: The effect of substituting high-polluting wall materials with lower-polluting materials on the air quality in the tests rooms (Wargocki et al. 2007); the scale coding was as follows: -1=clearly not acceptable; 0=just not acceptable/just acceptable; +1=clearly acceptable

3. The effects of using low-polluting materials on energy

The results presented in Fig. 2 show that reducing pollution sources by selecting lower-polluting building materials improved the perceived air quality and that this improvement was much greater than the improvement of perceived air quality by increasing ventilation rates in a range realistic for indoor environments. To examine the consequences of selecting low-polluting building materials on energy used for ventilation, dynamic simulations were performed of annual energy used for ventilation of a single office room. Simulations of energy used for different ventilation rates in the office were performed. Because the ventilation rates are proportional to the pollution load at a constant air quality level, varying the ventilation rates during simulations was equivalent to changing the pollution load or simply selecting materials that were more polluting or less polluting. Simulations were performed for 19 different total outdoor air supply rates. The maximum ventilation rate was 117 L/s. It was selected with due consideration to the limitations regarding maximum air velocities in the room. It corresponds to an air change rate of 8 h^{-1} and it was assumed to be the highest possible ventilation rate that can be delivered to the room without causing any local discomfort due to draught. The lowest ventilation rate was 6 L/s. It is based on the minimum requirements of ASHRAE Standard-62 for the case of adapted occupants (ASHRAE, 2007), i.e. 3 L/s per person.

Different configurations of the office were simulated. The office had two different orientations (windows facing south or north) and three different methods of reducing heat loads: solar shading, cooling the air supplied to the office by the HVAC system and night cooling. In addition, the conditions with normal and reduced heat loads in the office were simulated. In total, 69 different simulations were performed.

The modelled office had a floor area of 19 m^2 and a height of 2.8 m (volume 53 m^3). It was situated in Copenhagen, Denmark. The office was occupied by 2 non-smoking persons and was equipped with 2 computers, 2 desk lamps and general lighting. The occupants were scheduled to work in the room from Monday to Friday between 8 am and 4 pm excluding public holidays.

The room's envelope was designed according to Addendum 12 to the Danish Building Regulations (BR95, 2005). The air was supplied to the room by mechanical ventilation and the heating in winter was provided by a radiator. The supply air to the room was provided by a constant air volume (CAV) ventilation system. The air was taken from outside the building and was treated in an air-handling unit consisting of heat recovery unit, heating coil and in some cases cooling coil. No humidification of the air took place. It was assumed that the outside air was clean and that full mixing in the room took place. The heat from the exhaust air was recovered in a heat exchanger with the efficiency of 0.6; no cold or moisture recovery took place. The ventilation system was started one hour prior to arrival of occupants of the office and it was in operation until the end of working hours. Additionally, when the night cooling was simulated, the ventilation system was also operated at night. Infiltration to the room during non–occupancy period was assumed to be 0.2 h^{-1}. During working hours it was increased to 0.4 h^{-1}. The windows could not be opened.

Simulation of annual energy use was carried out using a BSim simulation programme (Wittchen et al. 2005); the energy used for the heating, ventilation and air-conditioning (HVAC) system was calculated. The energy consumption of the HVAC system includes the energy used for transporting, heating and, when applicable, cooling the air. The energy used for heating comprises that used for radiators and for the heating coil in the air-handling unit. The energy consumption for cooling is the energy consumed by the cooling coil in the air-handling unit. The energy consumption of a fan is proportional to both the airflow and the pressure rise. In the simulations it was assumed that the supply and return fans had flat characteristics within the considered range of airflows. Therefore, the pressure rise was constant in all simulations and the energy consumption by a fan depended only on the airflow. While calculating the total energy consumption for a HVAC system, the weighting factors for different types of energy were used as prescribed in the Danish Building Regulations (BR95, 2005). Assuming an average coefficient of performance (COP) of 2.5 for the cooling system, the cooling energy and the heating energy had the same weight and were added without correction by any factor. The electrical energy for fans was multiplied by a factor of 2.5. The total energy consumption for the HVAC system was thus calculated by adding the cooling and heating energy, and the energy for operation of fans, multiplied by the factor of 2.5.

Figures 3 and 4 show the results of simulations for an office facing south and north, respectively, for the relationships between energy used by the HVAC system and the ventilation rate. Separate relationships are presented for the different conditions simulated. Both figures show that the energy used by the HVAC system can be assumed to increase linearly with the increased ventilation rate, independently of the room orientation and different means of reducing heat in the office. They show also that when night cooling and air cooling are applied, the energy used by the HVAC system increased, as expected.

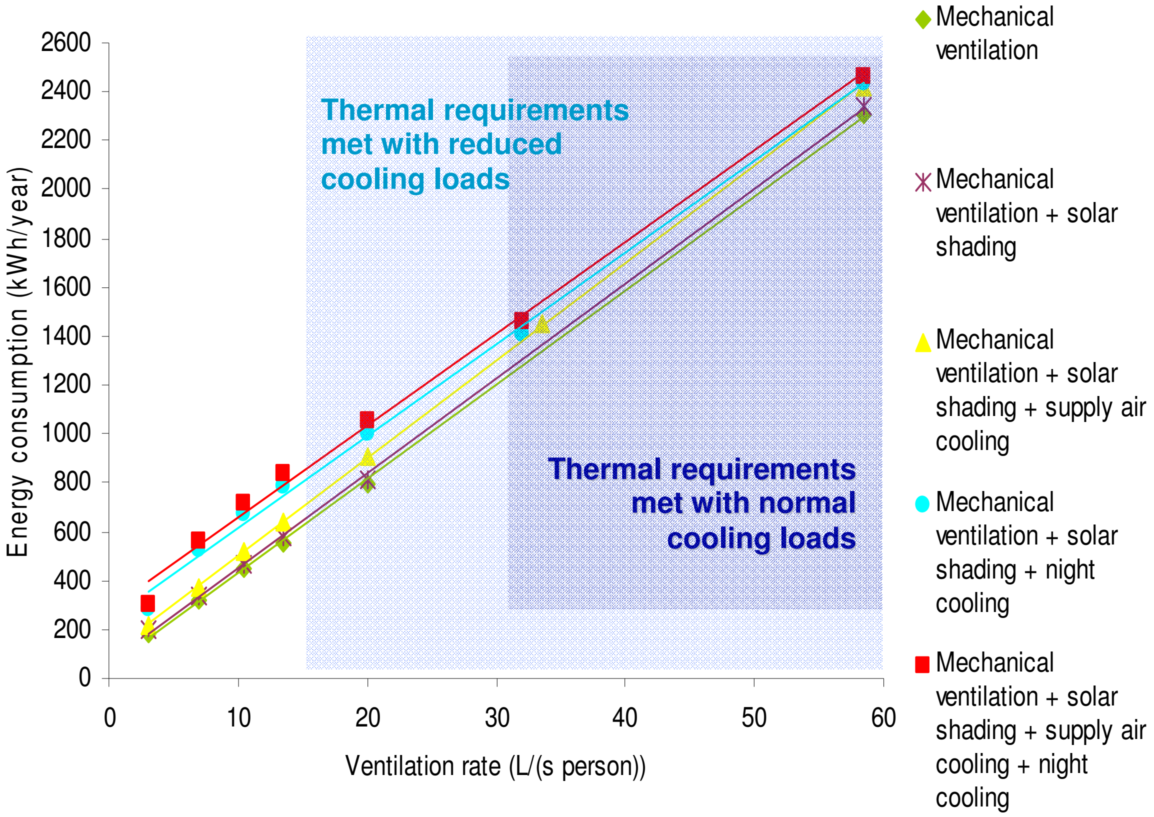

FIG 3: The relationships between energy used by the HVAC system and the ventilation rate for the room facing south for different simulated conditions

The results of simulations show that there is considerable potential for saving energy when low-polluting building materials are used. The ventilation rates can then be reduced significantly without compromising the perceived indoor air quality in the office. The greatest potential exists when ventilation is not used to cool the office to avoid overheating. The energy used by the HVAC system can then be reduced by about 90% when the ventilation rate is reduced to the minimum required by ASHRAE Standard 62 (ASHRAE, 2007) as a consequence of selecting low-polluting building materials (see the relationships in Figures 3 and 4 showing the results of simulations in the office ventilated by mechanical ventilation only and when the solar shading was applied). The potential for energy savings is lower when ventilation is used to cool the office so that it does not become overheated for longer periods than those specified in building regulations and standards. The maximum potential for energy savings in this case is illustrated in Figures 3 and 4 by the shaded areas, assuming that the periods with overheating are not longer than those specified by the Danish Standard DS 474 (DS 474, 1993); two cases are illustrated (1) for the office with normal heat loads and (2) when all efforts were made to reduce heat loads (by the application of energy-saving bulbs and low-energy PC monitors to reduce heat loads by 35% at their peak). In the office with normal heat loads, it was possible to decrease the ventilation rate to 32 L/(s•person) for the room with south orientation and 25 L/(s•person) for the room facing north when the supply air cooling, night cooling and solar shading were applied. This corresponds to about 50% reduction in energy use for the HVAC system, compared to the office ventilated with the maximum ventilation rate, but the minimum ventilation rates are still much higher than those prescribed by the current ventilation rates (ASHRAE, 2007; CEN CR 1752, 1998). In the office with reduced heat loads it was possible to reduce the ventilation rate to 16.5 L/(s•person) for the room with south orientation and 6.5 L/(s•person) for the room with north orientation without compromising the requirements of DS 474, the ventilation rates being similar to those specified by current ventilation standards. This corresponds to about 60% to 75% reduction in energy use for the HVAC system. It should be noted that when the office was ventilated by mechanical ventilation only, it was not possible to meet the requirements of DS 474 for either south or north orientation, even when solar shading was applied in the former case; the office was overheated for periods that were too long.

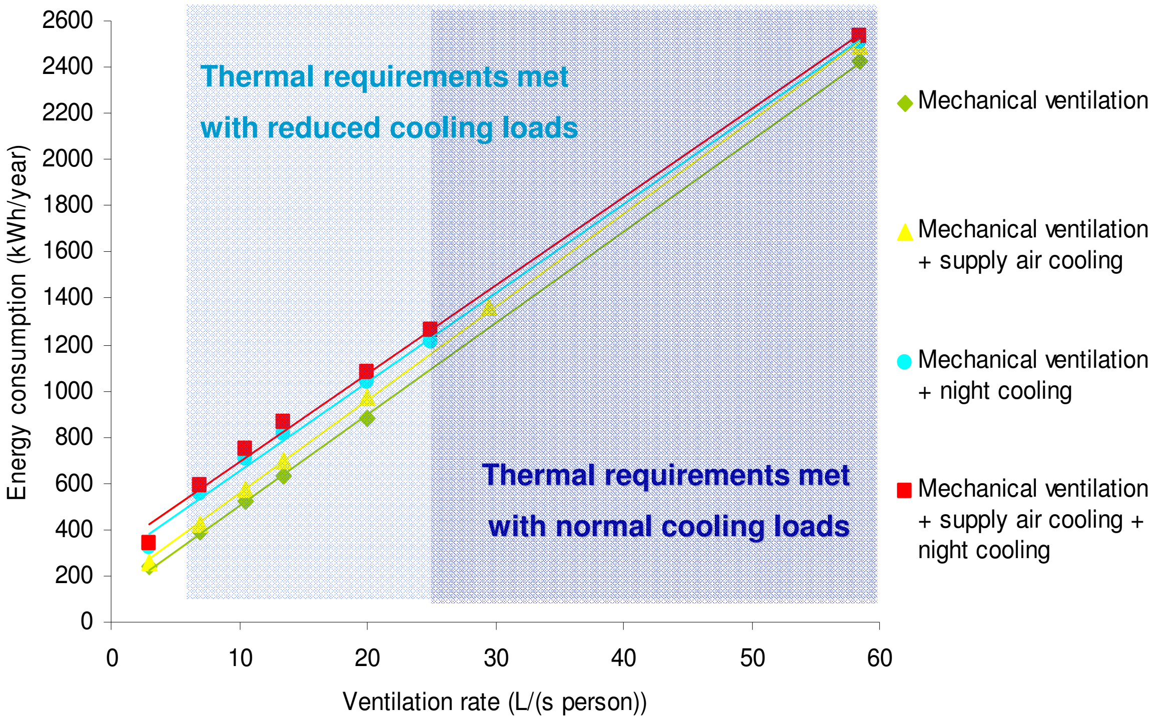

FIG 4. The relationships between energy used by the HVAC system and the ventilation rate for the room facing north for different simulated conditions

The results presented above show that when the supply air from the ventilation system is used to cool rooms, a great effort must be made to limit the heat gains in order to fully utilize the potential for energy saving when low-polluting building materials are used. This will lead to even higher energy savings as less energy will be used for light and equipment. At the same time, the requirements for both thermal climate and indoor air quality will not be compromised and the requirements of the EU Directive 2002/91/EC Energy Performance of Buildings will thus be met.

4. Conclusions

Data were summarized reporting the relationships between ventilation rate and perceived air quality when building materials are the main pollution sources. They show that these relationships vary for different building materials.

Substituting building materials with materials shown in small-scale chamber tests to be lower-polluting, improved the perceived air quality in full-scale tests.

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

Simulations of the operation of HVAC systems showed that the energy used by a ventilation system for transporting, heating and cooling the air can be assumed to be linearly related to the ventilation rate, e.g. halving ventilation rates can result in up to 50% reduction in energy use.

Energy simulations showed that reducing the ventilation requirements when low-polluting materials are selected will result in potentially large energy savings. However, they also show that the potential for energy saving may be limited if ventilation is used to control thermal conditions, e.g. for cooling the supply air to rooms. In this case, all efforts must be made to minimize heat loads so that energy saving as a result of using low-polluting building materials will be fully utilized.

5. Recommendations for future studies

The exposure-response relationships used in the present work express the influence of pollution from combinations of different building materials and furniture on the perceived air quality. However, the indoor air is also polluted by human bioeffluents. It is therefore recommended to create exposure-response relationships for combinations of building materials and people and in this way investigate how the presence of people influences the ventilation required for acceptable indoor air quality and consequently the energy used for ventilation.

The impact of other methods of improving indoor air quality without unnecessary use of energy should be investigated. These methods include the use of active and passive air cleaners and air-cleaning building materials.

It would be useful to validate the present results obtained in laboratory experiments in existing buildings. Energy simulations for other climate zones would also be useful considering that the energy simulations in the present project were performed only for a hypothetical building located in a moderate climate.

6. Acknowledgments

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