Emissions from Building Materials: Simulation of the Indoor Air Quality

Samuel Caillou, Paul Van den Bossche, Luk Vandaele

Belgian Building Research Institute (BBRI)
Lombardstraat 42, 1000 Brussel, Belgium
+32 2 655 77 11 samuel.caillou@bbri.be

ABSTRACT

The emission from materials is an important source of degradation of our indoor air quality. To investigate this field, it is necessary to determine pollutant concentration inside buildings, based on emission rates and air exchange rate (ventilation + envelope airtightness). This paper presents different method for such determination and their application to the case of formaldehyde from building materials. The simplest method, using simplified emission rates and simplified air exchange rates is only appropriate for a first screening to obtain order of magnitudes for pollutant concentrations, while more complex methods, using static or dynamic simulations of building air flows are powerful techniques to investigate in more details the effect of the emissions (rates, material distribution, etc) as well as ventilation system (type, flow rate).

KEYWORDS

Indoor air quality, material emissions, dynamic simulation, ventilation systems.

1. INTRODUCTION

The emissions from the building materials are more and more considered as causing a degradation of the indoor air quality (IAQ) and presenting a risk for our health. The improvement of the energy performance of buildings is related, among other, to a higher airtightness of the building envelope, decreasing the air exchange rate due to ex- and infiltration. At the same time, ventilation of buildings is now a legal requirement in most of the European countries. The evaluation of the health risk related to material emissions implies normally the following steps: (1) identifying the priority pollutants, (2) determining the pollutant concentration inside buildings, and (3) comparing this concentration with limit values. The aim of this paper is to show the different possibilities of pollutant concentration determination (step 2 above) with their advantages and limitations, illustrated with the case of formaldehyde.

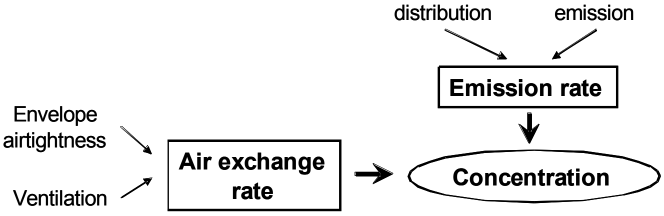

Figure 1: Dependence between the pollutant concentration, the air exchange rate and the emission rate.

As illustrated in Figure 1, the pollutant concentration depends on the emission rate (ER) and the air exchange rate (AER). For these input parameters, very simple values can be considered or more detailed ones, based on envelope airtightness and ventilation system on one hand, and on material emission and material distribution on the other hand.

2. METHODS FOR DETERMINING CONCENTRATION (CASE FORMALDEHYDE)

Method 1: Simplified emission rate + simplified AER → estimated concentration

The simplest way to obtain the pollutant concentration (C, µg/m³) inside the building is a calculation based on an average emission rate (ER, µg/h) and an average air exchange rate (AER, h^{-1}), using the following equation, where V is the volume of this room or building:

$$C = \frac{ER}{AER} \cdot \frac{1}{V}$$

For example, a flooring material with emission rate of 10 µg/h.m², in a sleeping room (2.6 m height) with an AER of 1 h^{-1}, leads to a roughly estimated pollutant concentration of 4 µg/m³. This simple method must however be used with care, eventually as a first screening.

Method 2: Detailed emission rate + static simulations → concentration per room

In this second approach, the sources of the pollutant as well as the AER (ventilation + airtightness) are investigated in more detail.

For the **emission sources**, different building materials, presenting their own emission rate, were taken into account. A detached house was considered (Verbeeck et al. 2006) and hypothesis were made on the distribution of the building materials in the different rooms, with the following categories of building materials: plaster and paint for all walls and ceilings, laminate/parquet in the living, carpet in the study room, soft flooring (vinyl, pvc, etc) in the 3 sleeping rooms, and wood panels for the cupboards in the kitchen and the bathroom. The flooring in the other rooms (tiles were considered) and building materials hidden by these finishing materials were considered as not contributing to pollutant emission. For each category of these materials, 4 values of emission rates for the formaldehyde were selected in the "BUMA" database (see www.enman.uowm.gr/bumaproject/): the highest and the lowest emission rates, after 24 hours (short term emission) and 30 days (long term emission) respectively. Based on these values and hypothesis, the total emission rates for each room of our model detached house were calculated and are given (in the form of rates per floor surface area, in µg/h.m²) in Table 1 (top).

For the **AER**, a simple ventilation system was investigated. This system provides permanently in each room, the flow rates (see Table 1) required by the regulation in Belgium (NBN D 50-001). According to this regulation, the fresh air is provided in the "dry rooms" (sleeping room, living room, office, etc), and transferred to the "wet rooms" (kitchen, bathroom, toilet, etc) from where the air is evacuated to outside. An envelope airtightness of 3 m³/h.m² (of building envelope) was used (corresponding roughly to n_{50}value of 3 h^{-1}). With such a system (mechanical supply and exhaust) and such good airtightness, the influence of the climate can be neglected (effect of wind and temperature differences). Airflow simulations using the software Contam (www.bfrl.nist.gov) were carried out in static conditions (one simulation; no variation of climatic conditions).

Table 1: Total emission rates per floor surface area for formaldehyde (µg/h.m²); and concentrations of formaldehyde (µg/m³) obtained using static simulation with ventilation flow rates according to the Belgian regulation.

		Living room	office	Sleeping room 1	Sleeping room 2	Sleeping room 3	Toilet	Laundry	Kitchen	Bathroom	Hall
Floor area (m²)		35.7	8.0	17.0	18.2	18.3	1.7	7.7	10.2	8.0	28.8
Total formaldehyde emission rates per floor surface area in each room (µg/h.m²)											
24h	**low**	6	9	7	6	6	21	10	12	11	7
	high	1648	3001	2207	2141	1986	6607	3075	5723	4623	2316
30d	**low**	0	0	0	0	0	0	0	0	0	0
	high	280	335	278	270	253	733	340	666	532	273
Flow rate (m³/h)		128	29	61	66	66	25	50	50	50	
Formaldehyde concentration in each room (µg/m³)											
24h	**low**	1.7	2.6	1.8	1.7	1.6	4.7	4.8	3.5	4.8	3.3
	high	456	824	610	591	552	1518	1576	1338	1727	1087
30d	**low**	0	0	0	0	0	0	0	0	0	0
	high	77	92	77	75	70	184	192	180	209	136

The formaldehyde concentrations obtained for each room, given in Table 1 (bottom), reveal firstly the big differences between the lowest/highest emitting materials and between 24h/30d emission data, although the variation between rooms is limited to a factor of around 3. Secondly, the ventilation flow rates according to the Belgian regulation are sufficient to keep formaldehyde concentrations below 10 µg/m³ for the lowest emitting materials, for short term emission (24h) as well as long term (30days). However, for the highest emitting materials from the BUMA database, the concentrations of formaldehyde are of the order of 100 µg/m³ for the long term emission data and of even 1000 µg/m³ for the short term emission data. Finally, when comparing the different rooms, the most important difference appears between so called dry rooms and wet rooms. The concentrations are more than 2 fold higher in the wet rooms, due to the air transfer from dry rooms to wet rooms.

Method 3: Simplified emission rates + dynamic simulations → occupant exposure

In this last method, the investigation focuses on the ventilation system (and airtightness), rather than on the emission rates. As shown above, the differences between the highest and lowest emitting materials are the biggest source of variation for the formaldehyde data in this study. So, the effect of the ventilation system was investigated in more details using the same **emission rate** per floor surface area in each room, with a value of 10 µg/h.m² (intermediate value between the lowest and highest emission data for 30days, see Table 1).

The tested **ventilation systems** were: (1) system D, mechanical supply and extract, providing permanently the design flow rates of the Belgian standard; (2) system C, natural supply and mechanical extraction, dimensioned according to the Belgian standard; (3) system D “occupancy”, mechanical supply and extract, with design the flow rates (from the standard) in case of occupant presence and 10% of this design flow rates in case of absence (room per room, but total supply and total extract flow rates always in balance). Dynamic simulations were carried out (using Contam) on one year, using the standard climatic data from Uccle (Belgium). Such simulations provide the pollutant concentrations in each room in function of time. But moreover, using an **occupancy profile** in the model (in this case, there were 4 occupants, with a given occupancy profile), the simulations provide the concentrations to which each occupant is exposed for each time spent inside the building.

In Figure 2, the occupant exposures are presented in the form of cumulative curves for 2 occupants (the most exposed ones). Such graphs indicate the fraction of time for which the occupants are exposed to a concentration higher than the concentration indicated on the “x scale”. For example, with the system D “occupancy”, both occupants are exposed to a concentration higher than 5 µg/m³ during around 20% of the time. The fraction of time at 0 concentration value corresponds to the fraction of time spent by the occupant inside the building (in this case, 68 and 90% for the two occupants respectively; the exposition outside the building is not taken into account).

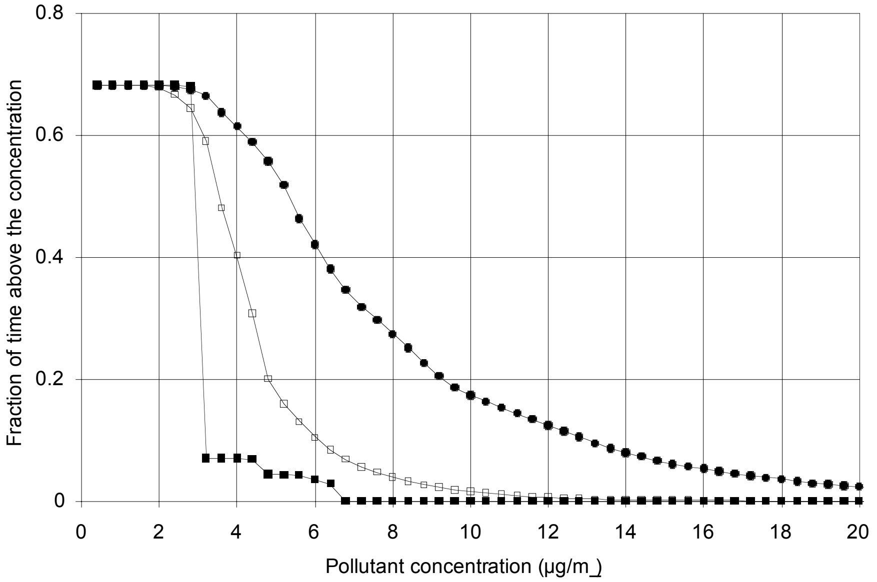

Figure 2: Cumulative occupant exposures to the pollutant, indicating the fraction of time for which the occupants are exposed to a concentration higher than the concentration indicated on the “x scale” for different ventilation systems: system D (closed squares), system D “occupancy” (open squares) and system C (closed circles).

These results indicate, among other, that the occupants are exposed to higher pollutant concentrations with the system D “occupancy” and above all with the system C compared to the system D. For the system D “occupancy”, the higher exposure occurs after the absence periods because of the lower flow rate during the absence. For the system C, higher concentrations are reached because the natural supply of this system is more dependent of the climatic conditions.

3. DISCUSSION AND CONCLUSION

The presented results give insight on the choice of the method for determining pollutant concentrations, but also on the action to carry out to decrease the health risk, in this case for formaldehyde, by action on either the emissions or the ventilation (see Figure 1).

Emission

Examination of the emission rates of building materials (for formaldehyde) from the BUMA database shows that they vary in a very big range for different materials from the same type (several orders of magnitude!). For the materials with the highest emission rates, the formaldehyde concentrations, obtained in this study for a detached house with mechanical ventilation system (higher than 1000 µg/m³), are highly above the limit values proposed by the World Health Organization (2000) for this pollutant (100 µg/m³ for acute exposition (30 min)). A first mean of action to decrease the health risk could be to limit the emission rates of building materials (in the limits of available materials on the market), by means of regulations, labels, etc, as this is already the case in Finland).

Concerning the emission rates, other questions remain open and could require more research. Firstly, a standardized method of measurement of the material emission rates (sampling, time after production, measurement protocol, etc) is necessary, because current data are not always comparable. The effect of time on the emission rates should be better understood to be able to fix limit values on materials. The emissions usually decrease with time; which time range is the most important: initial emission of the materials or long term emissions? The effect of temperature is also an open question, related to the use of heating systems by radiation in floors and walls, more and more common nowadays.

Ventilation

First of all, the results show that the flow rates required by the Belgian standard (system D) seem sufficient to limit the formaldehyde concentrations below 10 µg/m³, for the lowest emitting materials, for initial emission (24h) as well as long term emission data (30d). This confirms that ventilation is surely an important part of the solution to limit the effect of material emissions. Assuring the presence of efficient ventilation systems in buildings, by means of additional controls, quality systems, etc, could be an important action to limit the health risk of emissions. However, ventilation alone is surely not sufficient to solve all the problems.

In addition to a limitation of the material emissions (see above), specific measures could be envisaged to limit the occupant exposure during the initial emission of materials (new materials, new buildings), such as intensive ventilation (windows, etc), limited access to the building for sensitive people (children's, pregnant women, etc), etc.

The effect of the ventilation system itself is also important and could surely be considered in eventually fixing emission limits for materials. The different ventilation systems authorized by the Belgian regulation are not strictly equivalent: pollutant exposures are a bit higher with partially natural ventilation systems compared to fully mechanical systems, in the conditions used in this study. Demand ventilation systems based on occupant presence seem to be as effective as the other permanent systems to avoid occupant exposure, within the conditions used in this study involving a minimum flow rate during absence periods. Note that the effect of the ventilation system (and envelope airtightness) can only be investigated using complex simulations, working with pollutant concentration or with the concept of age of the air in the different rooms: simple or average air exchange rates are not sufficient.

Choice of the method to determine pollutant concentration

The choice of the method for determining the pollutant concentrations in the context of material emissions is very important and is related to (1) the questions to answer, (2) the reliability of the hypothesis made, and (3) the time available for calculations.

Simple methods using average air exchange rate values and average emission rates are surely sufficient for first screening of material emissions. Such very simple and fast method can provide an order of magnitude for the concentrations. Secondly, static simulations, using flow rate simulation tools (such as Contam) and simplified ventilation systems, allow checking the effect of different emission rates and eventually different material distributions in a building on the pollutant concentrations in the different rooms. For example, the effect of the flow rate from a regulation or standard can be rapidly (because static simulations) checked for detailed emission data. Thirdly, to finely compare different ventilation systems and building configurations (geometry, envelope airtightness, etc), dynamic simulations are required, but simplified emission data can be used to limit the complexity, the error introduced by the hypothesis and the time of calculation. This powerful technique is for example appropriate to check the effect of a demand ventilation system related to occupancy profiles. Note that standardization of the occupancy profiles used could be helpful. Finally, more complex dynamic simulations, taking into account, at the same time, for different emission sources, material distribution, evolution of the emission rate with time, etc, should be used only in specific cases, keeping in mind the question to answer and being very careful with the hypothesis made and signification of the obtained result.

REFERENCES

Belgian standard institute (1991). NBN D 50-001. Dispositifs de ventilation dans les bâtiments d'habitation. NBN, Belgium.

Verbeeck G., Hens H. (2006). Eindrapport GBOU-Project 020212 : Ontwikkeling via levenscyclusoptimalisatie van extreem lage energie- en pollutiewoningen (Deel 2a). University of Leuven, Belgium.

World Health Organization (2000). Air Quality Guidelines for Europe. WHO Regional Publications, European Series, No. 91.

AKNOLEDGEMENTS

The authors acknowledge the Belgian Science Policy (Belspo) for the financial support, the Flemish Institute for Technological Research (VITO) and the University of Gent (UGent) for their collaboration.