Material VOC Emissions and Indoor Air Quality Simulation

Michal Kraus¹, Ingrid Juhasova Senitkova¹

¹Institute of Technology and Business in České Budějovice, Department of Civil Engineering, Okružní 517/10, 370 01 České Budějovice, Czech Republic

Abstract. The contribution reports on a simulation study of indoor air quality in relation to different ventilation rates specified for 3 categories of the indoor environment according to EN 15 251. Indoor air quality and energy management are often at the opposite ends of the building management spectrum. The buildings are polluted by occupants of the building themselves. The indoor air quality can be expressed at the required level of ventilation or Carbon Dioxide (CO₂) concentration. Actually, the indoor air quality is influenced by emission from building surface materials and furnishing, occupants and their activities. VOCs play an important role in the indoor air quality evaluation process. VOC emissions adversely affect both occupant comfort and health. Most of the health hazards associated with VOC emissions occur during the first few weeks of building use. The Indoor Air Quality Emission Simulation Tool developed by National Research Council is used for simulating the VOCs emission impact of selected materials based on the amount of materials used and the ventilation rates in a model room, in this case study. IA-Quest predicts the emission of VOCs from building surface materials and furnishings, helping to select low-emission materials and effective ventilation strategies. The results showed the benefit of removing the increased amount of TVOC generated in time of the unoccupied period. The differences in TVOC concentrations were not obvious between two higher ventilation conditions (2.00 and 1.40 l/s.m²). More significant difference was estimated between categories A, B and category C (0.80 l/s.m²).

1. Introduction

According to WHO Guidelines for indoor air quality (2010), the quality of air in indoor homes, offices, schools, day care centres, public buildings, health care facilities or other private and public buildings where people spend a large part of their life is an essential determinant of healthy life and people’s well-being [1]. As the building technology advances, the indoor environment becomes more liveable and comfortable, and like the lifestyle changes, the time spent indoors increases [2]. The current lifestyle can be defined as "indoor generation" because most people's activities take place within an enclosed space, characterised by chemically diverse and complex air quality. Exposure to poor Indoor Air Quality (IAQ) is the cause of excessive morbidity/mortality [3]. Exposure to pollutants in the air may provide a certain health risk. The long-term unsatisfactory indoor environment is associated with Sick Building Syndrome (SBS). Sensitive people groups such as pregnant women, children with asthma or other respiratory symptoms, and elderly persons are most vulnerable to the ubiquitous pollution in their environment. Students spend approximately six to eight hours per day in various school microenvironments (classrooms, and playgrounds) exposure to pollutants in the air [4]. Indoor
Air quality in a building is not constant. It is influenced by changes in building operation, occupant activity and outdoor climate.

There is a need for specifying criteria for the indoor environment for design, energy calculations, performance and operation. There exist several international standards and guidelines, which specify criteria for thermal comfort and air quality (EN ISO 7730 Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria, and EN 16798-3 Energy performance of buildings - Ventilation for buildings - Part 3: For non-residential buildings - Performance requirements for ventilation and room-conditioning systems). These standards do however specify different classes, which may have a significant influence on the energy demand.

European standard EN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics [5] specify how design criteria shall be used for dimensioning of systems. It will also define how to establish and define parameters of the main impact and level classes to be used as input for building energy calculation methods and long-term evaluation of the indoor environment. The standard both give input to other standard related to Energy Performance Building Directive (EPBD) and using outputs from other standards. Standard EN 15251 is the first European standard that includes criteria for the four indoor environmental factors: Thermal comfort, air quality, lighting, and acoustic. Three levels (A, B, C) of the indoor environment are specified in European standard EN 15251. Category A corresponds to a high level of expectation and leads to the highest percentage of satisfied occupants with the indoor environment, category B is characterized by the medium level of air quality expectation and category C corresponds to the moderate level of expectation.

In the design and operation of the indoor environments, the main sources of pollutants should be identified and either eliminated or decreased. The remaining concentration of pollution is dealt with by ventilation. The most commonly used strategy for controlling indoor air quality (IAQ) is ventilation (dilution). Ventilation is supply to and removal of air from a space to improve the indoor air quality. To maintain an acceptable IAQ, systematic, reasonable and controlled ventilation is required. On the other hand, the tendency of energy conservation leads to decreasing of ventilation rate as possible. In the standard, the recommended ventilation rates in residential and non-residential buildings are defined, taking into account pollutant emission. The design total ventilation rate is calculated from two components: ventilation for pollution stemming from occupancy and ventilation for pollution from the building itself. Ventilation rates in naturally ventilated buildings are calculated on the basis of building construction, location and weather conditions. During unoccupied periods, minimum ventilation for the buildings shall be provided. Different ventilation rates are specified from the building pollution point of view, for very low polluting buildings, low polluting buildings and non-low polluting buildings. The ventilation rates $q_b$ according to EN 15 251 for the building emission are defined in table 1.

| Category  | Very low polluting building [l/s.m²] | Low polluting building [l/s.m²] | Non-low polluting building [l/s.m²] |
|-----------|-------------------------------------|---------------------------------|-------------------------------------|
| A (high)  | 0.50                                | 1.00                            | 2.00                                |
| B (medium)| 0.35                                | 0.70                            | 1.40                                |
| C (basic) | 0.30                                | 0.40                            | 0.80                                |

The indoor air quality can be expressed at the required level of ventilation or Carbon Dioxide ($CO_2$) concentration. It has become evident that building materials, furnishing and occupancy are the major sourcey of indoor volatile organic compounds. The VOCs influence mainly perceived air quality in a building.
quality from the odor loading point of view [6,7]. The VOCs are defined by WHO as having melting points below room temperature and boiling points ranging from 50 to 260°C. People perceive the VOC by their olfactory and chemical senses. As the TVOC are emitted by certain building materials, furnishings, consumer products and equipment, it is recommended to select materials and designs that minimizes the emission of VOC. Especially newly constructed buildings or newly-decorated nurseries can by significant sources of HCHO, NH3 and TVOC [8]. Almost 1000 organic substances were identified in the interior of buildings [9].

2. Research Methods

The Indoor Air Quality Emission Simulation Tool (IA – Quest) developed by National Research Council (NRC) is used for simulation the VOCs emission impact of selected materials based on the amount of materials used and the ventilation rates in a model room. The IA Quest software consists of two parts: a database and a simulation component. The database provides information on the emission ("off-gassing") of health-relevant "target" VOCs, abundant VOCs and TVOC (total VOC) from building materials commonly used in Canada. Specimen details and test conditions are available as well. The simulation component of IA Quest calculates the concentrations of contaminants that would occur in a room with known ventilation rate and schedule due to emissions from materials contained within that space. The calculation of concentrations assumes a simple single-zone mixing model. The emission characteristics of materials are obtained from the database packaged within the program. Users need to have the following information to simulate indoor air concentrations of chemicals arising from single or multiple building materials: volume of the space, ventilation rate and schedule, materials (selected from database), for each material: exposed/emitting surface area and entry and removal times to/from the space as well as simulation period. The software calculates indoor air concentrations using a mass balance approach as shown in the following equation:

\[ V \cdot \frac{dC}{dt} = Q \cdot C - Q \cdot C_{in} + \sum^{n} EF_i \cdot A_i \]  

where \( C \) is VOCs concentration \([\text{mg/m}^3]\), \( V \) is air volume \([\text{m}^3]\), \( Q \) is ventilation rate \([\text{m}^3/\text{h}]\), \( C_{in} \) is VOCs concentration in ventilation air \([\text{mg/m}^3]\), \( A_i \) is surface area of the \( i^{th} \) source \([\text{m}^2]\), \( EF_i \) is the emission factor of the \( i^{th} \) source \([\text{m}^2]\), and \( n \) is the number of sources.

Suitable indoor air quality is more important in schools and universities (no-industrial civic amenities) than in many other buildings. Indoor air quality in the university environment affects learning processes, concentration, and productivity of students. It also could affect the health of students and teachers in the long-term. Students are at greater risk because of the hours spent in educational facilities. The model experimental room is represented with classroom a floor area 48 (8 x 6) \( \text{m}^2 \) and indoor air volume 125 \( \text{m}^3 \). Material characteristics of the of the evaluated room are shown in table 2. The walls and ceilings are fitted with a classic internal plaster with white paint. Flooring is synthetic smooth flooring - linoleum. The windows are new, plastic with a shading system of internal blinds. The classroom equipment is classical and includes tables, chairs, whiteboard, computer and projector.

According to EN 15 251, the experimental classroom is classified as non low-polluting. The building can be defined as low polluting, if the majority of materials are low polluting. Low polluting materials are natural traditional materials which are known to be safe with respect to emissions, and materials which fulfil the following requirements:

- The emission of total volatile organic compounds (TVOC) is below 0,2 \( \text{mg/m}^2.\text{h} \),
- The emission of formaldehyde is below 0,05 \( \text{mg/m}^2.\text{h} \),
- The emission of ammonia is below 0,03 \( \text{mg/m}^2.\text{h} \),
The emission of carcinogenic compounds (IARC) is below 0.005 mg/m².h, The material is not odorous (dissatisfaction with the odour is below 15%).

Building materials and furnishing of the observed room do not meet criteria of low polluting materials for emission of TVOC. The TVOC emission date for building materials used for interior surfaces finishing and furnishing are obtained from IA-QUEST database as minimum and maximum values, as the nominal value was considered. The local outdoor concentration value 0.1 mg/m³ was found and was considered as the initial outdoor air TVOC concentration.

Table 2. Material characteristics of the tested classroom

| Construction | Material    | Emission surface [m²] | Range emission factor [l/s.m²] |
|--------------|-------------|-----------------------|-------------------------------|
| Flooring     | Linoleum    | 48.00                 | 0.056 – 0.894                 |
| Ceiling      | Interior paint | 48.00             | 55.287 – 154.450              |
| Walls        | Interior paint | 63.80             | 55.287 – 154.450              |
| Windows      | Glass       | 9.00                  | -                             |
| Furnishing   | Particleboard | 45.00             | 3.866 – 5.232                 |

The TVOC emission from building materials and furnishing are monitored for three levels of ventilation rates according to three indoor environmental categories (A–C). Table 3 shows the ventilation rate time schedule, which is established on the base of predicted using time schedule design ventilation standard requirements. The pre-ventilation is operated before the occupancy starts to ensure acceptable indoor air quality at the starting point of occupancy. The pre-ventilation period depends on the requirement that the value of ventilation rate is 2.0 per hour. Additionally, during the unoccupied periods, the classroom is ventilated with minimum ventilation rate than during the occupied period (0.15 per hour).

Table 3. Ventilation rate time schedule

| Category | Time Schedule | Working days (Monday – Friday) | Weekend (Saturday – Sunday) |
|----------|---------------|--------------------------------|-----------------------------|
| A        | 00:00 – 06:00 | 0.15 h⁻¹                       | 0.15 h⁻¹                    |
|          | 07:00 – 08:00 | 2.00 h⁻¹                       |                             |
|          | 08:00 – 19:30 | 2.77 h⁻¹                       |                             |
|          | 19:30 – 24:00 | 0.15 h⁻¹                       |                             |
| B        | 00:00 – 06:00 | 0.15 h⁻¹                       | 0.15 h⁻¹                    |
|          | 07:00 – 08:00 | 2.00 h⁻¹                       |                             |
|          | 08:00 – 19:30 | 1.93 h⁻¹                       |                             |
|          | 19:30 – 24:00 | 0.15 h⁻¹                       |                             |
| C        | 00:00 – 06:00 | 0.15 h⁻¹                       | 0.15 h⁻¹                    |
|          | 07:00 – 08:00 | 2.00 h⁻¹                       |                             |
|          | 08:00 – 19:30 | 1.11 h⁻¹                       |                             |
|          | 19:30 – 24:00 | 0.15 h⁻¹                       |                             |

3. Results and discussions
TVOC concentration versus time taken from the IA-Quest simulation diagram for the modelled classroom with the determined time schedule of ventilation rates for different levels of the indoor environment (A, B, C) are presented within the figures 1-3. The values of TVOC concentration were compared to designed ventilation rates with respect to recommended comfort value (TVOC concentration is below 200 µg/m³). The logarithmic scale expressing the TVOC concentration is chosen for better clarity.
Figure 1. TVOC concentration vs time taken from the IA-Quest simulation diagram for ventilation rate category A

The benefit of demand-controlled ventilation for pollution removal has been demonstrated for every expectation level of the indoor environment. The more systematic controlled ventilation was designed, the higher benefit was found. The built-in pollution level (TVOC concentration) as a projected parameter for ventilation rate has shown a significant correlation with the trend of scheduled air-change level declining. The occupied room with higher air pollution has to be designed and operated with higher air change level.

Figure 2. TVOC concentration vs time taken from the IA-Quest simulation diagram for ventilation rate category B
Figure 3. TVOC concentration vs time taken from the IA-Quest simulation diagram for ventilation rate category C

The simulation study of indoor air quality in relation to different ventilation rates specified for 3 categories of the indoor environment according to EN 15251 is presented in the paper. The acceptable level of TVOC 200.00 μg/m³ was obtained after 11 weeks in the case of category A. An acceptable level for category B was reached after 14 weeks. In the latter case, category C, an acceptable level is reached in the 23rd week of operation. No significant differences between category A and B are not found. The differences with category C are more obvious. Higher deviation is estimated between categories A and B comparing to category C.

4. Conclusions
Energy consumption of buildings depends significantly on the used criteria for the indoor environment, such as temperature, ventilation and lighting, and building design and operation. The indoor environment also affects health, productivity and comfort of the occupants. Presented case study showed that indoor environmental quality is strongly dependent on the cost of energy used in the buildings for the reason of hygiene and demand control ventilation. An energy saving declaration without a declaration related to the indoor environment makes no sense. There is, therefore, a need for specifying criteria for the indoor environment for design, energy calculations, performance and operation of the buildings. For energy saving reasons, it could be tempting to reduce ventilation flow rates. Indoor air quality and energy management are often placed at opposite ends of the building management spectrum. In reality, acceptable IAQ and good energy management are not mutually exclusive. In fact, combining the two concerns can result in a synergistic relationship that can create buildings that will operate healthfully and efficiently.

References
[1] The WHO European Centre for Environment and Health, *WHO guidelines for indoor air quality: selected pollutants*, 2010.
[2] S. Hormigos-Jimenez, M. Á. Padilla-Marcos, A. Meiss, R. A. Gonzalez-Lezcano, and J. Feijó-Muñozb, “Ventilation rate determination method for residential buildings according to TVOC emissions from building materials, “ *Building and Environment*, vol. 123, pp. 555-563, 2017.

[3] F. J. Kelly, and J. C. Fussell, “Improving indoor air quality, health and performance within environments where people live, travel, learn and work,” *Atmospheric Environment*, vol. 200, pp. 90-109, 2019.

[4] A. U. Raysoni, T. H. Stock, J. A. Sarnat, M. C. Chavez, S. E. Sarnat, T. Montoya, F. Holguin, and W-W. Li, “Evaluation of VOC concentrations in indoor and outdoor microenvironments at near-road schools,” *Environmental Pollution*, vol. 231, part 1, pp. 691-693, 2017.

[5] European Committee for Standardization, *EN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics*, 2007.

[6] I. Juhásová Šenitková, and M. Bučáková, “Percieved air quality and building materials,” *Selected Scientific Papers*, vol. 1, pp. 153-159, 2005.

[7] I. Juhásová Šenitková, and. M. Bučáková, “Indoor odours and perceived air quality,” *Proc. of the 10th international conference on indoor air quality and climate: Indoor Air 2005*, pp. 2019-2023, 2005.

[8] R. Tang, and Y. Wang,” Field study on indoor air quality of urban apartments in severe cold region in China,” *Atmospheric Pollution Research*, vol. 9, issue 3, pp. 552-560, 2018.

[9] M. Kraus, and I. Juhásová Šenitková, „Indoor Air Quality Analysis of Residential Buildings;“ *17th International Multidisciplinary Scientific GeoConference SGEM 2017*, vol.17, issue 62, pp. 651-658, 2017.