

INDOOR AIR QUALITY IN RELATION TO BUILDING ENVELOPE CHARACTERISTICS OF LOW-ENERGY AND PASSIVE SCHOOLS IN BELGIUM

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INTRODUCTION

As a result of the increased energy performance standards for buildings, newly built schools are characterised by a more airtight and better insulated building envelope, and a mechanically controlled ventilation system. Energy efficient schools therefore contrast to the majority of the Belgian school building stock, which is considerably less insulated, and aerated by window opening. Since, even more in airtight schools, building ventilation is indispensable to create and maintain a healthy indoor environment, the correct use and maintenance of the mechanical ventilation system will directly impact on the experienced indoor comfort. This work reports on physical, chemical and biological indoor air quality parameters in primary school classrooms in relation to (1) the ventilation system (balanced ventilation versus controlled exhaust ventilation), (2) the air leakage and (3) the total effective ventilation rate of the classroom.

METHODOLOGIES

Based on literature relevant chemical, physical and biological parameters to assess IAQ in energy efficient buildings (EEBs) were identified. A distinction was made between (1) priority selection criteria for buildings (air tightness if available, ventilation system, heat recovery, indoor activities, and outdoor environment), (2) parameters to be measured on-site (chemical, physical and biological) and (3) parameters to be included in building-related questionnaires (daily use of the mechanical ventilation system, amount of pupils, activities, and potential indoor and outdoor sources).

26 classrooms in 9 low-energy and certified passive ($n_{50} < 0.6/h$; annual energy demand $< 15 \text{ kWh/m}^2$) schools were selected to reflect current school building trends in Belgium. Simultaneous indoor and outdoor monitoring during 5 successive school days of 18 VOCs (MTBE, benzene, trichloroethene, toluene, tetrachloroethene, ethylbenzene, m-+p-xylene, styrene, o-xylene, 1,2,4-trimethylbenzene, 1,4-dichlorobenzene, hexane, heptane, cyclohexane, n-butylacetate, α -pinene, 3-carene, and d-limonene) and TVOC (radiello passive samplers for chemical desorption and GC-MS analysis), formaldehyde, acetaldehyde, and total other aldehydes (UMEx100 passive samplers for extraction and LC-UV analysis), $\text{PM}_{2.5}$ (Grimm

1.108 Dust Monitor Monitor and PM_{2.5} Harvard-type MS&T Area Samplers, Air Diagnostics and Engineering during teaching hours for gravimetrical analysis), CO₂, temperature, and relative humidity (Catec Climabox), total viable bacteria count and fungi in air (Andersen 6-stage impactor 5 minutes, 28.3L/min) and in deposited dust (swab sampling), total effective ventilation rate as a combination of air flow rate (flow box) and air tightness (building pressurization test) were preformed.

RESULTS AND DISCUSSION

Overall, no degradation of the IAQ was observed at increased building air tightness. However, the mechanical ventilation system type and the total effective ventilation rate were indicated to be related to the IAQ of the classrooms.

Although indoor CO₂ in the classrooms was not influenced by the mechanical ventilation system type, systems with balanced ventilation tended to reduce PM_{2.5} in incoming air, which led to a tendency of reduced indoor levels (Table 1), and PM_{2.5} I/O ration compared to rooms with trickle ventilators and mechanical exhaust.

Table 1. Indoor PM_{2.5} expressed in µg/m³ in classrooms with controlled supply and exhaust air (system D; 17 classrooms) and classrooms with trickle ventilators and mechanical exhaust (system C, 9 classrooms).

| | Average±stdev | Median | 75% percentile |
|--|---------------|--------|----------------|
| Indoor PM _{2.5} (grav) system C | 38.8 ± 23.4 | 33.3 | 60.5 |
| Indoor PM _{2.5} (grav) system D | 27.7 ± 13.6 | 27.5 | 34.5 |

The total effective ventilation rate of the classrooms was expressed IDA classes according to NBN EN 13779, as listed in Table 2 (note that the lowest ventilation rate category, IDA 5, was inserted for this study). Analysis of the data indicated that the total effective ventilation rate was fairly well associated with increasing indoor PM_{2.5} concentrations, as illustrated in the box and whiskers plot in Figure 1; the box frames are the upper and lower quartile, the line represents the median, and whiskers denote range. A similar pattern was found for indoor CO₂, PM_{2.5}, formaldehyde, and to a lesser extent toluene (Figure 2).

Table 2. NBN EN 13779 Ventilation for non-residential buildings.

| Class | Air supply p.p. | Description |
|-------|-----------------|---|
| IDA 1 | > 15 l/sec | Excellent air quality |
| IDA 2 | 10-15 l/sec | Average air quality |
| IDA 3 | 6-10 l/sec | Acceptable air quality |
| IDA 4 | < 6l/sec | Low Air quality |
| IDA 5 | < 3 l/sec | Defined for this study (not part of NBN EN 13779) |

Only one classroom fulfilled the ventilation conditions of class IDA 1 (an air supply p.p. larger than 15 l/sec and “Excellent air quality”), however due to noise nuisance (4 to 6 dB above the acoustic comfort value of 35 dB in prNBN S 01-400-2) the teacher switched off the ventilation during the sampling campaign. Therefore the data on IAQ were not considered as representative for this study.

In fact, a higher IDA class (lower air supply rate per pupil) implied increased indoor levels of the listed chemicals. The association between IAQ and IDA classes is in line with the outcomes of HEALTHVENT (www.healthvent.eu) in which health-based ventilation

guidelines are recommended for non-industrial buildings in Europe. In fact the advisable ventilation rate according to HEALTHVENT would be 7-8l/sec/pers in this type of classrooms, which according to NBN EN 13779 equals IDA 3 or better and equalises the recommended (although not always applied) ventilation level for Belgian classrooms.

It is however important to note that this general trend could not be identified for both total viable bacteria and fungi, implying that the concentration these levels decreased at increasing IDA class, i.e. lower air change rate. The constant airflow may keep resuspended microbes in the air rather than supporting settling and deposition of bacteria and fungi.

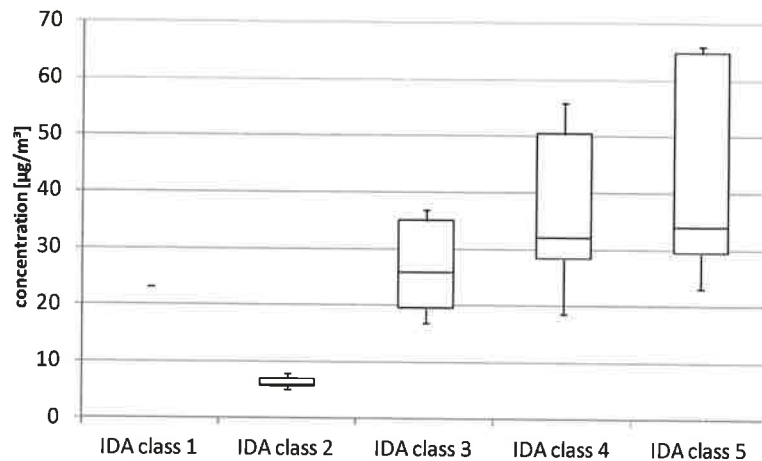


Figure 1. Box and whiskers plot of indoor PM_{2.5} (gravimetric assessment) as a function of the total effective ventilation rate, expressed in IDA classes.

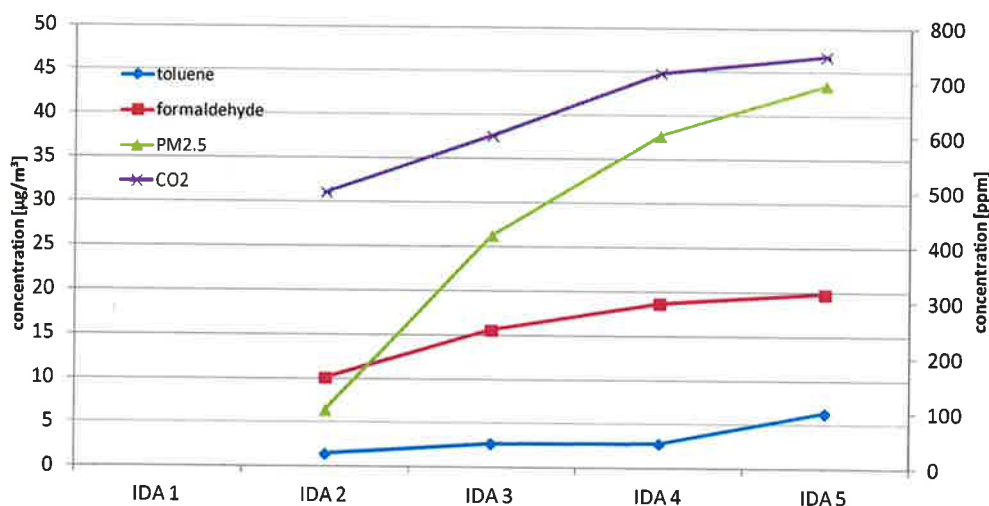


Figure 2. Average indoor concentrations per IDA class.

CONCLUSIONS

The total air supply rate per pupil was identified to be a considerable determinant of the indoor environment in classrooms, leading to improved situations for chemicals at increased total effective ventilation rates. I/O ratios of airborne bacteria and fungi did not show any clear pattern, but seemed to decrease with increasing IDA class. Clearly higher number of samples and equal group sizes are needed to study this aspect more in detail.