Indoor air quality in schools: influence of the ambient air, ventilation and classroom design

Summary

The general objective of this study is to assess the indoor air quality in Flemish primary school classrooms, by studying the influence of the outdoor air, of ventilation and of the classroom design. The effectiveness of remedial actions to improve the indoor air quality, the occurrence of mould in classrooms, the assessment of the main composites of the total volatile organic compounds (TVOC) and the respiratory health situation in a subset of the studied population, are evaluated as well. The remedial actions involve the measurement of the effectiveness of an educational program on classroom ventilation for pupils, called 'Lekker Fris'. Furthermore, simulating the filter of a mechanical ventilation system, the effectiveness of the use of a simple air cleaner, equipped with an HEPA-type filter, to reduce indoor PM (Particulate Matter) in a classroom, is studied. The results lead to the formulation of specific recommendations for environmental policy and other policy entities.

The research strategy involves a main study and 4 case studies. This design allows to address the general objectives in a larger group of classrooms; and to perform specific small-scale studies, with a distinct focus, in subsets of the main group. According to (1) the building age (built before 1990; built after 1990; renovated), (2) the educational network, and (3) the location (urban background, urban centre and rural background), 30 schools, distributed over all Flemish provinces, are selected to participate in the main study. Visual mould growth, and its relation to ventilation and humidity, is studied in all 30 schools. For the case studies on remedial actions, respectively 4 schools with intention to participate the 'Lekker Fris' program are selected to evaluate the educational program, and 3 schools, situated in urban centre or rural environment, are selected for the air cleaning intervention. The respiratory health of pupils is studied in all children, participating in the case studies on remedial actions.

The field campaign took place during the heating season (between the 3rd of November 2008 and the 3rd of April 2009). In each school, sampling took place in 3 classrooms -one in each primary school grade- and in 2 outdoor sampling sites – one in the playground and one on the school domain closest to the nearest road. This resulted in a set of 150 sampling sites. Within the main study, chemical as well as physical contaminants are monitored. For classrooms these include: MTBE, benzene, toluene, xylene isomers, ethylbenzene, tetrachloroethene, 1,2,4-trimethylbenzene, formaldehyde, acetaldehyde, total other aldehydes, TVOC (total volatile organic compounds), $PM_{2.5}$ (mass concentration, gravimetrically determined), PM_1-$PM_{2.5}$-PM_{10} time profiles (optically determined), CO_2, relative humidity, and temperature. The ventilation rate of each classroom was assessed using CO_2 decay profiles. In ambient air the same chemical and physical contaminants, with exception of PM_1-$PM_{2.5}$-PM_{10} time profiles (optically determined) and relative humidity, are sampled in parallel. Each of these compounds is monitored continuously over 5 successive school days, except for $PM_{2.5}$ in indoor air. This latter compound is sampled over 5 successive school days, only during 8-h teaching hours (from 8 a.m. till 4 p.m.). For the case studies on remedial actions, CO_2 is monitored before and after the intervention, to establish the effectiveness of 'Lekker Fris' on classroom ventilation; PM (mass concentration and time profile) is monitored before and after the intervention, to assess the effectiveness of the use of an air cleaner in a classroom.

Overall, it was concluded that the concentration level of most of the studied polluants was higher inside the classrooms, than in the corresponding ambient air. The monitoring program revealed some bottlenecks in the indoor air quality in Flemish primary school classrooms, participating in this study. In most classrooms the indoor levels of $PM_{2.5}$, PM_{10}, formaldehyde, total other aldehydes, benzene, TVOC and CO_2 exceeded the guidelines, as formulated in the Flemish Indoor Environment Decree. The stated intervention values for formaldehyde and benzene weren't exceeded in any of the classrooms. On the other hand, for MTBE, toluene, tetrachloroethene, ethylbenzene, acetaldehyde, and 1.2.4-trimethylbenzene, all measured concentrations were below the Flemish guideline values.

The influence of ambient air

The influence of ambient air was established for most of the traffic related pollutants. For benzene and MTBE a clear 1:1-relation between indoor and outdoor air was identified. Other traffic related pollutants, such as toluene, ethylbenzene, xylene isomers, TVOC and PM also showed this relation to traffic. However, for these compounds the Indoor/Outdoor ratio's were found to be consistently higher than 1 and showed more variability. This finding was attributed to the contribution of indoor sources, superposed on the influence of the ambient air, and/or to the longer residence times of the pollutants in indoor air. No significant difference was found between the indoor air quality at schools situated in rural and in urban environments; this probably resulted from the field study period, which took 5 months, due to its complexity and dimensions.

The influence of ventilation

None of the classrooms was equipped with a mechanical ventilation system; each room was ventilated manually. Only 25 of the 90 classrooms had registers next to the windows, but only 64% of these were actually used during the BiBa field study. The ventilation of most classrooms was insufficient and exceeded the 24-h average CO_2 guideline value from the Flemish Indoor Environment Decree in 99% of the classrooms. In presence of children, the CO_2 concentrations exceeded the limit value of 1000 ppm (ASHRAE) in 24% of the classrooms.

An univariate model on indoor CO_2 and the detected chemical contaminants indicated a positive influence of ventilation on all indoor pollutants (both those with mainly indoor sources, as well as those with mainly outdoor sources), except on TVOC.

The influence of classroom indoor design

Due to the wide variety of influencing factors, the construction and the ventilation characteristics within the BiBa dataset, no significant relation could be established between the indoor air concentrations of contaminants and the presence of specific indoor sources. There was a weak and non-significant correlation between the amount of children in a classroom and $PM_{2.5}$; between floor coverage and formaldehyde/total other aldehydes; and between the use of cleaning agents and TVOC.

Case studies

The presence of visible indoor moulds, reported in 7 of the 90 classrooms, correlated well with the presence of indoor moisture damage; but no relation with relative humidity, temperature, and ventilation was established.

The experiments on the effectiveness of the educational program on ventilation for pupils 'Lekker Fris', as a remedial action, indicated a reduction of indoor CO_2 to 73 ± 12% of the original indoor teaching hour (8h-)average concentration. The tests indicated the importance

of a good follow up by the teacher and of the ventilation possibilities of the classroom, on the results of ‘Lekker Fris’.

The remedial action to reduce indoor PM, using simple air cleaners, indicated to be effective as well. After installation of the air cleaning device, simulating air cleaning in a mechanical ventilation system, the PM Indoor/Outdoor ratio’s were reduced to 58 ± 19% of their original value. The effect seemed to be more pronounced in case the initial Indoor/Outdoor ratio’s were higher and seemed to be more effective on smaller size fractions of PM (due to the higher generation rate of the larger PM fractions in resuspension). Classroom PM appeared to have increased concentrations of soil dust elements, compared to ambient PM, indicating the contribution of resuspension to indoor PM enrichment.

The respiratory health of the pupils, measured as expired NO, wasn’t improved after the remedial actions. There was a weak positive and non-significant relation between the expired NO and the concentrations of $PM_{2.5}$, tetrachloroethene and TVOC in the classroom indoor air.

The study on the main composites of TVOC highlighted the much wider variety of VOC-compounds in indoor air, compared to ambient VOC. Several compounds, such as d-limonene and cyclohexane, were only detected in indoor air. Limonene was identified as the VOC-compound with the highest average contribution to TVOC in terms of percentage.

The study results of BiBa have led to the formulation of recommendations for environmental policy concerning classroom ventilation, ambient air quality, indoor sources, indoor moisture and moulds and more general on the indoor air quality of classrooms. Key issues for further research in this research field, are (1) the occurrence of new pollutants as a result of the use of ‘new’ products in classrooms (emerging pollutants such as the endocrine disruptors flame retardants, phthalates, or insecticides) and (2) the effect of new architectural styles (such as passive constructions) and their mechanical ventilation systems on the indoor air quality in classrooms.