INDOOR AIR QUALITY IN SCHOOLS: THE IMPACT OF VENTILATION CONDITIONS AND INDOOR ACTIVITIES

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ABSTRACT
The indoor air quality of two nursery schools and one primary school of Paris suburb is documented regarding ventilation strategy and occupants behaviour. Physico-chemical and microbiological measurements are performed indoors in two classrooms of each school and outdoors.

Indoor air quality is better in mechanically ventilated classrooms than in operable windows classrooms. CO_2 concentration ranges usually from 750 to 1500 ppm. The air change rate - derived from CO_2 monitoring - is around 0.4 ach in mechanically ventilated classrooms. In other classrooms, it ranges from 0.1 to 0.6 ach with regard to airtight conditions.

TVOC concentrations are much higher indoors (from 200 to 620 $\mu g.m^{-3}$) than outdoors. Indoor benzene and toluene originate from outdoors while school activities can explain high concentrations of some compounds like glycol ethers. Main source of bacteria indoors is human presence whereas fungi mainly originate from outdoors. The maximum bacteria concentrations range from 600 to 4000 $CFU.m^{-3}$ with regard to ventilation conditions.

INDEX TERMS
Ventilation, Human activities, VOCs, Biocontaminants, Schools.

INTRODUCTION
Clean air is considered to be a basic requirement for human health and wellbeing. For protecting public health from adverse effects of air pollutants, key issue is both the optimisation of ventilation strategy and the control of pollutant sources. For energy saving reasons, it could be tempting to reduce ventilation flow rates. Finding the best compromise between indoor air quality (IAQ) and energy savings remains a major stake. Ventilation in schools faces with peculiar problems because French regulation allows ventilation by simple operable windows. This ventilation technique often leads to either energy waste or insufficient indoor air quality. On the other hand, mechanical ventilation requires an important investment budget and a management of the system adapted to room occupation.

CSTB undertook investigation in three schools of Paris suburb to document the actual level of indoor pollution. Nursery and primary schools (children of less than 10 years) were chosen because adverse effects of pollutants are more acute on very young children whose respiratory system is underdeveloped. The study aimed at identifying and quantifying pollutant sources, assessing the impact of ventilation, occupant behaviour and indoor activities (e.g. opening of windows, children activities, cleaning practice, etc.) on IAQ.

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Three one-week sets of measurements were performed indoors in two classrooms of each school and outdoors in summer, autumn and winter seasons.

METHOD

Buildings description

A description of investigated schools is given in Table 1. Further information is available in a previous publication (Ribéron, Derangère, Kirchner *et al.*, 2000). School #1 is equipped with a mechanical exhaust ventilation system: fresh air enters into classrooms and contaminated air is exhausted from toilets via four roof ventilators. The others schools are ventilated only by operable windows. Table 1 gives the mean number of children per classroom. The air permeability of rooms has been evaluated from visual inspection of envelope components (leaks at doors and windows, presence of joints,…). There is no source of pollution near schools.

Table 1. Description of investigated schools

School	*ventilation*	*Classroom*			
		class room	*Surface area (m^2)*	*children*	*Air permeability*
#1 nursery	mechanical	#1	76	23	airtight
		#2	62	25	airtight
#2 primary	No ventilation	#1	56	21	fairly airtight
		#2	60	20	airtight
#3 nursery	No ventilation	#1	85	24	leaky
		#2	66	27	leaky

Procedure

Experimental approach is based on the characterisation of buildings and equipments (i.e. ventilation and heating systems, building material, furniture, floor and wall coverings, etc.), on physico-chemical and microbiological measurements performed indoors and outdoors, and on the collection of informations on behaviour via a survey notebook. For each classroom, the teacher filled a notebook for time reporting on the number of children present, the opening status of windows and doors, the type of children activities with regard to metabolic production (e.g. sleeping, listening, playing) and pollutant emissions (e.g. painting, pasting, felt-tip pen drawing).

Monitoring protocols

A monitor, called Mini Squalair, was used for measuring the main IAQ parameters: temperature, relative humidity, CO_2 and CO concentrations. Measurements were continuously performed during one week with a 10 minutes interval data acquisition. Outdoor parameters were continuously recorded using a meteorological monitor: temperature and humidity, wind speed and direction, CO_2 concentration.

Bacterial and fungal samples were simultaneously collected indoors and outdoors. A first set of indoor samples was taken in the morning before classroom occupation; a second set was taken as soon as the children left the room at the end of the day, before clean-up activities. Sampling method is based on the requirements of the European standard PrEN 13098 (CEN, 1997). Bacterial samples were collected using an Andersen N-1 sampling head with a flow rate of 28.3 lpm using trypticase soy agar (Fisher Scientific, Elancourt, France) culture medium (49 ml). Samples were incubated at 30°C for 48 h. Fungal samples were collected in a similar manner to the bacterial samples. Malt extract agar was used as the culture medium. Petri plates were incubated at 22°C for 3 days.

Volatile organic compounds (VOCs) samples were collected in order to cover periods where children were present and at the end of the day, during clean-up activities. Two samples were taken outdoors in the morning (8 a.m.) and in the afternoon (16 p.m.). VOCs were collected on TENAX TA tubes during one hour with a flow rate of 100 mlpm using an automatic sampling system (STS 25 Perkin Elmer). Sampling and analysis were made according the draft international standard ISO/DIS 16000-6 (ISO, 2000). Analysis is made using thermal desorption and gas chromatography. VOCs were identified with mass spectrometry and quantified with flame ionisation detector using the toluene response factor. The main 10 to 15 compounds have been identified. In addition, the total volatile organic compounds (TVOC) concentration has been calculated as the sum of concentrations of identified and unidentified compounds eluting between hexane and hexadecane (included) expressed in toluene equivalent.

RESULTS

CO_2 measurements

Carbon dioxide (CO_2) concentrations can be considered as an indicator of ventilation rate. Table 2 gives for each room the mean value and in brackets the standard deviation. The CO_2 monitoring show that concentrations vary from classroom to classroom and change according to ventilation type, room air tightness, window operation and occupation rate. Theses values are close to the levels commonly measured in other schools (Redding and Harrison, 1999). High CO_2 concentrations during summer in school #1 are due to the fact that ventilation was switched off.

Table 2. CO2 concentrations for each set of measurements

		Summer	*Autumn*	*Winter*
School #1	Classroom #1	1185 [287]	910 [192]	810 [198]
	Classroom #2	1070 [377]	890 [280]	860 [246]
School #2	Classroom #1	810 [330]	990 [333]	900 [239]
	Classroom #2	840 [320]	1010 [380]	1270[590]
School #3	Classroom #1	750 [247]	850 [433]	750 [280]
	Classroom #2	790 [230]	1490 [280]	1370[420]

The highest instantaneous CO_2 concentrations occur rather in winter (2600 ppm) and autumn (2400 ppm) than in summer (1900 ppm). The highest values have been recorded in the most airtight classroom when the windows are not opened (Figure 2). The recordings show that the maximum CO_2 level required in the French sanitary regulation (i.e. 1300 ppm) is often overstepped (RSDT, 1985). Indeed, in poorly ventilated schools, CO_2 concentrations can reach values up to 2600 ppm (Limb, 1997).

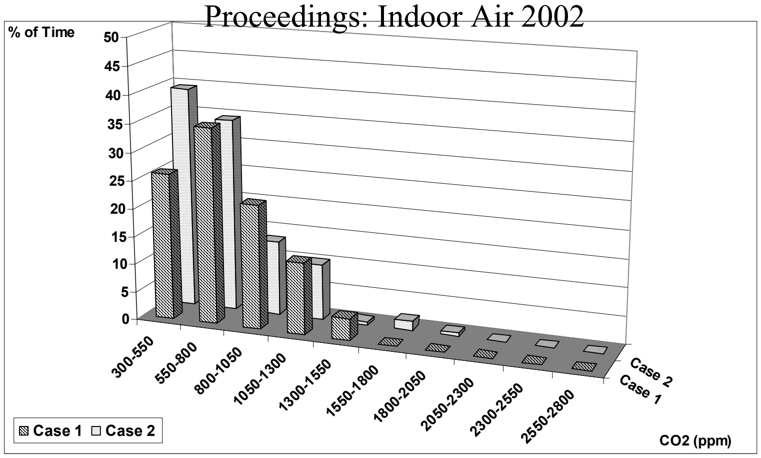

Figure 1. Distribution of CO_2 concentrations for different configurations.
Case 1: mechanical ventilation, windows closed
Case 2 : no ventilation system, windows continuously opened

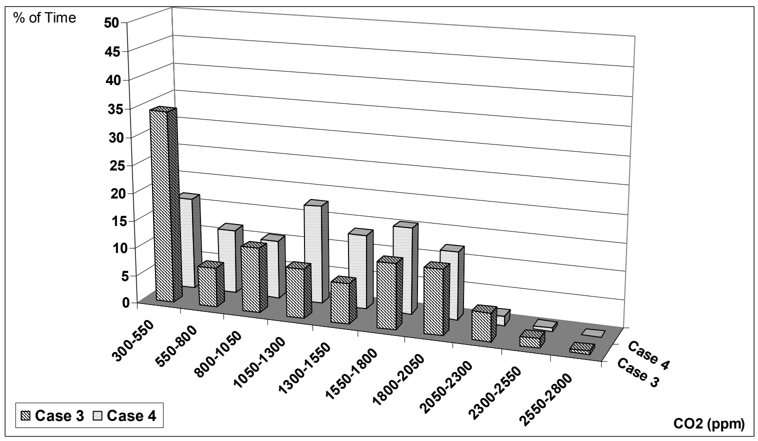

Figure 2. Distribution of CO_2 concentrations for different configurations.
Case 3: no ventilation system, airtight classroom, windows closed
Case 4: no ventilation system, leaky classroom, windows closed

Figures 1 and 2 present the occurrence distribution of CO_2 concentrations for different configurations according to air tightness and ventilation conditions. In cases 1 and 2, the 1300 ppm value is overstepped during less than 5% of time; whereas in cases 3 and 4 it is overstepped during 40%. It means that indoor air quality can be considered as good in cases 1 and 2 and poor in cases 3 and 4. This is corroborated by the results of chemical and microbiological measurements.

Biological measurements
Indoors, the main source of bacteria is human presence; whereas fungi mainly originate from outdoors. After occupation by children, bacteria concentrations are generally higher than 3000 CFU/m^3, except in the school equipped with mechanical ventilation system where the concentrations do not exceed 1000 CFU/m^3.

Indoor biocontamination can be assessed using indoor/outdoor (I/O) bacterial concentrations ratio. Before occupation by children, I/O ratios are generally lower than 5 (65% of cases) indicating that there is no background pollution. In 35% of cases, I/O ratios range between 10 to 20 revealing background pollution due to insufficient ventilation or inappropriate clean-up practices. After occupation, I/O bacterial contamination ratios are always superior to 5. The I/O fungal concentration ratios are always lower than 1 before occupation (except an atypical contamination case) and in most cases after occupation of classrooms.

VOC measurements

The main VOCs identified vary from a classroom to the other and from a school to the other. Among these compounds, we have mainly identified: decane, undecane, benzaldehyde, hexanal, nonanal, decanal, benzene, toluene, xylenes, ethylbenzene, trimethylbenzene, 2-butoxyethanol, 1-butoxy-2-propanol, 2-2-ethoxyethoxyethanol, 2-2-methoxyethoxyethanol, limonene, camphene, methylisobutylketone (MIBK) and TXIB. The global pollutant load expressed by the TVOC concentration is clearly higher inside classrooms that outdoors (Table 3).

Table 3. TVOC concentrations (µg/m^3) for each set of measurements (n.m: no measurement)

		Summer	*Autumn*	*Winter*	*All sets*
School #1	Classroom #1	620	230	205	385
	Classroom #2	545	240	250	365
	Outdoor	25	35	45	35
School #2	Classroom #1	230	380	n.m	310
	Classroom #2	n.m	245	270	255
	Outdoor	50	40	25	45
School #3	Classroom #1	470	445	n.m	460
	Classroom #2	190	405	415	360
	Outdoor	25	85	30	45

High TVOC concentrations during summer in school #1 are due to the fact that the ventilation was switched off. In classroom #2 of school #3, the TVOC concentration is lower in summer because windows are opened. These TVOC results are in the same order of magnitude than results from other surveys (Daisey and Angell, 1999).

DISCUSSION

Classrooms air renewal rates have been calculated from the variations of CO_2 concentrations. In the mechanically ventilated school, the air change rate is quite constant from classroom to classroom and variations are low; the air change rate remained generally around 0.4 ach. In the airtight classrooms, with closed windows, the mean air change rate is about 0.2 ach; but rates lower than 0.1 ach often occur. In leaky classrooms, the mean air change rate ranges from 0.5 to 0.7 ach; but it can commonly vary from 0.1 to 2 ach according to climatic conditions. When the windows are opened in classrooms, the air change rate can easily reach up to 4 ach or even 8 ach.

Among identified VOCs indoors, some compounds, such as benzene or toluene, mainly originate from outdoors; their I/O concentration ratio being close to 1. High concentrations of particular VOCs such as glycol ethers have been observed at the end of the afternoon. They are presumably due to cleaning activities since glycol ethers are frequently used as solvents in cleaning products. We have also punctually observed high concentrations of MIBK or ethylcyclohexane associated with children activities: drawing, pasting, using of felt-tip pens.

Here, more attention has to be paid to cleaning up activities. The results have shown that they do not always insure a satisfactory elimination of the bacterial pollution, and they could also cause high concentrations of certain pollutants, like glycol ethers. However, the high concentrations observed just after the cleaning operations had strongly decreased the next day when children entered the classrooms.

CONCLUSION

The best results in terms of indoor air quality are observed in school #1 which is equipped with a mechanical extract ventilation system. In this school, the air quality is considered as satisfactory since the teachers do not feel the necessity to open the windows. The ventilation system always works from Monday morning to Saturday afternoon; so, the ventilation strategy could be optimised in order to find a good balance between IAQ and energy saving. In schools without particular ventilation system, the indoor air quality is strongly depending on windows operation. IAQ is especially poor in airtight rooms where windows are kept closed.

TVOC reflects ventilation conditions since the highest TVOC concentrations are associated to poor ventilation. The main VOCs have been identified and, when possible, a tentative identification of their source has been proposed. In particular, we have identified specific episodes associated with school activities. Emissions of volatile compounds like MIBK are rather limited and presumably extremely dependent on the nature of the used materials (paints, paste, felts).

After cleaning operations in the evening, a residual bacterial pollution could still be found in the morning of the next day, whereas the CO_2 indoor concentrations are minimum. Further investigations would be necessary to better appreciate the effect of ventilation on the bacterial contamination of air. In the same way, effects of cleaning need to be more precisely explored by comparing the bacterial flora in air and fixed on the surfaces.

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