Monitoring indoor air quality in French schools and day-care centers

Nicolas Michelot, Caroline Marchand, Olivier Ramalho, Véronique Delmas, Marie Carrega

HVAC&R Research

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uhvc20

Monitoring indoor air quality in French schools and day-care centres

Nicolas Michelot [a] , Caroline Marchand [b] , Olivier Ramalho [c] , Veronique Delmas [d] & Marie Carrega [e]

[a] Ministry in charge of the ecology , France

[b] INERIS , France

[c] CSTB , France

[d] Air Normand , France

[e] Ministry in charge of the ecology , United States

Accepted author version posted online: 08 Jul 2013.

To cite this article: HVAC&R Research (2013): Monitoring indoor air quality in French schools and day-care centres, HVAC&R Research

To link to this article: http://dx.doi.org/10.1080/10789669.2013.812498

Monitoring indoor air quality in French schools and day-care centres

Mr. nicolas michelot (Corresponding Author)

Email: nicolas.michelot@developpement-durable.gouv.fr

Affiliation 1:

Ministry in charge of the ecology, France

Dr. caroline marchand

Email: caroline.marchand@ineris.fr

Affiliation 1:

INERIS, France

Dr. olivier ramalho

Email: olivier.ramalho@cstb.fr

Affiliation 1:

CSTB, France

Dr. veronique delmas

Email: veronique.delmas@airnormand.fr

Affiliation 1:

Air Normand, France

Dr. marie carrega

 ACCEPTED MANUSCRIPT

Email: marie.carrega@developpement-durable.gouv.fr

Affiliation 1:

Ministry in charge of the ecology, United States

ABSTRACT

Indoor air quality monitoring in public premises, especially those hosting vulnerable populations such as children, was introduced in the second French national environment and health action plan and then regulated by the first “Grenelle Environnement” law, on August 3rd, 2009. A national pilot monitoring survey of indoor air quality in 310 French schools and day-care centres was performed in two phases from 2009 to 2011. This paper is dedicated to the results of the first phase (2009 to 2010, in 160 schools and day-care centres), another paper being in preparation about the whole survey results. Formaldehyde, benzene and air stuffiness were the targeted compounds. They were measured for 1-2 weeks during heating and non-heating season in each investigated building. The results of the first phase are presented in this paper. They show, referring to the management values suggested by the French committee for public health, that air quality is acceptable in most establishments tested. Nonetheless, a few cases required additional investigations or corrective measures. Furthermore, the air stuffiness (based on carbon dioxide measurements) was found to be very high in 16% of the classrooms (up to 25% in elementary schools). In 47% of the elementary schools, at least one classroom had very high air stuffiness. The Mayors and School Principals were informed and provided with means to identify the main sources of pollution and to implement remediation actions. The outcomes of this research have led to another step towards mandatory indoor air quality monitoring of public premises in

France. France is the first country to implement a routine and mandatory assessment of air quality in public buidings accommodating vulnerable people.

1. INTRODUCTION

Indoor air quality surveillance in public premises, especially those hosting vulnerable populations such as children, was introduced in the second French national environment and health action plan (NEHAP) and then regulated by the first "Grenelle Environnement" law, on August 3rd, 2009. A national pilot monitoring survey of indoor air quality in 310 French schools and day-care centres was performed in two phases from 2009 to 2011 (160 in 2009-2010 and 150 in 2010-2011). The 160 schools and day-care centres chosen for the first phase have different characteristics in terms of geographical location and year of construction, with a majority of schools located in urban areas. However, this sample is not statistically representative of all French establishments (53,798 nursery and elementary schools in 2011; 11,156 day-care centres in 2010).

Carried out and funded by the Ministry in charge of the Environment, with the Ministries of Health and Education, the pilot survey was conducted with the technical and organizational support of the National Institute for Industrial Environment and Risks (INERIS), in the framework of its missions in the Central Laboratory for Air Quality Monitoring (LCSQA), and the Scientific and Technical Building Center (CSTB). The measurements have been carried out by the officially approved associations for monitoring air quality (AASQA). A technical audit of buildings was also performed by several public and private experts.

The goal of this pilot monitoring survey was to validate monitoring protocols and management procedures to be implemented (*i.e.*, sampling strategy, pollutant source identification, remediation, etc.). The survey focused on two priority pollutants selected because of their classification as high priority pollutants in dwellings (Mosqueron *et al.*, 2003) and also in schools and offices by the French national agency for environmental and occupational health safety (ANSES, 2011):

- formaldehyde: irritant to the nose and the respiratory tract and probable carcinogen, emitted by some building materials, furniture, glues, cleaning products. In France, median formaldehyde level between 20 and 30 µg/m^3 was found in dwellings (Kirchner *et al.*, 2007; Marchand *et al.*, 2008), between 10 and 15 µg/m^3 in several day-care centers (Roda *et al.*, 2011). In an earlier study, a mean value of 22 µg/m^3 was found in French schools (Banerjee and Annesi-Maesano, 2012). This compound has been re-classified in 2004 as carcinogenic to humans (Group 1) by the International Agency for Research on Cancer (IARC) based on the observed data on nasopharyngeal cancers;
- benzene: carcinogen, originating mostly from combustion processes such as incense and candle burning, smoking, and exhaust gas in particular implying a non-negligeabloe contribution of outdoor air to indoor levels (Chiappini *et al.*, 2011). Median benzene levels in France varied between 1.4 - 2.1 in day-care centers (Roda *et al.*, 2011) and 2

μg/m^3 in dwellings (Kirchner *et al.*, 2007). This compound is classified by IARC as carcinogenic to humans (Group 1) on the basis of excess of leukemia observed in professional occupational exposures and is also classified as carcinogenic category 1 by the European Union.

The measured formaldehyde and benzene concentrations were compared with reference values suggested by the French committee for public health (HCSP 2009 and HCSP 2010). These values take into account health guideline values determined by the French National Agency for Environmental and Occupational Health Safety (Mandin *et al.*, 2009) such as the existence of chemical substitutes or alternative techniques. The reference value for long-term exposure to formaldehyde is 30 μg/m^3 with remediation actions needed for any observed level above 100 μg/m^3 (HCSP, 2009). The reference value for long-term exposure to benzene is 5 μg/m^3 with remediation actions needed for any observed level above 10 μg/m^3 (HCSP, 2009).

In order to be as representative as possible of the long-term exposure of children, measurements have lasted for one to two scholar weeks. Formaldehyde and benzene were measured at two different seasons, in order to estimate an annual average concentration.

Carbon dioxide (CO_2) was also continuously monitored and was used to calculate an air stuffiness index. This index, detailed later, provides a mean to assess pollutants accumulation in a closed space. Although carbon dioxide by itself does not have a significant effect on health at

ACCEPTED MANUSCRIPT

typical levels found in the environment, air stuffiness seems associated with a high prevalence of respiratory symptoms (Sundell *et al.*, 2011).

In addition, a simple audit of each building was carried out, including a description of each investigated room, heating and ventilation systems and cleaning habits. This audit can provide first clues of explanation when high concentrations are observed (failing ventilation system, specific sources...).

This paper is dedicated to the results of the first phase. He presents the methods and materials developed during this campaign and the results of the first phase for formaldehyde, benzene and air stuffiness in schools and day-care centres, as well as building audits.

2. MATERIAL AND METHODS

2.1 Chemical indicators: formaldehyde and benzene

The implemented protocols for formaldehyde and benzene monitoring were based on those developed through the work of the Central Laboratory for Air Quality Monitoring (LCSQA, 2008a). Formaldehyde and benzene were measured with Radiello® passive diffusion radial tubes, respectively code 165 (2,4-dinitrohydrazine sorbent for carbonyl compounds measurement) and code 145 cartridges (Carbograph 4 sorbent for volatile organic compounds measurement). The analysis of formaldehyde was performed by chemical desorption, followed by high performance liquid chromatography (HPLC) coupled with UV detection. The analysis of benzene was carried out by thermal desorption, followed by gas chromatography (GC) coupled with flame ionization detection (FID) and mass spectrometry (MS). Details of the analytical methods are given in the LCSQA protocols (LCSQA, 2008a).

2.1.1 Temporal sampling strategy

In order to be as representative as possible of a long-term exposure of the children, measurements were performed from Monday morning to Friday afternoon, *i.e.* during 4.5 days (and there were no measurements during the scholar holidays). As pollutant concentration can vary greatly from season to season, formaldehyde and benzene were measured both during the heating (H) and non-heating (NH) season. The non-heating season extends from mid-September to mid-October and from April to May, whereas the heating season extends from November to February. The heating season does not really apply to overseas departments of France due to their tropical climate, but the measurements were realised during the two defined periods. The two measurements were averaged in order to represent an annual mean.

In parallel of passive samplers, indoor and outdoor temperature was also monitored with a datalogger and taken into account to correct the uptake rate of pollutants for concentration calculation.

The uncertainty linked to the temporal sampling strategy for formaldehyde was also studied during the first phase of this pilot monitoring survey. For 12 establishments out of 160,

 ACCEPTED MANUSCRIPT

formaldehyde measurement was performed for 16 consecutive scholar weeks (not including holidays), partly during heating and non-heating seasons, and the rest during the transition period between those 2 seasons.

2.1.2 Spatial sampling strategy

For each building, one or two rooms were monitored for each floor level, according to the following rule: if the floor level included up to three rooms, then one was instrumented, when more than three rooms were available, two rooms were selected. The selected rooms represent any classroom or living room occupied by teachers and pupils in the context of school education outside specific activities (paint shops, library...). Thus, any housing or office function or technical areas were not taken into account. Dormitories in day-care centres were not investigated. Outdoor measurement of benzene was also realised for each period. When one room was instrumented, the outdoor point was on the same side as the room monitored. If several rooms were instrumented, the outdoor measurement was realised on the most "polluted" side (street side for example).

2.1.3 Quality control

Laboratory and field blanks were carried out to check the absence of contamination on new and used cartridges before use, and during transport and storage. Field blanks (one indoor for formaldehyde and benzene and one outdoor for benzene) were performed for each establishment, at each investigated period. Moreover, within each building, two parallel measurements (duplicates) were performed in one room in order to determine measurement repeatability.

ACCEPTED MANUSCRIPT

2.2 Indoor air stuffiness

Indoor air stuffiness inside a building room involves two concepts: the available space (exiguity or spaciousness) and the air renewal (or aeration). A stuffy air represents air that is not sufficiently renewed by fresh air. When pollutant sources are involved, in particular human presence, pollutant may quickly accumulate in a stuffy air. The less spacious the room is, that is to say the highest the density of occupation, and more the room should be ventilated to avoid stuffiness.

2.2.1 Air stuffiness index (ICONE)

A good indicator of the air stuffiness is provided by the measurement of carbon dioxide concentrations from metabolic production. CO_2 concentration was continuously monitored with a time step of 10 minutes for two consecutive weeks using an instrument based on a non-dispersive infrared sensor (Lum'Air®) developed by Ribéron *et al.* (2011). CO_2 monitoring was realised in the same rooms selected for formaldehyde and benzene measurements. The instrument measures CO_2 concentrations up to 5000 ppm. The uncertainty of measurement is ± (50 ppm + 3% of read value). An air stuffiness index called ICONE (*Indice de CONfinement d'air dans les Ecoles*) was developed by Ribéron *et al.* (2011). It is based on the exceedance frequency of CO_2 values above the defined threshold values of 1000 and 1700 ppm during the week. Only children occupancy periods are taken into account. CO_2 levels measured during inoccupancy are discarded. A classroom is considered occupied when at least half of the usual

 ACCEPTED MANUSCRIPT

number of children is present. The air stuffiness level of the room is then expressed by a score from 0 to 5. A score of 0 corresponds to non-stuffy air (CO_2 level always below 1000 ppm) and is the most favorable situation. A score of 5 corresponds to an air with extreme stuffiness (CO_2 level always above 1700 ppm during children occupancy) and is the worst situation. Middle scores correspond to a gradient of varying exceeding situations (Table 1). When the CO_2 level remains between 1000 and 1700 ppm, the score is 2.5 rounded to 3.

The final result for a given classroom is the average of two weekly scores rounded to the nearest integer and corresponding to one of the six categories of air stuffiness (0 to 5). This calculation method allows minimizing the influence of under-occupancy or special events that can take place during the week. The air stuffiness index reflects the quality of the air change during occupancy but does not provide any information during unoccupied periods. The score for one building is represented by the highest value registered among instrumented rooms.

2.3 Operational measurements progress and building audit

As indicated previously, measurements were performed during one to two consecutive scholar weeks (1 or 2 x 4.5 days), depending on the target compound, and at two different seasons, except for CO_2 that was measured only during the heating period. All measurement systems were placed on Monday morning, before 8:30am to avoid disturbing courses. Passive diffusion tubes were generally hanged from the ceiling (figure 1). The measurement was stopped when children left the classroom, on Friday after 4:45pm. One to eight rooms per establishment were investigated, depending on its size (number of buildings, number of floors and rooms per

ACCEPTED MANUSCRIPT

building...). The studied rooms were the same for both seasons. For benzene specifically, an outdoor measurement was also performed in order to evaluate the outdoor contribution.

The building audit consisted in a set of questions that included a general description of the facility, housekeeping/cleaning premises, products used for this purpose, aeration habits and ventilation system, activities. This questionnaire was filled by a building expert. Audits were performed during the heating season in order to check heating systems (from November 2009 to February 2010). The audits did not include any measurement.

3. RESULTS

3.1 Chemical indicators: formaldehyde and benzene

Average concentrations of formaldehyde and benzene for each establishment (mean of the annual concentrations registered in the different rooms) are detailed in Table 2. 89% of the investigated establishments had an average concentration of formaldehyde below 30 $\mu g/m^3$. For benzene, 43% of the establishments had an average concentration lower than 2 $\mu g/m^3$. These levels are satisfactory and did not imply specific actions. 75% of the establishments with a benzene concentration ranging from 2 to 5 $\mu g/m^3$ reported a mean level lower than 3 $\mu g/m^3$. In

75 % of the cases for which benzene concentrations were higher than 2 µg/m^3, indoor and outdoor levels were statistically equivalent.

The uncertainty associated with the temporal sampling strategy for formaldehyde annual mean calculation is reported in Table 3. As indicated previously, for 12 establishments (*i.e.* 21 investigated rooms), formaldehyde measurements were performed for 16 consecutive scholar weeks, partly during the heating (H) and non-heating (NH) period and the rest during the transition period between those 2 seasons (T). Each 16 week measurement in a room was considered as a measurement series. Each one of the 21 series can be divided into 3 strata (H, NH T). It was assumed that the 16 week measurement was representative of a whole scholar year with its seasonal variations and that the defined 3 strata represented a complete partition of the year.

The theoretical uncertainty due to the temporal sampling strategy was calculated according to the sample survey theory and depended on the concentration variance within each temporal stratum and on the number of measurements drawn in each stratum (Tillé, 2001; LCSQA, 2008b). Dividing the year in different strata is efficient for reducing the uncertainty. Indeed, for the same number of measurements during a year, the uncertainty is lower when several strata are considered. The second line in table 3 corresponds to the sampling strategy followed in this survey and appears to be the best compromise between cost (number of measurements) and precision (calculated uncertainty).

3.2 Indoor air stuffiness

Results for the air stuffiness index are compiled in Table 4. 23% of the investigated establishments had at least one room with a very high air stuffiness index, such as a score of 4 or 5 (2% of the day-care centres, 18% of the nursery schools and 47% of the elementary schools). None of the overseas sites at Reunion Island did show any sign of stuffy air. The typical climate of the island (around 28°C and 80% relative humidity both indoors and outdoors) favours well-ventilated indoor environments.

3.3 Building audits

The results of the 160 building audits confirmed that a low percentage of schools (18%) are equipped with a mechanical ventilation system in the classrooms. However in day-care centres, children playrooms are more often equipped with a mechanical ventilation system (51%), as well as air conditioning systems in 30% of cases. The occurrence of mechanical ventilation system in classrooms and playrooms is detailed in table 5.

The use of auxiliary heating was reported in 12% of cases, but it always involved electrical devices (not kerosene or gas heaters). Units of air purification or disinfection have been used in 12 establishments (8%). In 34 establishments (21%), a flood was reported and mold stains were visible in 16 establishments (10%). As health effects were associated with mold exposure in several studies, schools were highly recommended to get rid of this contamination. When the building included a kitchen (12% of establishments), additional moisture is generated that favours mold growth. Recent renovation or refurbishing work (less than one year old) occurred in respectively 31 and 22 establishments (19% and 14%). In these establishments, school principals were specifically asked to be vigilant about ventilation in order to limit VOC emissions from renovations.

4. DISCUSSION

Formaldehyde and benzene concentrations as well as air stuffiness indexes were compared during the heating period. To do so, the annual average concentrations for each establishment were categorized into three classes, according to the reference values. For formaldehyde, the three classes were < 30 µg/m^3, 30-50 µg/m^3 and > 50 µg/m^3. For benzene, the three classes were < 2 µg/m^3, 2-5 µg/m^3 and > 5 µg/m^3. For the air stuffiness index, values of 4 and 5 were grouped together, as the latter occurred only once.

The distribution of air stuffiness index scores was then determined in each class of pollutant concentration (Figure 2).

The distribution of air stuffiness indexes did not seem to depend on the formaldehyde concentrations. For benzene, the proportion of establishments with levels higher than 5 µg/m^3 was greater if the air stuffiness index was equal to or greater than 3. However, this tendency did not reflect a significant association between these 2 variables. Thus, a situation of high or very high air stuffiness was not sufficient to explain high pollutant concentration levels that also implied the presence of specific emission sources. Moreover, it is important to note that the comparison of air stuffiness indexes with benzene and formaldehyde levels must be made with caution since formaldehyde and benzene data included both occupied and unoccupied periods,

 ACCEPTED MANUSCRIPT

especially nights (due to the limitations of the sampling method), whereas the air stuffiness index took exclusively into account occupied periods. The occupied periods represent about 20-25% of the total 4.5 days sampling time. Another possible explanation to this discrepancy is that ventilation conditions in classrooms may be different during occupied and unoccupied periods.

The building audits provided data to check if the buildings were in good working order in relation to the indoor air quality. They allowed the identification of risk situations (e.g. mold), which were not identified by the measurements of the two chemical parameters. The audits thus represent a real decision tool for building managers, insofar as it is easy to identify different remediation actions (e.g. clean dirty air inlets, replace non-operable windows, correct ventilation duct connection, remove mold stains, transfer cleaning products stored within the classroom to a specific storage area).

The study showed that the management of poor indoor air quality situations was not always easy, especially when the specific sources of formaldehyde or benzene remained unidentified. A more preventive risk management system was adopted in the second French NHAP through several institutional policies that should gradually improve air quality in schools and day-care centres in France, *i.e.* improving ventilation practices and reducing source emissions. In particular, as from March, 2011 (Official Journal of the French Republic, JORF, 2011) new building materials and decoration products are labelled according to their volatile organic compounds emissions. At last, another step towards a better indoor air quality in France is the statutory decree of December 2nd, 2011 (JORF, 2011) that defines the mandatory monitoring of indoor air quality in some public premises hosting sensitive people. The guidelines of this mandatory monitoring are based on the study described in this paper.

This mandatory survey should be done every 7 years, or every 2 years if limit values are exceeded. The results of the survey will be made public by the owner of the premises. When limit values are exceeded, investigations to identify sources of pollution must be conducted and the regional prefect is alerted. The application of this mandatory survey will be gradual:

- January 1, 2015 for the 9,000 nurseries and 17,000 day-care centres,
- January 1, 2018 for 38,000 elementary schools,
- January 1, 2020 to 17,000 secondary schools and recreation centers,
- January 1, 2023 for other establishments (hospitals, swimming pools...).

The national decree specifying the conditions of this survey in schools, day-care centres and recreation centers has been published Jan. 5, 2012 (JORF, 2012). France is the first country to implement a systematic and mandatory monitoring of indoor air quality in public establishments especially those hosting vulnerable people.

In order to accompany local authorities in the new regulation, two indoor air quality guides in public buildings have been published in 2010 (available on www.sante.gouv.fr and www.invs.sante.fr). A booklet has also been published to explain the new regulation to regional government agencies. In 2012, a measure of perchloroethylene was included in schools located near a dry cleaning laundry.

5. CONCLUSIONS

The results of the first phase of this pilot monitoring survey showed that indoor air quality, through the evaluation of two chemical indicators and an air stuffiness index, was satisfactory in 26 % of the investigated establishments, *i.e.* air stuffiness index below 3 and annual concentration below 30 $\mu g/m^3$ for formaldehyde and below 2 $\mu g/m^3$ for benzene). However, 31% of the establishments registered a poor indoor air quality for at least one of the three parameters, *i.e.* air stuffiness index greater than 3 or annual concentration higher than 50 $\mu g/m^3$ for formaldehyde or higher than 5 $\mu g/m^3$ for benzene). These establishments were strongly encouraged to quickly conduct further investigations in order to identify pollutant sources. For 47% of elementary schools, the air stuffiness index was very high in at least one classroom. However, it was not always associated with high pollutant concentrations. Establishments with an air stuffiness index greater than 3 in at least one room were advised to improve the ventilation during children occupancy and to check the ventilation system, where available. These actions, which contribute to the improvement of the air quality in the building, do not necessarily require significant financial resources.

Finally, the results of this large-scale field study were used to define the basis of a national mandatory survey of indoor air quality in public premises, especially those receiving sensitive people, such as children.

 ACCEPTED MANUSCRIPT

6. REFERENCES

ANSES (French national agency for environmental and occupational health safety). 2011. *Proposal of indoor air quality guidelines. Change in the elaboration method of indoor air quality guidelines.* Collective expertise report. Saisine 2010 SA-0307. 89 p. (in French)

Banerjee S., Annesi-Maesano I., 2012. Spatial variability of indoor air pollutants in schools. A multilevel approach. *Atmospheric Environment,* 61, 558-561.

Chiappini L., 2011. Benzene in indoor air: review of measured concentrations. *Pollution Atmosphérique*, 210, 155-162.

HCSP (High council for public health), 2009. *Report of the specialised commission in environmental risks: Reference values for air quality management in closed spaces – Formaldehyde.* 41 p.

HCSP (High council for public health), 2009. *Report of the specialised commission in environmental risks: Reference values for air quality management in closed spaces – Benzene.* 89 p.

JORF (Official journal of the French republic), 2011. Décret n° 2011-321 du 23 mars 2011 relatif à l'étiquetage des produits de construction ou de revêtement de mur ou de sol et des peintures et vernis sur leurs émissions de polluants volatils.

JORF (Official journal of the French republic), 2011. Décret n°2011-1727 du 2 décembre 2011 relatif aux valeurs-guides pour l’air intérieur pour le formaldéhyde et le benzène

JORF (Official journal of the French republic), 2011. Décret n° 2011-1728 du 2 décembre 2011 relatif à la surveillance de la qualité de l'air intérieur dans certains établissements recevant du public.

 ACCEPTED MANUSCRIPT

JORF (Official journal of the French republic), 2012. Décret n° 2012-14 du 5 janvier 2012 relatif à l'évaluation des moyens d'aération et à la mesure des polluants effectués au titre de la surveillance de la qualité de l'air intérieur de certains établissements recevant du public.

Kirchner S., Cochet C., Derbez M., Duboudin C., Elias P., Gregoire A., Jedor B., Lucas J.P., Pasquier N., Pigneret M. & Ramalho O., 2007. Etat de la qualité de l'air dans les logements français. *Environnement Risques & Santé*, 6(4), 259-269.

LCSQA (Central laboratory for air quality monitoring), 2008a. *Report of the Central Laboratory for Air Quality Monitoring: Monitoring protocols of formaldehyde, benzene and carbon monoxide in closed spaces*. LCSQA-CSTB-EMD-INERIS-DRC-08-94298-15176A.

LCSQA (Central laboratory for air quality monitoring), 2008b. *Report of a working group of the Central Laboratory for Air Quality Monitoring. Sampling design and data reconstitution*. ADEME Editions.

Mandin C., Bonvallot N., Kirchner S., Keirsbulck M., Alary R., Cabanes P.A., Dor F., Le Moullec Y., Mullot J.U., Peel A.E., Rousselle C., 2009. Development of French indoor air quality guidelines. *CLEAN - Soil, Air, Water*, 37(6), 494–499.

Marchand C., Le Calvé S., Mirabel Ph., Glasser N., Casset A., Schneider N., de Blay F., 2008. Concentrations and determinants of gaseous aldehydes in 162 homes in Strasbourg (France). *Atmospheric Environment*, 42(3), 505-516.

Mosqueron L., Nedellec V., Kirchner K. et al. 2003. *Ranking indoor pollutants according to their potential health effect, for action priorities and costs optimization in the French permanent survey on indoor air quality.* Proceedings of Healthy building 7th International Conference; vol. 3: pp. 138-143.

Ribéron J., Derbez M., Lethrosne M., Kirchner S. 2011. *Impact of airing behaviour on air stuffiness in schools and daycares centres: Development of a specific tool for ventilation management*. 12th International conference on indoor air quality and climate, Indoor Air'2011, Austin (USA), June 5-10, short communication.

Roda C., Barral S., Ravelomanantsoa H., Dusséaux M., Tribout M., Le Moullec Y., Momas I., 2011. Assessment of indoor environment in Paris child day care centers. *Environmental Research*, 111(8), 1010-1017.Sundell J., Levin H., Nazaroff W. W., Cain W. S., Fisk W. J., Grimsrud D. T., Gyntelberg F., Li Y., Persily A. K., Pickering A. C., Samet J. M., Spengler J. D., Taylor S. T. and Weschler C. J., 2011. Ventilation rates and health: multidisciplinary review of the scientific literature. *Indoor Air*, 21(3), 205-218.

Tillé Y. 2001. *Sample survey theory. Sampling and estimation with finite population. Lessons and exercises with corrections*. Dunod Editions, Paris, 284 p.

Table 1: Air stuffiness according to the ICONE index.

ICONE	Frequency of CO_2 values	
0	100% CO_2 values < 1000 ppm	Non-stuffy air
1	1/3 values > 1000 but < 1700 ppm	Low stuffiness
2	2/3 values > 1000 but < 1700 ppm	Moderate stuffiness
3	2/3 values > 1000 with 1/3 > 1700 ppm	High stuffiness

ACCEPTED MANUSCRIPT

4	2/3 values > 1700 ppm	Very high stuffiness
5	100% CO_2 values > 1700 ppm	Extreme stuffiness

Table 2. Annual mean levels of formaldehyde (FA) and benzene (BE) (n=160 establishments)

Average concentration of FA (µg/m^3)	Proportion of establishments (%)	Average concentration of BE (µg/m^3)	Proportion of establishments (%)
0 - 30	89.4	0 - 2	44.7
30 - 50	8.8	2 - 5	52.8
50 - 100	1.8	5 - 10	2.5
> 100	0.0	> 10	0.0

Table 3. Theoretical uncertainty in annual mean calculation due to the temporal sampling strategy based on 21 measurement series.

Temporal sampling strategies		Average uncertainty (%)	Standard deviation (%)
Number of strata per year	Total number of measurements per year		
3 (H, NH, T)	3 (1/stratum)	21	7

ACCEPTED MANUSCRIPT

2 (H, NH)	2 (1/stratum)	26	8
1	3	25	6
1	2	32	8
1	1	46	12

Table 4. Distribution of the air stuffiness index (n=160 schools and day-care centres).

Icone	Distribution of the maximum air stuffiness index determined in each establishment (%)			
	All n = 160	Day-care centres n = 46	Nursery schools n = 61	Elementary schools n = 53
0	9.3	15.2	11.5	1.9
1	14.4	23.9	16.4	3.8
2	18.8	23.9	21.3	11.3
3	33.8	34.8	31.2	35.8
4	22.5	2.2	18.0	45.3
5	0.6	0	0	1.9
INV	0.6	0	1.6	0

**INV: Invalid data or insufficient occupancy that does not allow the calculation of the index score.*

Table 5. Occurrence of mechanical ventilation system in classrooms and playrooms.

Mechanical ventilation system	All	Day-care centres	Nursery schools	Elementary schools
Balanced ventilation	5%	14%	2%	4%
Exhaust ventilation (air outlet in a separate room, e.g. toilets)	10%	21%	10%	4%
Exhaust ventilation (air outlet in the room)	12%	27%	6%	11%
No mechanical system	73%	38%	82%	81%

Figure 1. Passive samplers of formaldehyde and benzene near the ceiling, and the Lum'air sensor at the back of the room (source: Air Normand).

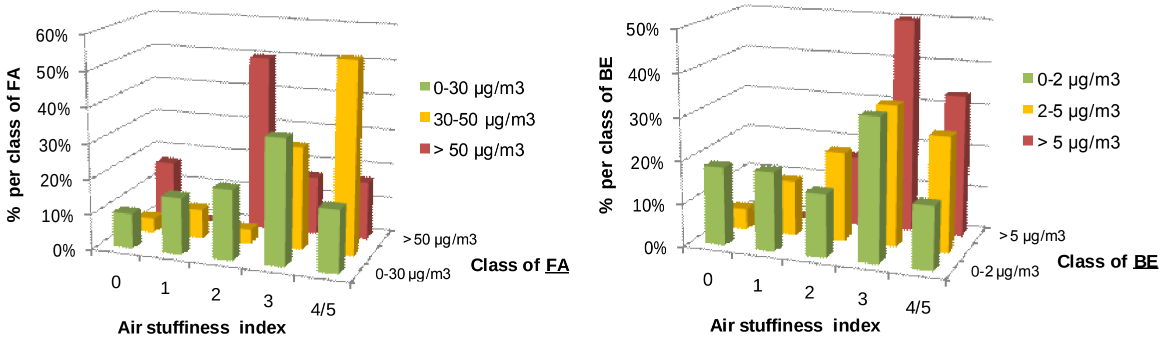

Figure 2. Distribution of air stuffiness indexes according to the different classes of formaldehyde (FA) (left) concentrations, or benzene (BE) (right) concentrations