Indoor air quality measurements in 35 schools of South-Western Europe

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ABSTRACT

The ClimACT project has been developed under the priority axis "Low Carbon Economy" of the Interreg SUDOE program. It aims to support the transition to a low carbon economy in schools. Environmental audits addressing energy and water consumptions, waste management, travels to school, procurements and green spaces have been carried out in 38 pilots schools of Portugal, Spain, France and Gibraltar. Indoor air quality and ventilation measurements were also achieved. The concentrations of 9 aldehydes and 10 selected VOCs were measured from passive sampling in two classrooms of each school. In addition, TVOC, CO_2, CO, $PM_{2.5}$ and PM_{10} concentrations were monitored for a period of 2 days or 1 week in French schools. Of all the individual VOCs and aldehydes investigated, only formaldehyde exhibit some concentrations over the guideline. On the other hand, PM_{10}, $PM_{2.5}$, CO_2 and TVOC concentrations during the class hours are over the guidelines in 64%, 45%, 43% and 20% of classrooms, respectively. The time series of concentrations highlight that a significant part of TVOCs originates from the occupants. Similarly, PM_{10} concentrations over the guideline are mainly contributed by biogenic emissions and resuspension of settled particles. Another interesting conclusion coming from the study is that there are no significant differences in the characteristics of the air pollution in secondary schools, high schools and universities, when compared to primary schools. However, the characteristics of indoor air pollution in classrooms may be slightly different in Spain, Portugal, Gibraltar and France.

KEYWORDS

Indoor air quality, schools, particle matter, volatile organic compounds, aldehydes

1 INTRODUCTION

Different studies have demonstrated that poor indoor air quality (IAQ) in school buildings may result in illness leading to student absenteeism, adverse health symptoms, and decreased learning performance (Sundell et al, 2011). Exposure to poor indoor air quality may immediately result in olfactory discomfort and complaints about stuffy and stale air. In the short term, it can also affect health through symptoms such as eye irritation or red eyes, feeling of dry throat or throat irritation, blocked or runny nose, headache, unusual fatigue, dizziness. Finally, in the short and medium term, serious health effects such as incidence of infections or asthma can occur (REHVA, 2010).

From the middle of the nineties, Smedje et al. (1997) studied various health aspects including asthmatic symptoms in 627 high school students from 39 schools in Uppsala (Sweden). Comfort parameters but also chemical and biological contaminants were measured in 28 classes among these schools. The authors found that asthma was significantly and positively correlated with school size, low temperatures, high relative humidity, as well as formaldehyde, volatile organic compounds (VOC), bacteria and mold concentrations. A few years later, the same authors extended these conclusions on a larger sample of 1437 children aged 7 to 13 and 100 classes (Smedje and Norbäck, 2001). The highest incidences of asthma were observed in children exposed to school dust and cat allergens. The authors also achieved positive relationships with formaldehyde and mold concentrations. Similar conclusions arose from the study by Daisey et al. (2003), who showed that the most commonly observed symptoms related to air quality in schools were asthma and sick building syndrome (SBS). Biological pollutants are the main determinants but chemicals including VOCs and formaldehyde are also involved.

The International Study of Asthma and Allergies in Childhood (ISAAC) investigated allergic diseases related to allergy caused by the exposure to indoor and outdoor sources of air pollution in elementary schools. The past and present status of asthma, allergic rhinitis, eczema, and allergic conjunctivitis were investigated by providing a questionnaire to 61350 children from 438 elementary schools worldwide (40522 children responded). Meanwhile, volatile organic compounds, aldehydes, and particulate matter (PM_{10}) were measured inside and outside the schools (ISAAC, 2007), as well as in some homes. Allergic and asthmatic symptoms were found to be associated with indoor and outdoor air quality, among other things (WHO, 2007). However, as underlined by Diette et al (2008), people have a much greater ability to modify indoor environments and exposures, which makes addressing indoor air pollution an attractive target for disease prevention.

More recently, Madureira et al (2015) conducted a cross-sectional survey to characterize indoor air quality in schools and its relationship with children's respiratory symptoms. Concentrations of volatile organic compounds (VOC), aldehydes, $PM_{2.5}$, PM_{10}, carbon dioxide, bacteria and fungi were assessed in 73 classrooms of 20 public primary schools located in Porto, Portugal. Children who attended the selected classrooms (1134) were evaluated by a standardised health questionnaire completed by spirometry and exhaled nitric oxide tests. High levels of total VOC, acetaldehyde, $PM_{2.5}$ and PM_{10} have been associated with higher odds of wheezing in children.

Mendell and Heath (2005) conducted a literature review on the links between air pollutants in schools and parameters such as student attention and absenteeism. They concluded to significant links between NO_2 concentrations, ventilation rates, and the observed parameters. Furthermore, after pointing out that CO_2 concentrations above 2000 ppm cause headaches, general fatigue, impaired alertness and drowsiness, the authors concluded that an increase of the CO_2 concentration from 1000 ppm to 2000 ppm was significantly related to a decrease of 0.5% annual presence rates.

The CO_2 concentration and ventilation rate are also commonly used parameters to describe indoor air quality when investigating its influence on academic performance. A synthesis of studies from Wargocki et al (2005), Shaughnessy et al (2006), Haverinen□Shaughnessy et al

(2010) and Bako-Biro et al (2012) lead to the conclusion that learning performance at school strongly decreases with ventilation rates below 4 l/s/person. On the other hand, the performance linearly increases with ventilation rate up to 13 l/s/person, but the data for ventilation rates up to 7 l/s/person are limited. Based on ventilation measurements in 108 classrooms of 60 Finnish schools and questionnaires, Toyinbo et al (2016) found an association between lower mathematics test results and schools that do not meet the Finnish recommended ventilation rate of 6 l/s/student.

The ClimACT project has been developed in Spain, Portugal, Gibraltar and South-Western France. It aims to promote the transition to a low carbon economy in the educational sector. Environmental audits dealing with energy and water consumptions, renewable energy use and production, waste management, travel to school and green spaces were conducted in 38 pilot schools in the four countries, among other technical and educational tasks. The objective of these audits were to assess the schools performance in each environmental sector as a way to help the decision-making on measures to improve the performance. Indoor air quality, ventilation, and thermal comfort were also considered. Measurements have been carried out as a way to ensure that energy related measures do not lead to discomforts, poorer air quality, and subsequently health symptoms or decreased cognitive performance. The methodology used for IAQ measurements is described in the first section of the paper. Then the results are analysed by reference to guidelines and by comparison with other studies. Particular emphasis is put on highlighting mean concentration discrepancies from one country to another and analysing the reasons why mean pollutant concentrations are over the guideline in some schools.

2 MATERIAL AND METHODS

Indoor air quality measurements have been carried out in 38 primary schools, secondary schools, high schools, and university departments across France, Gibraltar, Spain and Portugal. (Table 1). Two rooms have been investigated in each school using continuous monitoring of some IAQ parameters and time-integrated measurements of individual VOCs and aldehydes from passive sampling.

Table 1: Distribution of ClimACT pilot schools by country

Location	Primary school	Secondary school	High school	Secondary and high	University department	Total
France (La Rochelle)	6	-	2	-	1	9
Spain						
Andalucia	4	-	-	5	-	9
Madrid area	1	-	-	3	-	4
Portugal						
Lisbon area	4	-	1	-	1	6
Porto area	2	-	1	-	-	3
Gibraltar	5	1	-	-	1	7

2.1 IAQ Monitoring

Carbon dioxide (CO_2), carbon monoxide (CO), total volatile organic compounds (TVOC), fine particles ($PM_{2.5}$) and breathable (PM_{10}) concentrations have been monitored for two consecutive school days in Portuguese, Spanish and Gibraltarian schools, and a full school week in French schools. The instruments used and measurement time steps are listed in Table 2. It is important to underline that particle mass concentrations have been assessed from particle counts, which is not a standard method. Furthermore, different optical counters have been used in the four countries. The conversion from counts to mass concentrations were achieved based on the shape factors and density functions implemented in the instruments, except for Gibraltar where the assumptions of spherical particles and a uniform density of 1650 kg/m^3 were considered. This adds to the uncertainty when comparing the $PM_{2.5}$ and PM_{10} concentrations coming from different countries, or comparing measured concentrations to the guidelines.

Table 2: Instruments used for IAQ monitoring in classrooms and measurement timestep

School location	CO_2	CO	$PM_{2.5}/PM_{10}$	TVOC	Occupancy hours(*)
France	HD21AB17 (DeltaOhm) Δt = 1 min	HD21AB17 (DeltaOhm) Δt = 1 min	OPC-N2 sensor (Alphasense) Δt = 1 min	VOC-103L probe (Graywolf Sensing Solutions) Δt = 1 min	9 am to 5 pm
Spain	HD21AB17 (DeltaOhm) Δt = 2 min	HD21AB17 (DeltaOhm) Δt = 2 min	Optical Particle Sizer OPS 3330 (TSI) Δt = 2 min	VOC-103L probe (Graywolf Sensing Solutions) Δt = 2 min	9 am to 2 pm
Portugal (Lisbon area)	Graywolf IQ-610 probe (WolfSense Solutions) Δt = 1 min	Graywolf IQ-610 probe (WolfSense Solutions) Δt = 1 min	DustTrak monitor 8530 (TSI) Δt = 1 min	Graywolf IQ-610 probe (WolfSense Solutions) Δt = 1 min	9 am to 5 pm
Portugal (Porto area)	Testo 400 Probe (Testo) Δt = 5 min	Testo 400 probe (Testo) Δt = 5 min	DustTrak monitor 8530 (TSI) Δt = 1 min	Graywolf IQ-610 probe (WolfSense Solutions) Δt = 1 min	8 am to 7pm
Gibraltar	HD21ABE17 (DeltaOhm) Δt = 1 min	HD21ABE17 (DeltaOhm) Δt = 1 min	3016IAQ (Graywolf Sensing Solutions) Δt = 1 min	No monitoring	9 am to 5 pm

(*)Period considered for the calculation of mean concentrations

The instruments have been installed in the rooms in such a way that the measurements are representative of the occupants' exposure. Care was taken to avoid situations where the measurements can be directly influenced by a too short distance from a potential pollutant source, windows, or air inlets. Practical constraints related to the class functioning had nevertheless to be taken into account, which lead to non-optimal positioning of the instruments in some situations.

The occupants' exposure was assessed by computing the mean pollutant concentrations over the occupancy hours. The latter are listed in Table 2. A same occupancy period was considered for all schools of a same country, although it can actually be slightly different in some schools.

2.2 Measurement of individual VOC and aldehyde concentrations

The concentrations of 10 individual VOCs (benzene, trichloroethylene, toluene, tetrachloroethylene, ethylbenzene, m+ p-xylene, styrene, o-xylene, alpha-pinene, 1,4-dichlorobenzene) and 9 specified aldehydes (formaldehyde, acetaldehyde, acrolein, propanal, butanal, benzaldehyde, isopentanal, pentanal, hexanal) were determined from passive sampling in the rooms over one school week, from Monday morning to Friday afternoon. RAD145 carbograph 4™ cartridge adsorbents (Radiello™) and RAD165 2,4-DNPH coated cartridge adsorbents (Radiello™) were used for VOC and aldehyde sampling, respectively. VOC concentrations were determined by thermal desorption and gas chromatography coupled with mass spectrometry (GC-MS). RAD 165 aldehyde concentrations were analyzed by high performance liquid chromatography coupled to ultra violet detection (HPLC-UV). ICSM SPA SB (Italy) performed all the analyses.

2.3 Selected indoor air quality guidelines

Several international or national health agencies have established health-based indoor air quality guidelines. Besides, some countries have also set guidelines for regulations establishing compulsory measurements of indoor air quality in public buildings. The latter are most often higher than health-based values as a way to combine health and socio-economic considerations. Both kinds of guidelines have been considered to define threshold limit values for the largest number of pollutants investigated (Table 3). However, health-based values were considered first, and the lowest value was taken when several guidelines exist for a same contaminant. No relevant guideline for schools could be found for propanal, isopentanal and benzaldehyde.

Table 3: Selected indoor air guidelines

Pollutant	Guideline	Source
PM_{10}	20 µg/m^3	World Health Organization (WHO) – Health-based guideline for a long term exposure (WHO, 2010)
$PM_{2.5}$	10 µg/m^3	WHO guideline for a long term exposure (WHO, 2010)
CO	10 µg/m^3	INDEX project - European health-based guideline for a 8h-exposure repeated each day of the week (Kotzias et al, 2005)
CO_2	1250 ppm	Portuguese guideline for compulsory IAQ measurements(1)
TVOC	600 µg/m^3	Portuguese guideline for compulsory IAQ measurements (1)
Formaldehyde	30 µg/m^3	INDEX project - European health-based guideline for a 30 min-exposure (Kotzias et al, 2005)
Acetaldehyde	200 µg/m^3	INDEX project - European health-based guideline for a long term exposure (Kotzias et al, 2005)
Acrolein	0.8 µg/m^3	ANSES(2) – French health-based guideline for a long-term exposure
Benzene	2 µg/m^3	ANSES(2) - French health-based guideline for a long-term exposure
Toluene	250 µg/m^3	Portuguese guideline for compulsory IAQ measurements (1)
Xylenes (m+o+p)	200 µg/m^3	INDEX project - European health-based guideline for a long term exposure (Kotzias et al, 2005)
Trichloroethylene	20 µg/m^3	ANSES(2) – French health-based guideline for a long-term exposure
Tetrachloroethylene	250 µg/m^3	WHO – Health-based guideline for a long term exposure (WHO, 2010)
Styrene	250 µg/m^3	INDEX project - European health-based guideline for a long term exposure (Kotzias et al, 2005)
1,4-dichlorobenzene	150 µg/m^3	EU-JRC – Lower Concentration of Interest (LCI)(3) (European Commission, 2016)
Butanal,	650 µg/m^3	EU-JRC – LCI(3) (European Commission, 2016)
Pentanal	800 µg/m^3	EU-JRC – LCI(3) (European Commission, 2016)
Hexanal	900 µg/m^3	EU-JRC – LCI(3) (European Commission, 2016)
α-pinene	200 µg/m^3	German Committee on Indoor Guide Values(4) - German guideline for a long-term exposure.

(1) Portatia nº 353-A/2013. Regulamento de Desempenho Energético dos Edifícios de Comércio e Serviços (RECS). Requisitos de Ventilação e Qualidade do Ar Interior

(2) https://www.anses.fr/fr/content/valeurs-guides-de-qualit%C3%A9-d%E2%80%99air-int%C3%A9rieur-vgai

(3 LCI are health-based threshold limit values that aim at the harmonization of mandatory labelling of material emissions in Europe

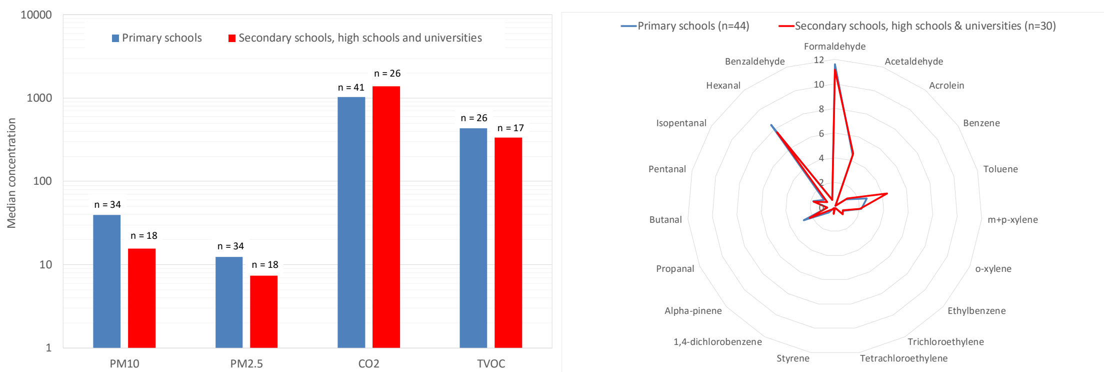
(4) https://www.umweltbundesamt.de/sites/default/files/medien/355/bilder/dateien/0_ausschuss_fur-innenraumrichtwerte_empfehlungen_und_richtwerte_20180412_en.pdf.

3 RESULTS AND DISCUSSION

Table 4 presents the statistical data of pollutant concentrations in classrooms together with the median concentrations coming from recent studies on IAQ in European, Portuguese, Spanish and French schools. Here, the concentrations were taken to half of the limit of quantification (LOQ) when they are lower. The reasons for the smallest number of online measurements are threefold: first is that $PM_{2.5}$ and PM_{10} concentrations have been monitored in only one classroom of Spanish schools, and have not been monitored at all in two of them, due to technical constraints. Similarly, no TVOC measurements have been carried out in any Gibraltarian school. Finally, a small number of measurements were obviously not correct and invalidated.

The studies listed in Table 4 investigated VOC and aldehyde concentrations in schools from passive samplers. Therefore, all concentrations are 24 h integrated values that are comparable. First, it can be noted that most median VOC and aldehyde concentrations coming from the present study are lower than those coming from the other studies. Then, $PM_{2.5}$ concentrations are close to the median concentration in French primary schools (OQAI, 2018), which indicates that PM concentration measurements are reliable despite the methodologic uncertainty. On the other hand, the median TVOC concentration in ClimACT schools is much higher than the ones reported by Madureira et al (2015) and Villanueva et al (2018). However, the discrepancies most probably reflect differences in concentrations returned by different TVOC sensors rather than real differences in the TVOC content of the air. This point must also be considered when comparing TVOC concentrations coming from different countries in the frame of the present study.

One specificity of the ClimACT study, when compared to other studies dealing with IAQ in schools, is that different types of schools have been investigated, including primary schools, secondary schools, high schools and universities. The indoor air quality in classrooms might be different with students' age and related school activities. As a result, Figure 1 compares the median pollutant concentrations in primary schools to the median concentrations in secondary schools, high schools and universities together. Any obvious difference is observed between the two data subsets. Concentrations are very close each other.



All concentrations in µg/m[3], except for CO_2 (ppm); n : number of data

Figure 1: Comparison of pollutant concentrations by type of schools

Propanal, isopentanal and benzaldehyde have no guideline, but their concentrations are low in all ClimACT schools. Furthermore, there are no significant concentration differences from one country to another, except maybe for propanal which concentrations are a bit higher in France then in the other countries (Figure 2).

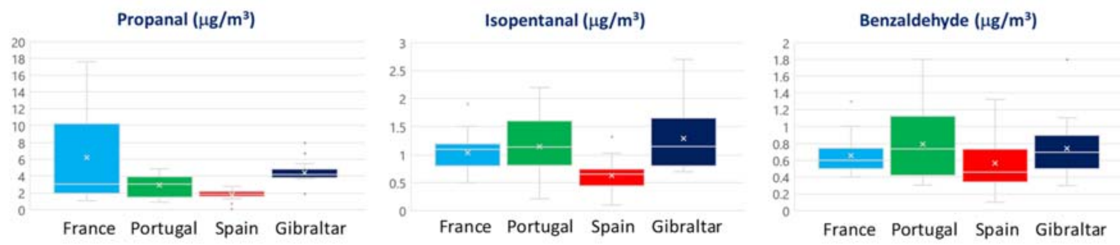


Figure 2: Concentrations distributions of pollutants with no guideline, by country

All VOC and aldehyde concentrations, except formaldehyde, are (far) below the selected guidelines (Table 3). One noticeable point is nevertheless that the highest hexanal concentration in a French school was measured in a school library, which may indicate that books emit hexanal. Another interesting point is that the highest hexanal concentration of all measurements was found in the classroom that also exhibits the highest formaldehyde concentration. This suggests that, in this classroom, the two aldehydes may originate from a same source.

Unlike individual VOCs and aldehydes, PM_{10}, $PM_{2.5}$, CO_2, TVOC and formaldehyde concentrations are over the guideline in 64%, 45%, 43%, 20% and 9% of classrooms, respectively (Figure 3). The distribution of exceedances for each pollutant, together with the concentration distributions presented in Figure 4, may suggest significant discrepancies in the concentration level of these pollutants in the four countries, although the number of data is definitely too small to get a statistical evidence. On the other hand, Figure 4 does not allow to identify any similarity in national indoor air quality profiles, nor any global trend towards lower concentrations in a country. Besides, it is somewhat surprising that Spanish schools have low PM, TVOC and formaldehyde concentrations while exhibiting the highest CO_2 concentrations, which indicates air stuffiness and poor ventilation.

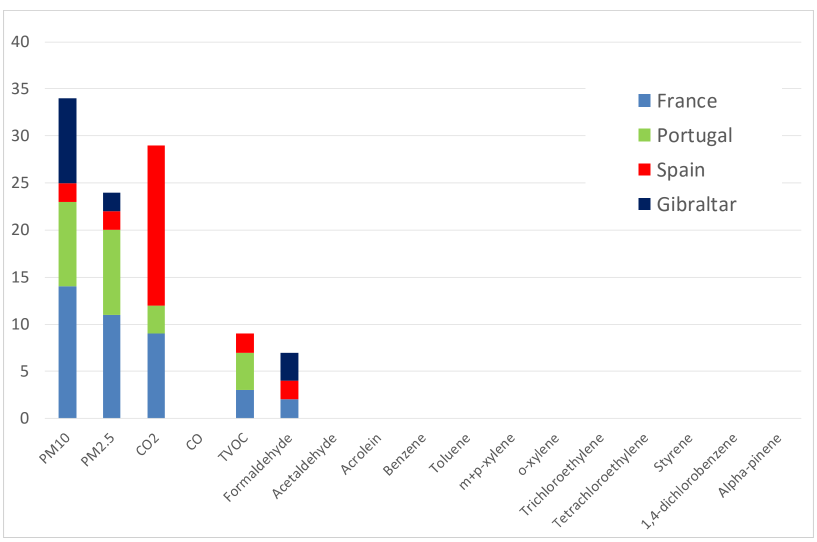


Figure 3: Number of measurements over the guideline by country

Formaldehyde concentrations exceed the guideline of 30 μg/m^3 by a small amount in six of seven cases, and by a large amount in only one classroom (91 μg/m^3). On the other hand, PM_{10} and $PM_{2.5}$ guidelines are exceeded by a large amount in many situations, which calls for explanations. Figure 5 provides a representative example of airborne particle dynamics in a classroom. The case of the French high school that is depicted is most particularly interesting to understand the fate of fine and coarser particles in classrooms since: 1/ $PM_{2.5}$ and PM_{10}

concentrations have been monitored for a full week, starting from Friday afternoon; 2/ the number of occupants have varied all the days long, with a maximum of 35 occupants (teachers and students change classroom each hour or each 2-hours) and windows were opened from time to time; 3/ The time series of outdoor concentrations during the experimental period were available from an ambient air quality m onitoring station which is located next to the school (see inner chart on Figure 5); and 4/ $PM_{2.5}$ peaked outdoors on the day before the end of the measurement period, which corresponded to an officially-declared ambient air pollution episode.

Figure 4: Concentration distributions of pollutants showing exceedances of guidelines, by country

Figure 5 shows that transports from outdoors define the background concentrations of $PM_{2.5}$ and PM_{10} concentrations in the classroom. Indoor and outdoor concentrations are close each other during the weekend, and the indoor $PM_{2.5}$ concentration reach a maximum of 32 µg/m³ when peaking outdoors. Then, indoor PM_{10} concentration tremendously increase as soon as people are in the room, with the consequence that the weekly mean concentration during the occupancy period (65 µg/m³) is far over the WHO guideline of 20 µg/m³. Therefore, it is clear that humans are the main contributors to the effective emissions of PM_{10} in classrooms. The sources can actually be of three types. First is direct shedding from the human envelop, including the release of previously deposited particles from clothing surfaces, hair or bare skin; Bhangar et al (2015) estimated from measurements with fluorescence techniques in a university classroom that the shedding rate can be as high as 3 10^6 part/h/person. Second are educational activities such as plastic art works or chalk writing on a blackboard. Finally, sources can also include the resuspension of particles that had previously settled onto upward facing indoor surfaces. The parts of each type of source to the concentrations are difficult to assess, but the first and last ones are likely to be dominant in a majority of the classrooms investigated.

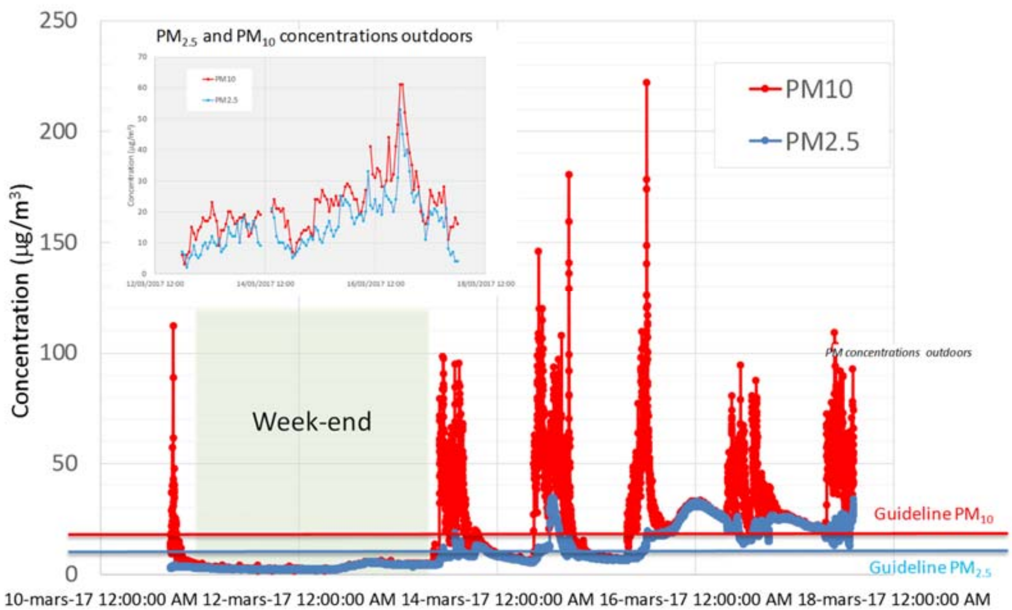


Figure 5: Time series of PM_{10} and $PM_{2.5}$ concentrations over one week in room N11 of high school No 23

$PM_{2.5}$ concentrations are also affected by occupants, but in a weaker way. There are no evident internal sources of $PM_{2.5}$ in schools. Furthermore, the deposition rate of fine particles onto indoor surfaces is lower than that of coarser particles. As a result, unlike PM_{10}, neither internal sources nor resuspension are expected to dominate the dynamics of $PM_{2.5}$ in classrooms.

TVOC concentrations also strongly correlate with occupancy, as illustrated in Figure 6. The advective transports from outdoors and the emissions from building materials and furnishings define the background concentration level that can be assessed at night times and during weekends. Then, as for PM_{10}, concentrations increase as soon as students come in the room, keep high during the class hours, and decay when occupants go out. Human-related TVOC sources include the products used for school activities (marker pens, glues, paints, etc.), biogenic direct emissions from the body surface and the exhaled air, cosmetics (body lotion, fragrances, etc.), and possibly second-hand tobacco-smoke desorbed from the hair and clothes of the oldest students. For the case study presented in Figure 6, the background TVOC concentration is 520 µg/m^3. Concentrations peaked at 1000 µg/m^3, and even 1300 µg/m^3 when students were the more numerous and windows were kept closed, which shows that the part of human related emissions to the TVOC concentrations in a classroom can definitely be significant.

Table 4: Statistics of pollutant concentrations from this study and related recent studies in Europe, Portugal, France and Spain

		This study					Madureira et al (2015)[1]	Csobod et al (2014)[2]	OQAI (2018)[3]	Villanueva et al (2018)	
		n	Median	25th percentile	75th percentile	Maximum	Median	Median	Median	Median[a]	Median[b]
PM_{10}	µg/m³	52	32.4	9.8	61.9	99.0	127				
$PM_{2.5}$	µg/m³	52	10.0	4.6	19.8	41.0	82	44	18		
CO_2	ppm	68	1104	831.3	1555.4	2434.1	1469	1433			
CO	ppm	68	0.9	0.0	1.0	2.2					
TVOC	µg/m³	43	431	274.3	520.5	853.9	140.3			75	56
Formaldehyde	µg/m³	74	11.4	8.5	18.2	91.4	17.5	12	18.8	27.7	20.4
Acetaldehyde	µg/m³	74	4.5	3.7	5.2	11.4	7.7		5.1	6.6	5.1
Acrolein	µg/m³	74	0.1	0.1	0.2	0.2				5.7	9.7
Benzene	µg/m³	74	1.1	0.8	1.3	1.8	2.5	2	1.2	0.27	0.48
Toluene	µg/m³	74	2.9	1.9	5.8	92.9	6.4		3.4	2.27	2.94
m+p-xylene	µg/m³	74	2.1	1.5	3.5	9.2	5		2.1	1.52	1.10
o-xylene	µg/m³	74	0.8	0.6	1.4	4.6	2.3		1		
Ethylbenzene	µg/m³	74	0.8	0.6	1.3	3.1			0.8	0.92	0.62
Trichloroethylene	µg/m³	74	0.1	0.1	0.1	0.1		3			
Tetrachloroethylene	µg/m³	74	0.1	0.1	0.2	1.2	2.9	1	< LOD		
Styrene	µg/m³	74	0.5	0.4	0.9	6.3	1.2		0.7	2.71	< LOD
1,4-dichlorobenzene	µg/m³	74	0.1	0.1	0.1	0.3					
α-pinene	µg/m³	74	0.5	0.3	1.1	7.0	1.8		13.8	3.41	1.30
Propanal	µg/m³	74	2.3	1.9	4.3	17.6				2.3	1.2
Butanal	µg/m³	74	0.6	0.6	0.7	0.9					
Pentanal	µg/m³	74	1.8	1.4	2.6	5.0				2.4	1.2
Isopentanal	µg/m³	74	1.0	0.7	1.2	2.7					
Hexanal	µg/m³	74	8.0	6.6	12.1	28.4			11.4	15.2	10.7
Benzaldehyde	µg/m³	74	0.6	0.4	0.9	1.8				0.9	0.4

[1] Indoor air measurement campaigns in 73 classrooms from 20 public primary schools in the area of Porto (Portugal)

[2] Data coming from the EU Sinphonie project: measurements in 3classrroms of 114 primary schools from 23 European countries.

[3] French nationwide survey on indoor air quality in primary schools. Measurements in 588 classrooms of 301 randomly selected schools across France between 2013 and 2017

[4] Measurements in a primary classroom of 18 schools located in the province of Ciudad Real in central southern Spain, a = rural area, b = urban area

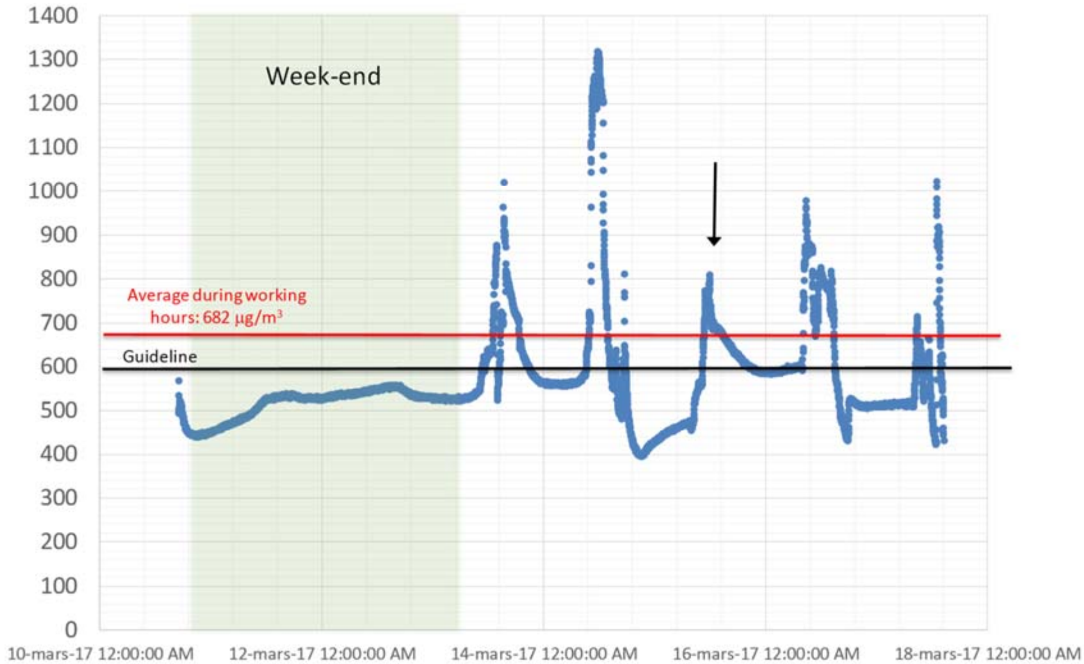


Figure 6: Time series of TVOC concentrations over one week in room N11 of high school No 23

4 CONCLUSIONS

Indoor air quality in schools, and its impact on health and educational performance, have been extensively studied during the last two decades. The measurements carried out in the frame of the ClimACT study are original in the sense that they allow to address the similarities or specificities of schools in four countries having the same climate on the one hand, and to compare the indoor air quality in various types of schools, from primary schools to university, on the other hand. Somewhat surprisingly, the pollutant concentration levels of secondary schools, high schools and universities, as a same subset of data, were found to be very close to those of primary schools. The results also highlight possible national trends in the indoor air pollution of schools, but here the data are obviously too few to draw definitive conclusions.

Despite uncertainty coming from the measurement method, the computed mean $PM_{2.5}$ and PM_{10} concentrations are consistent with previously published data. The fact that PM_{10} concentrations exceed the WHO guideline by a large amount in many situations, together with the demonstration that a large part of coarse particles are of human origin, raises concern about the users' health first, and then about the technical means to decrease exposure. Shall airborne particle concentrations become the criterion for next regulations on school ventilation? Is air cleaning not the solution to provide school users an acceptable air quality while controlling energy consumptions? The state of knowledge on indoor air quality in schools is now sufficiently advanced to consider that those questions are worthy of debate, and measures should be taken urgently.

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