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Analysis of CO_2 monitoring data demonstrates poor ventilation rates in Albanian schools during the cold season

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Abstract Poor ventilation in schools is associated with accumulation of indoor-generated pollutants, which is associated with "stuffy" air, elevated risk of infectious diseases and impaired learning outcomes. This survey in Albania was conducted as part of WHO's efforts to facilitate assessments of indoor air quality and other environmental factors in schools in the European Region. The survey was conducted in 36 classrooms in 12 middle schools (eight urban and four rural) from December 2011 through March 2012. In each school, carbon dioxide (CO_2) was continuously measured in three classrooms during one school week. Ventilation rates during classes were estimated using the build-up and steady-state mass balance equations utilizing CO_2 concentration data, classroom occupancy and classroom volume. All 12 schools had gravimetric ventilation systems. Heating systems were absent or not operational in most schools. Average classroom temperatures during lessons varied from 9.1 to 14.4 °C (median 11.7 °C) with lower temperature associated with poorer ventilation. Weekly average CO_2 levels during classes ranged from 1286 to 5546 ppm (median 2776 ppm) while average ventilation rates ranged from 0.8 to 3.6 (median 1.8) litres per second per person. Classrooms with indoor combustion heaters had higher indoor temperature, lower CO_2 levels and higher levels of carbon monoxide (CO). WHO guidelines on 1- and 8-h CO exposure levels were exceeded in one classroom. Classroom CO_2 levels were substantially above and ventilation rates below existing national and international guidelines. Detrimental impacts of poor ventilation on health and learning outcomes are likely to be substantial in Albanian schools during the cold season. Indoor temperature in most classrooms was below the commonly recommended levels.

Keywords Schools · Classrooms · Indoor air quality · Ventilation · Carbon dioxide · Carbon monoxide

Introduction

Carbon dioxide (CO_2) is a common indicator of indoor air quality. CO_2 is emitted primarily by building occupants but can also originate from indoor combustion sources. The levels of CO_2 in indoor premises can range from the ambient concentration of approximately 400 to over 10,000 ppm. Ventilation rate is a strong predictor of the CO_2 levels and the overall indoor environmental quality as it affects dilution of indoor-generated chemical and biological pollutants and removal of occupant-generated moisture (WHO 2009). Studies have linked high levels of CO_2 and/or poor ventilation in classrooms with adverse impacts on pupils' health (Wålinder et al. 1998; Daisey et al. 2003; Bakó-Biró et al. 2012) and academic performance (Haverinen-Shaughnessy et al. 2011). While CO_2 has been used as an easy-to-measure proxy for exposure to other indoor air pollutants in

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observational studies, randomized controlled experiments have also shown that CO_2 itself can adversely affect learning and cognitive performance at relatively low levels commonly found in indoor premises (Satish et al. 2012).

The importance of adequate ventilation for health and wellbeing has been recognized as early as the mid-nineteenth century when Max von Pettenkofer recommended a maximum CO_2 level of 0.1% or 1000 ppm for indoor spaces (Locher 2007). The same maximum level is currently recommended for classrooms in Germany (UBA 2008). The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends 15 cfm/min (approximately 7.5 lps pp (litres of fresh air per second per person)) ventilation rate for indoor spaces which corresponds to 700 ppm CO_2 level at steady state for sedentary adults with the average CO_2 generation rate of 0.31 L/min (ANSI/ASHRAE Standard 62.1-2007) (ASHRAE 2007b). The Federation of European Heating, Ventilation and Air-Conditioning Associations (REHVA) in the Guidebook 13 proposes performance-based standards limiting the CO_2 concentration to 1500 ppm over a full school day from 9:00 to 15:30 and setting a minimum ventilation rate of 3 lps pp in all teaching and learning spaces when they are occupied (d'Ambrosio et al. 2010).

Protecting children's health from unfavourable effects of environmental factors is an international goal set forth during the Fifth Ministerial Conference on Environment and Health in the WHO European Region held in Parma, Italy, in March 2010 (WHO 2010a). The Parma Declaration established numerous commitments to achieve better health in children by improving environmental quality, including a commitment to prevent disease by improving the quality of ambient and indoor air. In order to monitor progress towards this goal, WHO organized technical meetings where experts and representatives of the European Region Member States identified a set of indoor air quality indicators including an indicator reflecting ventilation rates in classrooms (WHO 2010c). In order to facilitate the application of these indicators, promote harmonized approaches to data collection and improve international data comparability, WHO has coordinated the development of data collection and analysis toolkits for national surveys of environmental conditions in schools (WHO 2011). The approach involves a randomized clustered survey design to allow for efficient survey organization and data collection within predefined geographically compact clusters representing a range of geographic and socioeconomic conditions in a specific country (WHO 2011).

This was the first national survey of indoor air quality and other environmental factors in schools conducted by WHO, which was used for pilot testing and refining the WHO school survey toolkit, which was later applied in several other European countries (WHO 2015). The survey applied a novel approach involving the estimation of air exchange and ventilation rates from continuously collected CO_2 data and classroom occupancy data, along with continuously collected data on carbon monoxide (CO) and indoor temperature. It built upon the results of previously conducted international SINPHONIE survey (Csobod et al. 2014) with indoor air quality modelling in schools (Silva et al. 2016) and involved an alternative approach to in-depth analysis of factors affecting indoor air quality in a bigger number of randomly selected urban and rural schools. Study protocol was designed to enable its implementation with minimum of specialized skills and at minimum cost.

Materials and methods

Field measurements

The survey was conducted in the winter of 2011–2012. It involved data collection on a variety of environmental exposures in schools. This manuscript presents the results of indoor air quality monitoring in classrooms using automatic monitors and data loggers for CO_2, CO, and temperature.

The field data collection was conducted by the National Public Health Institute of Albania in collaboration with WHO. Three geographic clusters were selected: two urban clusters in the cities of Tirana and Elbasan and a rural cluster in the Tirana county near the capital city of Tirana. Four elementary-middle schools were selected in each cluster taking into account the type of school building, its proximity to major roads and willingness of school administration to participate in the survey. While fully random selection was not feasible for this pilot demonstration survey, the survey team aimed at making the selected schools representative of school building types and community characteristics in each geographic cluster. All 12 schools involved in this survey were public general education elementary-middle schools. Each school consisted of only one building. All school buildings were constructed of brick or concrete. Indoor air quality monitoring was conducted from December 12, 2011, to March 2, 2012.

In each school, three representative classrooms (typically, on the first and top floors and on different sides of the building) were selected for air quality monitoring using the school's floor plan. Survey technicians measured the dimensions of each designated classroom, recorded the presence of indoor combustion sources and characterized heating and ventilation systems in standardized inspection forms.

CO_2 and CO levels were monitored using automatic monitors and data loggers Delta Ohm models HD21AB (in two classrooms per school) and HD21AB17 (in one classroom per school). The HD21AB17 units were also equipped with sensors for temperature. New factory-calibrated monitors were purchased for the survey. Parallel test measurements were conducted with all monitors for their cross-validation prior to the survey. Ambient CO2 levels outside of school buildings were measured before the beginning of indoor monitoring. The outdoor measurements confirmed that outdoor levels did not vary substantially and were close to the global ambient concentration of approximately 400 ppm, which was used as the background level adjustment. The data analysis tool included a two-point calibration correction function. While the absolute CO_2 measurement values depend on correct calibration, it should be noted that the estimation of ventilation rates via air exchange rates is not dependent on equipment calibration (Hänninen 2013).

All measurements were collected once per minute during one school week. In each of the 36 classrooms, teachers kept a classroom use diary in which they recorded the schedule of classes and breaks and the number and average age of pupils in each lesson. Only data collected during lessons when pupils were present in classrooms were used in data analysis. Data collected during breaks between classes were excluded.

Analysis of ventilation rates

Three basic methods are available for estimating the air exchange rate or ventilation rate using CO_2 as a tracer gas and applying mass balance equations to CO_2 concentration time-series data (reviewed by Hänninen 2013). These are (i) the build-up method, (ii) the steady-state method, and (iii) the decay method.

The build-up method is based on the analysis of time intervals during which CO_2 concentration increases (typically, from the beginning of each class until the steady state is reached or the class ends, whichever occurs earlier). The build-up method has been successfully used in past studies (e.g. Dols and Persily 1994). A similar approach is described in a paper by Mudarri (1997) detailing a method to approximate steady state based on time of occupancy. The single-zone mass balance for the analysis is expressed in volumetric terms as

$$C(t) = \frac{G}{aV}\left(1 - e^{-at}\right) + C_{\mathrm{r}} \tag{1}$$

where

$C(t)$ concentration (ppm) at time t (h)
G CO_2 generation rate (mL/h) introduced at $t = 0$
a air exchange rate (h^{-1})
V room volume (m^3)
C_{r} concentration in the replacement air (ppm(v)).

The build-up air exchange rate can then be solved as

$$a = \frac{1}{t}\ln\left(\frac{C_{\mathrm{ss}} - C_0}{C_{\mathrm{ss}} - C_{\mathrm{t}}}\right) \Leftrightarrow a = -\frac{1}{t}\ln\left(1 - \frac{C_{\mathrm{t}} - C_0}{C_{\mathrm{ss}} - C_0}\right) \tag{2}$$

where.

a air exchange rate (h^{-1})
t time (h) between observing C_0 and C_t
C_{ss} final steady-state concentration (ppm(v)) as solved or observed
C_0 concentration (ppm(v)) at the beginning ($t = 0$) and C_t at time t.

The build-up method is based on the assumptions of (i) constant CO_2 emission rate in the room, (ii) constant ventilation rate and (iii) constant CO_2 concentration in the air entering the room. When these assumptions are met, the build-up CO_2 concentration curve is smooth and concave reflecting a progressively decelerating increase in CO_2 concentration.

The steady-state method also known as equilibrium analysis, is based on a steady-state, single-zone mass balance of CO_2 in an indoor premise (ASHRAE 2007a). Given a constant ventilation rate and constant CO_2 emission rate, the CO_2 concentration corresponding to approximately 95% of the steady state is achieved after three air exchanges. Therefore, a steady-state level is only achieved within a 45-min class when the air exchange rate is sufficiently high. Using the mass balance equation, the steady-state concentration can be expressed as

$$C_{\mathrm{ss}} = \frac{nG_{\mathrm{p}}}{Va} + C_{\mathrm{r}} \tag{3}$$

where

C_{ss} is the steady-state concentration (ppm(v));
N is the number of persons present;
G_{p} is the average CO_2 generation rate of a person (mL/h);
V is the volume of the room (m^3);
C_{r} is the CO_2 level in the replacement air in ppm.

The CO_2 generation level depends on age, gender, body weight and activity level of the occupants. In this analysis, standard age-specific CO_2 emission rates were used assuming that pupils had sedentary activity level. When the CO_2 emission level is known, the ventilation rate per person can be estimated as follows:

$$Q_{\mathrm{p}} = 10^3 \times \frac{G_{\mathrm{p}}}{C_{\mathrm{ss}} - C_{\mathrm{r}}} \tag{4}$$

where

Q_{p} is the fresh air flow per person into the space (L/s).

The decay method is based on the assumption that there are no CO_2 sources in the room. The concentration of CO_2 declines monotonously until it reaches the ambient level. The shape of the curve is convex. The application of this method is limited to situations when the classroom is unoccupied, such as breaks between classes and the time after the end of the school day. In many naturally ventilated schools, such as those surveyed in the present study, windows are opened during times when classrooms are unoccupied resulting in a higher air exchange rate than during classes. Assessing air exchange rates using decay events after school and during the night time characterizes the properties of school buildings (e.g. how airtight the building is) rather than exposure of pupils during school classes.

The analysis of ventilation rates in the Albanian schools was initially conducted using the build-up method only as steady state was not achieved during most classes (Hänninen et al. 2012). This was later expanded to include steady-state events which were observed in some classrooms in order to utilize a greater proportion of monitoring data and provide more reliable estimates of ventilation rates. Breaks between classes were omitted from this analysis and therefore, the decay method was not used.

Ventilation analysis toolkit

Data from CO_2 monitors, classroom inspection sheets and classroom use diaries were uploaded into a Microsoft Excel-based data analysis toolkit, which was developed specifically for this survey. The toolkit includes a set of macros to aid with data processing and analysis by minimizing manual data inputs and providing data summaries in standardized formats. Specifically, it is programmed to handle output files from several commonly used models of CO_2 data loggers. Analysis is limited to 32,000 data rows, which is equivalent to approximately 22 days of observation with 1-min temporal resolution. The toolkit automatically generates interactive plots of CO_2 concentration vs. time, selects and marks time intervals when CO_2 levels increased relatively smoothly (build-up events) or remained relatively flat (steady-state events) suggesting that the assumptions of constant CO_2 emission and constant ventilation were satisfied, fits the equations for build-up and steady-state methods, produces fit statistics for each automatically fitted build-up curve and excludes intervals with poor fit (when the assumptions of constant emission and constant ventilation are expressly violated) from further analysis.

It then automatically calculates air exchange rate (h^{-1}) and ventilation rate (lps pp) for each selected time interval or "event" that satisfies the assumptions for either build-up or steady-state method. Analysts trained on the use of the tool can inspect preliminary results and make manual adjustments to the beginning and end of each interval or exclude certain intervals from analysis.

The tool then automatically estimates weighted average ventilation rates (lps pp) for each classroom and each school and compiles classroom-level and school-level summary tables comprising ventilation rate data as well as other health-relevant indicators, such as average temperature during classes and proportions of person-time that pupils spent at specific CO_2 concentration bands (<1000, 1000 to 2500, >2500 to 5000 and >5000 ppm).

The analysis of data from the Albanian school survey involved several iterations with applications of the toolkit followed by review and adjustments of results by two trained analysts; subsequent modifications of the tool were followed by re-analysis and new review. The process was repeated until the Excel tool produced results which required only very minor manual adjustments. The final version of the tool verified using the Albanian data was then applied in several other school surveys in Europe (WHO 2015).

Results

Characteristics of participating schools

Analysis of school inspection, interview with school administrator and classroom inspection data show that central heating systems were absent in nine schools. While the other three schools were equipped with central heating, however, it appeared that these heating systems were not operational during the survey despite the cold weather. None of the eight urban schools had indoor combustion-based heating units; three out of four rural schools used either indoor gas heaters (one school) or wood stoves (two schools). Small electrical heating units were also present in many classrooms in schools which did not have indoor combustion heaters. Ten out of 12 schools operated in two shifts with classes held in the morning/early afternoon and in the afternoon/evening for different groups of pupils. The school sizes ranged from 140 to 1380 pupils (average size 620 pupils). Rural schools tended to be smaller (average size 420 pupils) than urban schools (average size 720 pupils).

Description of classrooms

Classroom floor areas ranged from 20 to 50 m^2 (average 33 m^2) while classroom volumes ranged from 51 to 151 m^3 (average 95 m^3). Classroom occupancy levels ranged from 11 to 36 pupils (median 26 pupils). The per capita classroom floor area ranged from 0.6 to 2.5 m^2/pupil (median 1.3 m^2/pupil) while per capita classroom volume ranged from 1.7 to 7.8 m^3/pupil (median 3.9 m^3/pupil). The average class-level age of pupils reported by teachers in classroom diaries ranged from 7 to 15 years. The average class sizes tended to be smaller in the rural schools than in urban schools (21 ± 5 vs. 28 ± 6 pupils, respectively; $p < 0.05$). However, there were no significant differences in the average floor area or classroom volume per pupil between rural and urban schools.

All measurements were conducted during one school week in each classroom (usually from Monday to Friday). The actual duration of monitoring varied among classrooms due to logistical reasons and ranged from 1.9 to 4.3 days (median 4 days).

Classroom temperature

Although the climate in Tirana and Elbasan is rather mild, monitoring was conducted during the winter season when outdoor temperatures were near freezing at night. Temperatures in classrooms varied from as low as 6 °C at the beginning of classes in the morning to 18 °C later in the school day. An example of temperature and CO_2 graph from a typical classroom without heating is presented in Fig. 1. The graph shows that the indoor temperature was very low; it increased somewhat during classes due to higher day-time ambient temperature and to the heat generated by pupils but remained below 13 °C even at the end of the school day. The levels of carbon dioxide increased in parallel with the temperature. Average classroom temperatures during classes varied from 9.1 to 14.4 °C (median 11.7 °C) with lower temperature associated with poorer ventilation. It was observed during the study that pupils and teachers tended to keep windows and doors closed when the indoor temperature was uncomfortably low in order to preserve warmth released by the occupants.

Concentrations of carbon monoxide

In 16 out of the 36 classrooms that were monitored, all CO measurements were below the 1 ppm limit of detection. All six classrooms in schools which used wood stoves, two out of three classrooms in the school which used gas heaters and 12 of 27 classrooms in schools which did not report using combustion heaters had detectable CO levels. In the subset of 20 classrooms with detectable CO levels, maximum CO concentrations ranged from 1 to 12 ppm (1.17 to 14.0 mg/m^3) in 19 classrooms and reached 85 ppm (99.0 mg/m^3) in one classroom in a school with wood stoves. Plots of CO and CO_2 levels in that classroom on the day when the maximum CO level was reached are presented on Fig. 2. The maximum 15-min, 60-min and 8-h moving CO averages in that classroom were 50.0, 39.9 and 10.6 mg/m^3, respectively. The latter two levels exceeded the WHO guidelines for 1-h average exposure (35 mg/m^3) and for 8-h average exposure (10 mg/m^3) while the 15-min exposure guideline of 100 mg/m^3 was not exceeded (WHO 2010b). Peak CO levels in other classrooms were well below WHO guidelines. CO levels poorly correlated with CO_2 levels in particulate classrooms because combustion heaters, which released both CO and CO_2, were operated intermittently. In addition, it appears that ventilation rates were higher when combustion heaters were used, probably because teachers were more likely to keep windows open.

Concentrations of carbon dioxide and exposure distribution

A typical example of CO_2 concentration vs. time graphs in two classrooms (with two shifts and with one shift) is presented in Fig. 3. During a single school day, CO_2 concentrations increased fairly fast, reaching 2500 ppm in most of the classrooms within the first lesson of the day. In most classrooms,

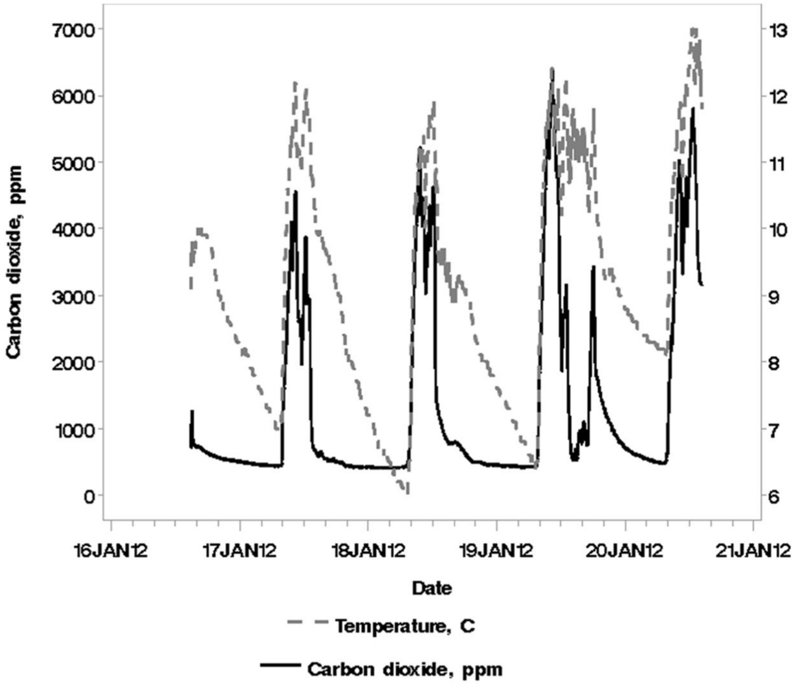
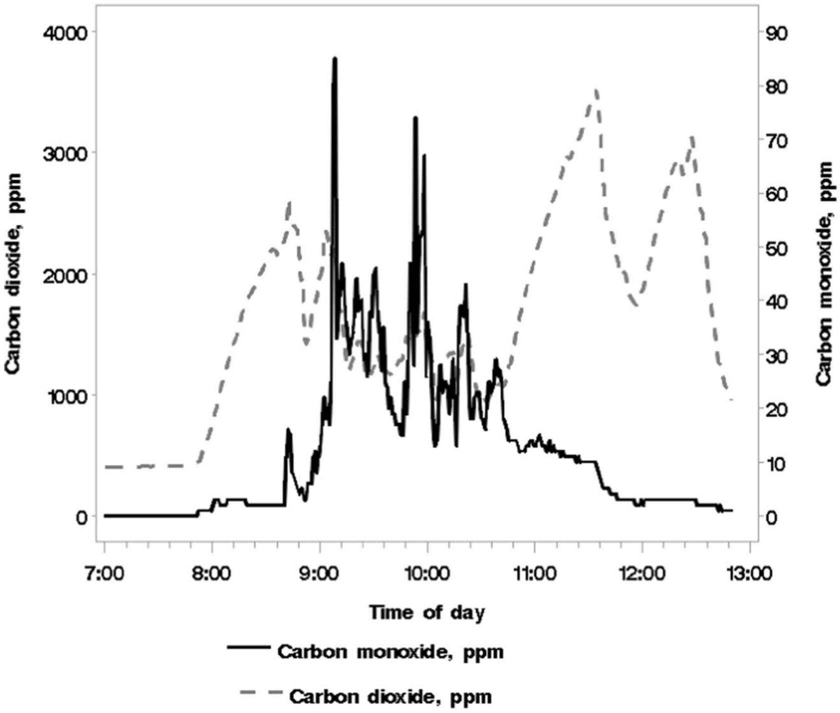


Fig. 1 Temperature and carbon dioxide levels in a selected classroom during a school week

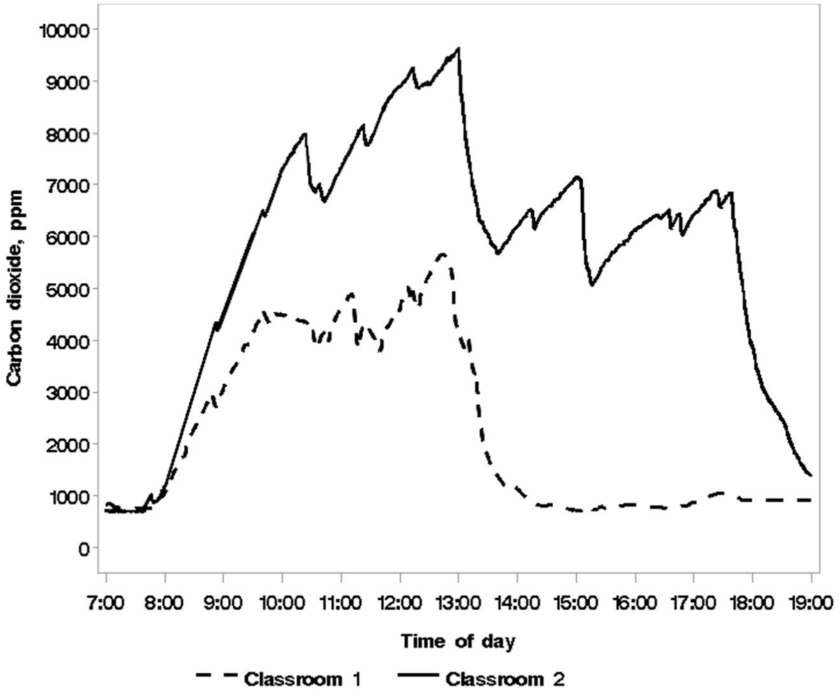
Fig. 2 Levels of carbon monoxide and carbon dioxide in a selected rural classroom



CO_2 levels kept increasing throughout the school shift (or school day). Periodic declines in CO_2 levels reflect opening of windows during breaks and sometimes during classes. Temporal patterns of CO_2 in many other classrooms with levels of CO_2 increasing rather monotonously through the school day/shift (not shown) suggest that windows were kept closed during breaks in many classrooms.

The overall average CO_2 level during classes in all 36 classrooms was approximately 2700 ppm. Average and median CO_2 levels during classes exceeded 1500 ppm in all classrooms (Table 1). In each school, pupils spent from 87.5 to 99.8% of their time in classrooms exposed to CO_2 concentrations above 1000 ppm (Fig. 4). Furthermore, in some schools, a substantial amount of person-time (up to 40%) was spent in

Fig. 3 Levels of carbon dioxide in two typical classrooms on a selected school day



CO_2 concentrations above 5000 ppm. Overall, in the 12 schools that took part in this survey, pupils spent 94.5% of their classroom time at CO_2 levels exceeding 1000 ppm including 7.6% of person-time at levels exceeding 5000 ppm.

Ventilation rates

Average ventilation rates in classrooms ranged from 0.8 to 3.6 lps pp with an overall average ventilation of 1.8 ± 0.6 lps pp (Table 1). Estimated ventilation rates tended to be higher on average in the rural schools compared to the urban schools (2.1 ± 0.7 vs. 1.6 ± 0.4 lps pp, respectively; $p < 0.05$).

Discussion

The pilot WHO survey in 12 typical middle schools in Albania demonstrated that, during the cold season, CO_2 levels were much higher and ventilation rates much lower than the health-based guidelines, such as REHVA guidelines in Europe (d'Ambrosio et al. 2010), ASHREAE guidelines in the USA (ASHRAE 2007b) and national guidelines in Germany (UBA 2008).While Albania did not have a national standard for ventilation rates in schools and it was not an EU Member State at the time of this survey, the poor ventilation and resulting stuffy air in classrooms are likely to have detrimental impacts on the health of the pupils and their learning process. As most schools did not have heating systems, low outdoor temperature led to uncomfortably low indoor temperatures in all classrooms. As a result, windows were usually kept closed during classes. This, in combination with high occupant density in classrooms, resulted in rapid accumulation of CO_2.

The findings were rather consistent in all schools that participated in this pilot survey. The results of this survey are also in agreement with the results of the international Schools Indoor Pollution and Health–Observatory Network in Europe (SINPHONIE) project, which involved CO_2 monitoring in 23 countries in the WHO European Region (5 to 6 schools per country). In that project, Albanian schools had the highest average CO_2 levels, the highest average relative humidity and the third lowest average indoor temperature (Csobod et al. 2014).

The approach to data analysis used in this survey aimed to maximize the use of CO_2 monitoring data collected during classes. Only intervals when assumptions behind the steady-state and build-up methods were expressly violated (e.g. varying ventilation rate or varying room occupancy) were excluded from data analysis. Breaks between classes were excluded from this analysis. While breaks could be used to ventilate classrooms reducing pupils' exposure to stuffy air, the fact that levels of CO_2 kept increasing throughout the school day in many classrooms suggests relatively poor efforts to ventilate classrooms during breaks, probably due to uncomfortably low outdoor temperature. Lack of adequate ventilation overnight was also evident in some of the classrooms where CO_2 levels were still substantially above the ambient level (e.g. greater than 1000 ppm) at the beginning of first morning class.

This article presents data on various indicators of indoor air quality in classrooms including average CO_2 concentration during classes, proportion of person-time pupils spent at

Table 1 Carbon dioxide concentrations and ventilation rates in Albanian schools during classes

School ID	Monitoring dates (month/date)	Mean age of pupils (years)	Carbon dioxide concentration (ppm)				Ventilation rate (lps pp)
			10th %	Mean	Median	90th %	Mean (s.d.)
Urban Tirana cluster (TIR)							
1	12/12–12/16	11.7	1515	2758	2605	4197	1.74 (0.21)
2	12/19–12/23	10.2	1595	2766	2547	4539	1.31 (0.12)
3	01/16–01/20	12.3	2097	4680	4472	7685	1.28 (0.21)
4	01/16–01/20	11.7	1823	3618	3651	5414	1.15 (0.27)
Rural Tirana cluster (RTR)							
5	01/23–01/27	11.9	958	2097	1780	3895	2.27 (0.78)
6	01/23–01/27	13.3	849	2271	2206	3684	2.70 (0.80)
7	01/30–02/03	13.0	1163	2760	2309	5145	1.51 (0.59)
8	01/30–02/03	11.5	1354	2685	2554	4091	2.02 (0.19)
Urban Elbasan cluster (ELB)							
9	02/06–02/10	11.4	980	1818	1709	2810	1.31 (0.07)
10	02/06–02/10	12.6	756	1664	1671	2614	2.03 (0.38)
11	02/27–03/02	14.0	1360	2974	3109	4396	2.05 (0.08)
12	02/27–03/02	14.0	1655	2797	2735	4013	1.93 (0.54)

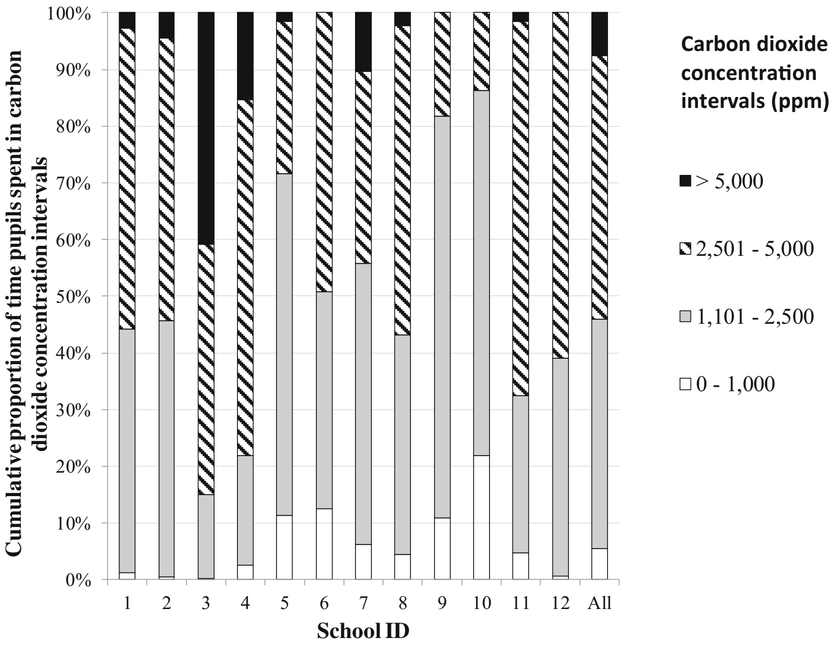


Fig. 4 Percentage of person-time that pupils in the Albanian survey schools spent at specific CO_2 concentration intervals

certain CO_2 concentration intervals and average ventilation rates in litres per second per pupil. Each indicator provides data suitable for a specific purpose. For example, results summarized in terms of exposure to CO_2 can be used for assessing health risks or detrimental impacts on cognitive performance. Air exchange rate data reflects the performance of gravimetric ventilation; these data can be compared with existing guidelines and standards.

The results of this survey suggest that ventilation rates were higher in rural schools. However, the actual values for rural schools with indoor combustion heaters should be interpreted with caution. Typical residential indoor combustion heaters generate substantial amounts of CO_2 (e.g. a wood stove with a 10,000 kJ/h or 2.8 kW output would generate approximately 1 kg of CO_2 per hour or as much as 28 adults doing office work). Poorly vented or unvented gas heaters and wood stoves could emit substantial amounts of CO_2 in the indoor environment, which was not accounted for in the data analysis. Therefore, ventilation rates in those classrooms could be underestimated due to the underestimation of CO_2 generation rates. It should be noted, however, that the use of unvented or poorly vented combustion sources that release CO_2, CO and other combustion gases into the indoor air requires a much higher ventilation rate to maintain acceptable indoor air quality.

The levels of CO in Albanian schools with wood stoves or gas heaters were comparable with CO levels found in US residences using unvented kerosene heaters (Mumford et al. 1991). The level of CO in one classroom exceeded the WHO guidelines for 60-min average exposure (during a 1.5 interval) and for 8-h average exposure (during one school day). If the practice of using indoor combustion heaters in rural schools is as common as the data on this small sample of rural schools suggests (three out of four rural schools used combustion heaters), exposure to harmful levels of CO and other combustion-related pollutants in rural Albanian pupils can be rather common during the cold season. While the results of this small survey do not allow extrapolation to the entire population of Albanian rural school, further surveillance should be encouraged in order to evaluate the scope of this problem and stimulate targeted interventions.

This was the first survey to apply an indoor air quality monitoring and ventilation analysis toolkit developed by WHO for assessing the quality of the school environment. The successful demonstration of harmonized approaches to assessing ventilation rates and other indoor environmental factors in Albanian schools led to further application of these approaches in several national surveys in schools in Europe (WHO 2015). The results of these WHO surveys and a previously conducted international survey in 23 Member States of the WHO European Region (Csobod et al. 2014) demonstrated that insufficient ventilation in classrooms and CO_2 levels exceeding existing guidelines are common problems. While France remains the only country in the European Region that requires monitoring CO_2 in all schools and kindergartens (Michelot et al. 2013), the results of the WHO survey call for more attention to improving indoor air quality in schools in limited resource settings.

Conclusions

Sufficient ventilation is an important prerequisite of academic performance of school children, but also, other indoor environmental quality parameters such as temperature should be considered. In this study, we used a WHO survey protocol to assess these conditions in a sample of 12 classrooms in rural and urban areas of Albania. As part of the survey, automatic monitors were used to record carbon dioxide (CO_2) concentrations and temperatures in 1-min temporal resolution. The monitoring data was used to estimating ventilation rates in classrooms. Very low ventilation rates in Albanian schools during the cold season appeared to be due to the lack of heating and uncomfortable low temperature in classrooms. The high classroom occupant density resulted in the rapid accumulation of CO_2 during classes and very stuffy air, which was evident to the occupants even without monitoring data. The use of indoor combustion heaters was linked with elevated carbon monoxide (CO) levels, which exceeded WHO guidelines on one occasion, but may affect the academic performance even at lower levels. The observed poor ventilation and stuffy air in classrooms are likely to be associated with detrimental effects on health and cognitive performance of pupils. These findings highlight the need for monitoring CO_2 and ventilation rate in countries with limited resources.

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Compliance with ethical standards

Disclaimer The authors alone are responsible for the views expressed in this publication.

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