ANALYSIS OF THE INDOOR AIR QUALITY IN GREEK PRIMARY SCHOOLS

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ABSTRACT

The exposure of children to indoor air pollutants in school classrooms might cause them adverse health effects. In order to confront this issue, the in-depth study and evaluation of the indoor air quality in classrooms is necessary. The aims of this study are to characterize the environmental factors that affect indoor air quality. Several indoor air pollutants such as the concentrations of the particulate matter (PM) of several different size ranges, carbon dioxide (CO_2), carbon monoxide (CO) and VOCs, were simultaneously measured in classrooms as well as the outdoor environment in nine primary schools in Athens, Greece during April 2013. Measurements were performed for more than 7 hours per day, for a period of one to five days in a classroom, per school. The first results indicate extreme PM_{10} concentrations in many cases with varying fluctuations throughout the day, mainly attributed to the presence of students, inadequate level of ventilation and chalk dust while the ultrafine particles (UFP) remained in rather low levels. In most of the cases the indoor concentrations exceeded the outdoor ones by more than ten times. Carbon dioxide concentrations in many cases exceeded the recommended limit value indicating inadequate levels of ventilation.

KEYWORDS

Indoor Air Quality, PM, CO_2, CO, VOCs, Schools, Ventilation

1 INTRODUCTION

In recent years there is an increasing concern in the investigation of the indoor air quality (IAQ) in school buildings, since the exposure of students to indoor air pollutants may be associated with serious adverse health effects (WHO, 2005). Children are more vulnerable compared to adults, due to their growing lungs and their higher metabolic rate (Schwartz, 2004). Also they spend a considerable amount of their time within classrooms (Leickly, 2003). Apart from the impact that the exposure of indoor air pollutants have on student's health, more recent studies have shown that a degraded indoor environment may also affect their learning performance by reducing their productivity (Mendell and Health, 2005).

Particulate matter (PM) are major indoor air pollutants that depending on their size, can penetrate from the upper respiratory tract to deeper parts of the lungs and can even deposit in tracheobronchial and alveolar regions (Hinds, 1999). Numerous epidemiological studies have associated exposure to PM with morbidity or even mortality (Pope et al., 1995). Studies conducted in schools have shown that indoor PM levels are greatly affected by the presence of pupils and the outdoor PM levels (Annesi-Maesano et al., 2007). Although major indoor PM sources such as smoking or cooking are absent in school environments, the PM concentration levels are often high (Fromme et al., 2008).

Carbon dioxide (CO_2) is another important air pollutant that in many studies has been used as an indicator of indoor air quality (Twardella et al., 2012). CO_2 concentrations levels are associated to ventilation rates and since ventilation plays a key role in maintaining IAQ, CO_2 measurements are always crucial. Studies conducted in Greek schools have found that CO_2 concentrations levels frequently exceed their recommended limit values (Synnefa et al, 2003, Santamouris et al., 2008). According to the international literature, the indoor environment of school classrooms is encumbered by air pollutants due to insufficient ventilation, inadequate maintenance and also due to lack of the necessary funding (Mendell and Health, 2005). Thus, the understanding in details of the existing situation of air pollutants in classrooms is essential in order to come up with certain proposals to improve the indoor air quality.

The main objectives of this study are: 1. to investigate the levels of air pollutants in school classrooms aiming to create an integrated concentration profile for the period of measurement, 2. to evaluate air pollutant levels based on the exceedance of their recommenced by international certification bodies limit values, 3. to compare the indoor versus the outdoor PM concentrations and to identify possible relationships between them and 4. to investigate the possible activities and to which extend they affect pollutant concentrations.

2 MATERIALS ANS METHODS

2.1 Sampling site description

Eight primary schools located in the north-western part of Attika (Thrakomakedones, Acharnae) Greece and one school located in the eastern regional area of Attika (Pallini) were monitored during spring 2013 (Figure 1). According to CORINE 2000 land cover database (Geodata, 2010), most of the schools (code names: 1, 14, 4, 18, 2, 8, see Table 1) are in areas characterized as 'discontinuous urban fabric' in which a great percentage of the land is covered by structures (EEA, ETC/TE, 2004). One of the schools (code 12) is at an area of 'continuous urban fabric' where buildings and roads cover more than 80% of the total surface, and two other schools (codes: 3 & 11) are in areas having 'complex cultivation patterns' where small areas of annual crops are present.

Figure 1: Map of Attika (left) and locations of schools (right)

The experimental campaign was conducted in one classroom per school. The main characteristics of the school buildings' and classrooms' where the measurements took place are summarized in Table 1.

Table 1: Characteristics of sampling sites

School name	**School code name**	**Measurement period (Number of measurement days)**	**Year of construction**	**Classroom's floor area (m^2)**	**Classroom's volume (m^3)**	**Classroom's number of Students**	**Classroom's board type**	**Classrooms' orientation**
Acharnae 14	1	1-5/4/13 (5 days)	2001	53	165	17	Chalk	North
Thrakomakedones 1	14	8-12/4/13 (5 days)	1978	64	198	25	Chalk	Northwest
Axharnae 4	4	14-18/4/13&24/4/13 (5 days)	1986	50	155	24	Chalk	Southwest
Pallini 3	3	19&22/4/13 (2 days)	-	46	137	25	Chalk	West
Acharnae 18	18	23/4/13 (1 day)	1991	47	138	18	Chalk	South
Acharnae 12	12	13-17/5/13 (5 days)	1980	49	157	25	Marker	South
Thrakomakedones 2	2	20-24/5/13 (5 days)	2003	50	162	25	Marker	East
Acharnae 8	8	27-29/5/13 (3 days)	1999	52	159	19	Marker	West
Acharnae 11	11	31/5/13 (1day)	1994	55	172	15	Chalk	South

2.2 Instrumentation and parameters measured

The indoor PM_{10}, PM_5, $PM_{2.5}$, PM_1 and $PM_{0.5}$ concentrations were measured using Handheld 3016 IAQ (Lighthouse, worldwide solutions) and the outdoor PM_{10} concentrations were sampled using Osiris, an airborne particulate monitor (Turnkey Instruments Ltd) in units of mass per unit volume ($\mu g/m^3$). Ultrafine particle (UFP) concentrations were measured using the portable counter P-Trak (TSI, Model 8525), in units of particles per unit volume (pt/cm^3), while the detection range of P-Trak is from 20nm to 1μm. CO_2, CO and Volatile organic compounds (VOCs) were measured using MultiRAE IR (RAE Systems) in units of parts per million (ppm). Particulate matter, were simultaneously monitored in the outdoor environment. The instruments measuring the outdoor air were placed at the roof terrace so as to collect a representative sample of the atmospheric air. All of the above mentioned parameters were monitored with a sampling interval of 5 min and the duration of measurement was approximately 7 hours per day.

2.3 Sampling protocol

The sampling period was during April and March 2013 (Table 1), where measurements lasted from one to five days for each of the nine schools. Measurements started 40 min prior to the arrival of students in the classrooms (at around 7:30 a.m.) and lasted until about 14:40, 40min after the students left school. Sampling took place in one classroom per school and the experimental equipment were placed at 1.1 m above the floor according to the standard ISO

7726:1998 for seated persons, as close as possible to the centre of the classroom. Any kind of indoor activities that could possibly affect the indoor air pollutant concentrations such as students' presence, window opening etc. were written on daily diaries marking the exact starting and ending time and duration of the activity.

2.4 Data processing and analysis

Statistical analysis was performed using SPSS and pollutant concentration distributions were studied through box plots calculated for every school. Descriptive statistics were estimated in order to have a clear profile of the extent to which the classrooms were polluted and the percentage of exceedance of the recommended limit value was calculated. Furthermore, ratios of indoor to outdoor concentrations were estimated. The dataset was classified in two categories of common characteristics (schools using chalk and schools using marker), whose ratios were calculated. Finally diurnal variation of pollutants was also investigated as a function of several factors that could possibly affect them.

3 RESULTS AND DISCUSSION

3.1 Distribution of indoor air pollutants

Figure 2 shows the distribution of PM_{10}, $PM_{2.5}$ and PM_1 for the entire measurement period in each of the schools in box plots. The two horizontal lines represent the recommended limit values by the WHO of 50μg/m^3 (pink line) and 25μg/m^3 (green discontinuous line) for PM_{10} and $PM_{2.5}$ respectively (WHO 2005). It is obvious that the majority of PM_{10} concentrations exceed by far the limit value. The total average value of PM_{10} in all schools is 245 μg/m^3, which is a value, exceeding by 5 times the proposed limit value. There were even cases where the indoor concentrations outreached 1,000 μg/m3 (code: 14, 1, 3 and 18). PM_{10} concentrations of school 8 schemed to be the lowest compared to all the other schools. The distribution of PM_{10} concentrations in the first seven schools (code: 14, 1, 4, 3, 18, 12, 2) is very close. The total average concentration of $PM_{2.5}$ in all schools is 18 μg/m^3, however there were several cases in which the concentrations exceeded the limit value of 25 μg/m^3 (code: 14, 1, 4, 3, 18, 12, 2). The mean PM_1 concentrations in all schools where the measurements took place was 7 μg/m^3.

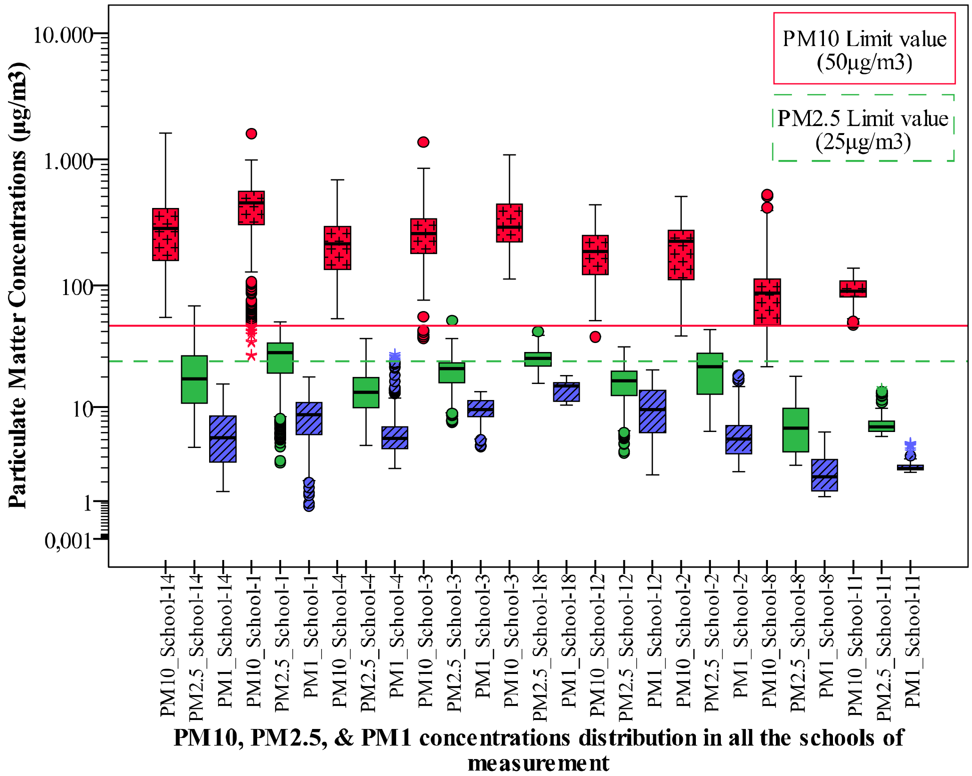

Figure 2: PM_{10}, $PM_{2.5}$ and PM_1 concentrations distribution per school

The distribution of PM in the ultrafine size range (UFP), have strong differences from school to school (Figure 3). Furthermore, one could assume that in schools 3 and 11 being at areas of 'complex cultivation patterns', away from vehicle emissions low values of UFP concentrations were expected. However the concentrations in these schools exhibit high values while the average value of UFP in all the schools is 5,584 pt/cm^3.

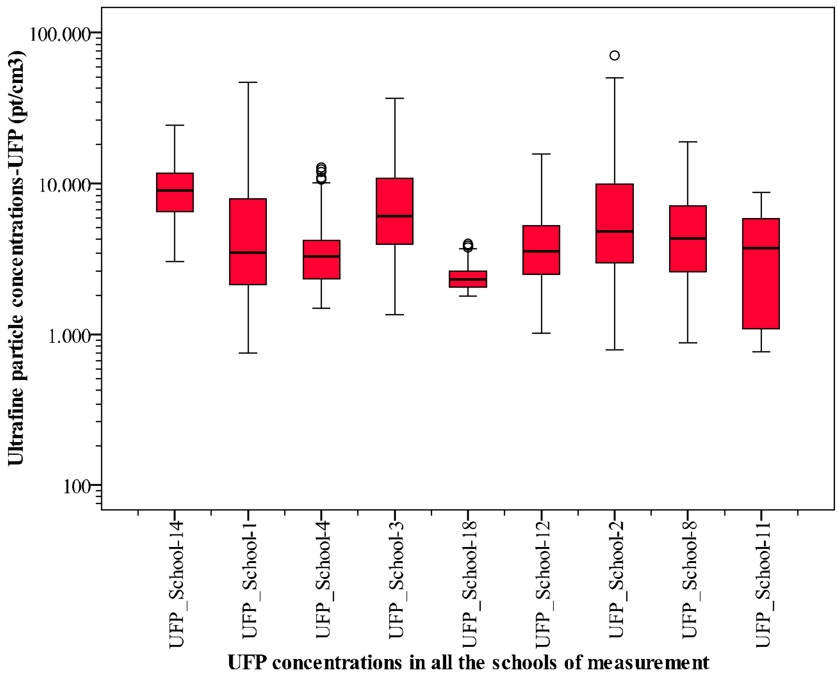

Figure 3: UFP concentrations distribution per school

Table 2 summarizes the descriptive statistics of CO, CO_2 and VOCs for the entire period of measurement in all schools. In the majority of the cases the mean value of CO_2 is above the threshold limit value of 1000 ppm (ASHRAE 62-1989), indicating inadequate levels of ventilation. CO concentrations were rather low in most schools however in schools 8 and 11 they were much higher. The mean values of VOCs concentrations were rather low in schools 14, 1, 4, 3 and 18 while in schools 12, 2, 8 and 11 the concentrations levels were higher.

Table 2: Descriptive statistics of CO, CO_2 and VOCs in all schools

		CO				CO_2				VOC			
School	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**	**Mean**	**Std. Dev.**
14	399	0,0	0,8	0,1	0,1	556	2910	1219	604	0,0	9,4	1,0	1,1
1	428	0,0	0,9	0,1	0,2	538	5049	2082	933	0,0	5,9	1,1	1,0
4	429	0,0	1,4	0,2	0,4	546	3547	1105	601	0,0	5,7	1,1	1,0
3	191	0,0	1,1	0,2	0,3	577	2364	1209	461	0,0	5,0	1,5	1,1
18	89	0,0	0,0	0,0	0,0	566	2385	1118	536	0,0	0,8	0,2	0,2
12	406	0,2	4,0	1,3	0,8	558	4365	1437	942	0,0	51,9	6,4	9,0
2	424	0,2	8,3	2,9	2,2	587	1729	893	205	0,0	27,2	6,6	6,8
8	268	1,3	11,1	7,2	2,0	573	2207	1018	301	0,3	39,9	7,8	6,4
11	81	4,2	13,9	12,1	2,3	689	1172	971	135	3,0	39,7	15,5	8,7

Figure 4 summarizes the percentages of exceedance of the recommended limit values of CO_2, PM_{10} and $PM_{2.5}$ of the total days of measurement per school. The schools presented in the horizontal axis are shorted from low to high exceedance percentages of CO_2 concentrations. It is obvious that the majority of PM_{10} concentrations exceed by far the limit values. The limit value of $PM_{2.5}$ (25 μg/m^3) was not exceeded in schools 8 and 11.

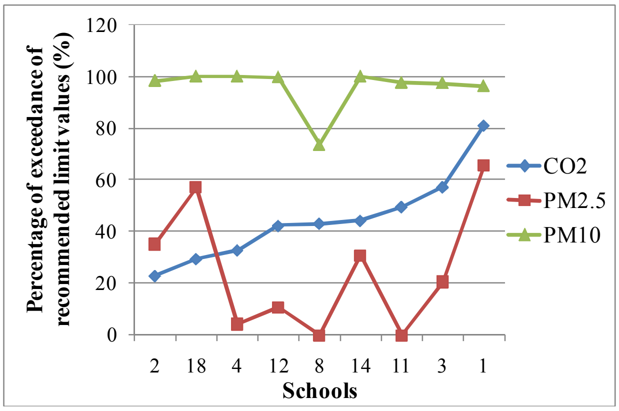

Figure 4: Percentages of exceedance of the recommended limit values

3.2 Indoor vs Outdoor particulate matter concentrations

In order to investigate if the outdoor PM_{10} concentrations affect the indoor ones, the ratio between these two concentrations has been estimated. It should be noted the indoor and outdoor concentrations were measured using two different instruments. In order to compare the results obtained from the two instruments, a correction factor has been calculated after several trial measurements took place at a lab under constant conditions without any pollutant sources.

Figure 5 presents the averaged indoor to outdoor (I/O) PM_{10} concentration ratios per school for the entire period of measurement arranged in decreasing ratios. It can be seen that for all schools the indoor concentrations are by far greater than the corresponding outdoor ones. In school 2 the I/O ratio was rather low as both the outdoor and indoor concentrations were extremely high. The extreme outdoor concentrations at this school can be possibly attributed to the fact that this school is situated at the foothill of mountain Parnitha, where on days with south-westerly winds (sea-breeze), the air pollutants exhibit high concentrations due to their transport from the city of Athens to this area, where they were trapped.

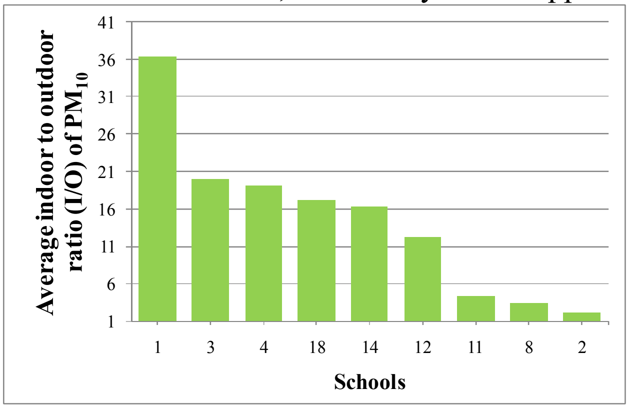

Figure 5: Average indoor to outdoor PM_{10} concentrations ratios (I/O) for the entire period of measurement in each school

3.3 Air pollutant concentrations as a function of indoor sources

3.3.1 Use of chalk (blackboard) vs the use of marker (whiteboard)

In this section the schools are divided in two categories (those using chalk -blackboard and those using marker-whiteboard) (see Table 1 column 8). Figure 6 gives the ratio of the averaged pollutant concentrations in schools using chalk (No: 14, 1, 4, 3, 18, 11) to the ones using marker (No: 12, 2, 8). It is evident that the PM concentrations in the schools using chalk are much higher that the corresponding ones using marker. The chalk dust is probably responsible for the extreme PM concentrations and especially for particles of greater size ($PM_{2.5}$ and PM_{10}). On the contrary the CO and VOCs concentrations are greater in the schools using marker as of VOCs emitted by markers. To summarise, the gain from the PM reduction using marker white boards is lost in increase of VOCs and CO concentrations.

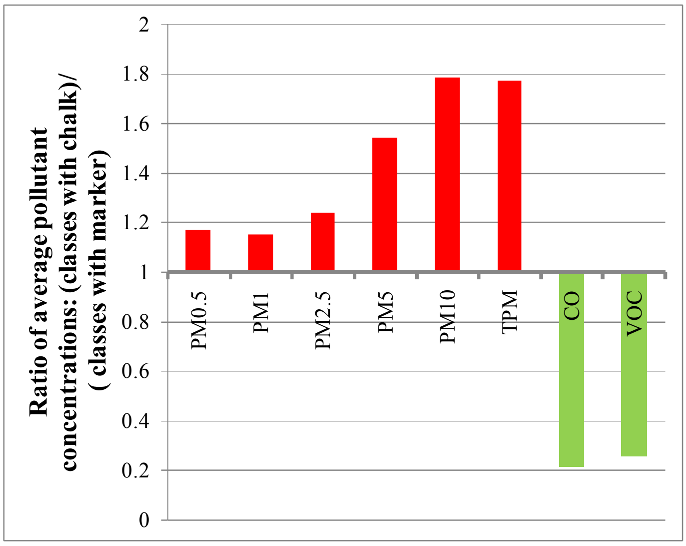

Figure 6: Ratio of the averaged pollutant concentrations of schools with blackboard using chalk to the ones with whiteboard using marker

3.3.2 PM_{10} concentrations as a function of window opening

The temporal distribution of PM_{10} concentrations was studied in detail in order to reveal the main factors responsible for the extremely high values of concentration. Figure 7 presents the diurnal PM_{10} concentrations (blue transparent area) of a representative day (15/4/2013) in school 4. In the same figure the windows opening schedule throughout the day is also marked. It can be seen that when the windows are closed (bordeaux dotted bar) the indoor concentrations significantly increase. When either half or all windows are open (purple checkered and green striped), the indoor concentrations drop significantly.

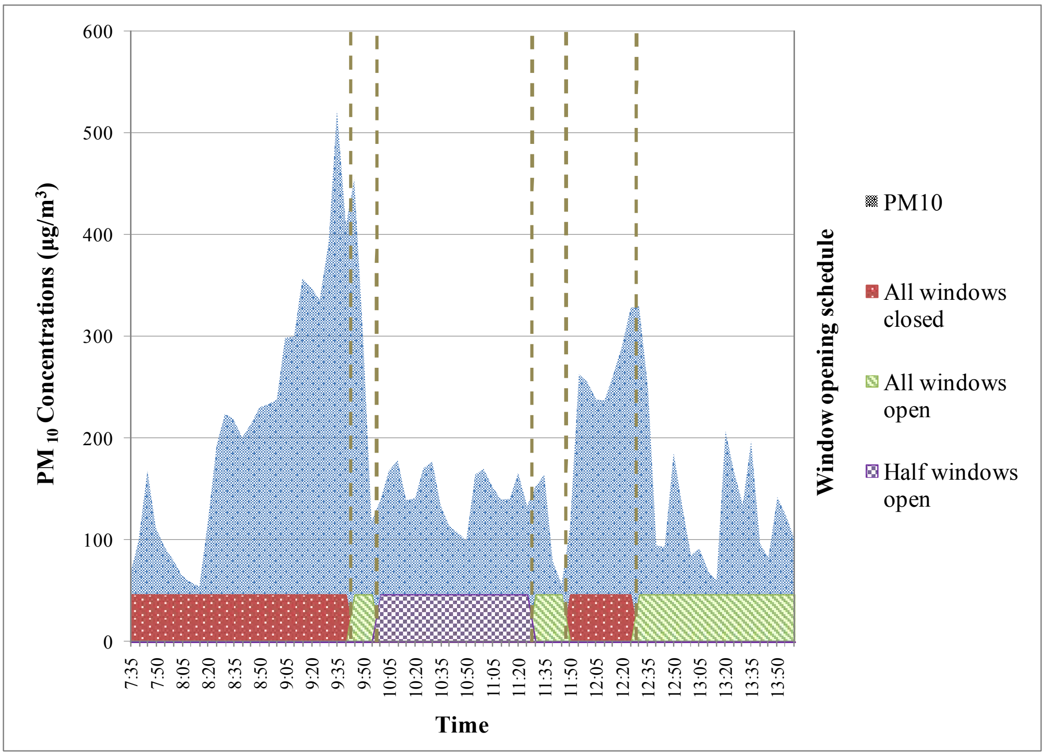

Figure 7: Diurnal variation of PM_{10} concentrations in school 4 on April 15th in relation to the window opening

Human presence is also important but this factor is studied separately in the next paragraph.

3.3.3 PM_{10} concentrations as a function of human presence

Figure 8 presents again the diurnal fluctuation of PM_{10} concentrations (blue striped area) throughout the same representative day as in Fig. 7 and the transparent pink area corresponds to the number of students being present in the classroom ranging, from 2 to 27.

As the students enter the classroom in the morning (08:20), the PM_{10} concentrations increase rapidly (with windows closed). At 09:40, students leave the classroom for the first break causing a fast decrease of the PM_{10} concentrations which can be also attributed to window opening (see Figure 7). When students enter again the classroom at 10:00, there is a fast increase but without reaching the peak values of the previous session, probably due to the fact that windows are now kept half open (see Figure 7). This pattern is repeated until children leave the classroom for the day.

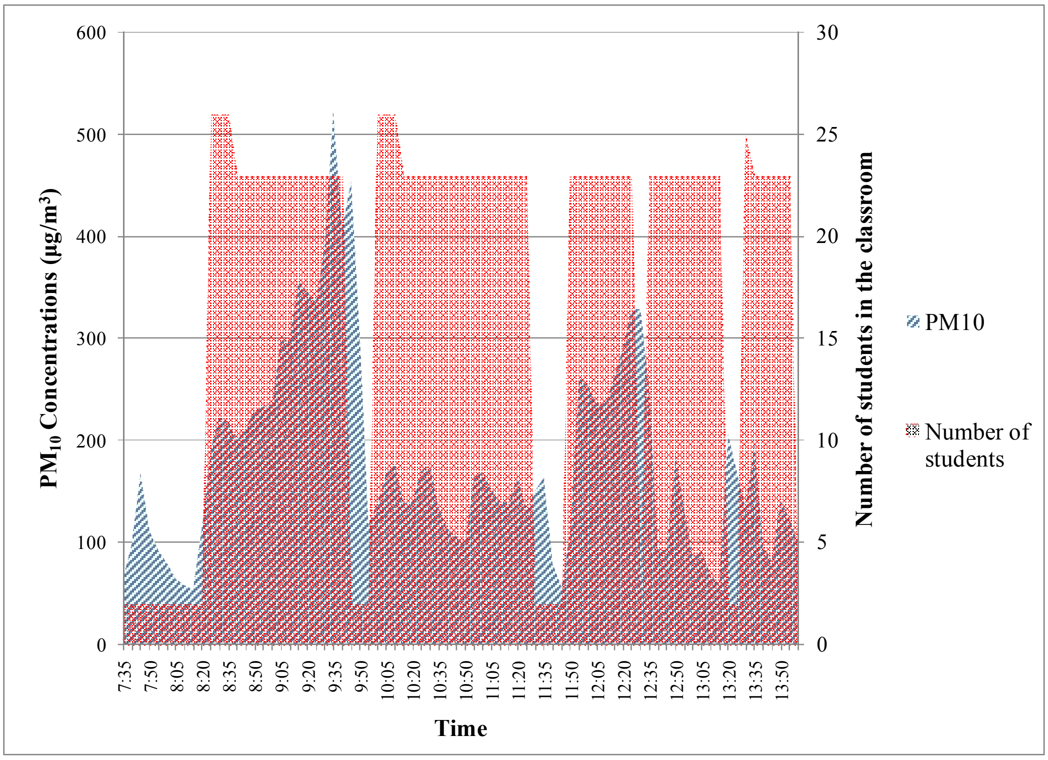

Figure 8: Diurnal variation of PM_{10} concentrations in school 4 on April 15th in relation to the number of students

4 CONCLUSIONS

The main conclusions arisen from this study are: (1) extremely high values of indoor PM_{10} concentration were measured in most of the schools, exceeding by far the recommended limit values, (2) the total average $PM_{2.5}$ concentrations from all the schools was below the limit values however, there were cases in which they were outreached, (3) ultrafine particle concentrations remained in rather low levels, (4) carbon dioxide in many cases exceeded the limit value of 1,000 ppm indicating inadequate levels of ventilation and overcrowded classrooms, (5) indoor PM_{10} concentrations are by far greater than the outdoor ones indicating that for the studied cases, the indoor environment is not affected by the outdoor environment, (6) classrooms using chalk in blackboard are characterized with significant concentrations of large sized particles ($PM_{2.5}$ & PM_{10}), while classrooms using marker in whiteboards from increased VOCs and CO concentrations, (7) window opening and the presence of students in the classrooms significantly affected the variation of the indoor PM_{10} concentrations.

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