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Classrooms Indoor Air Quality – Comfort Parameters and Outdoor Particulate Matter Influence Over Indoor Concentration Levels in Romanian Schools

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ABSTRACT

This experimental study presents new data on indoor comfort parameters and PM evolution over a school day. Results showed that comfort parameters did not meet recommended levels during teaching activities and an increase of PM concentrations from the beginning until the end of classes. Correlations between indoor/outdoor/PM concentrations and the ventilation rate showed that the main PM source was in the classrooms. I/O ratios demonstrated that the concentration of indoor pollutants was not necessarily influenced by outdoor sources, the poor ventilation determining the existing but low influence of outdoor concentrations.

Introduction

The primary causes of indoor air quality problems are sources that release gases or particles into the air. An inadequate ventilation of the space in use can increase pollutant levels by not bringing in enough outdoor air or by not carrying indoor air pollutants out of the area.

Numerous studies of particulate matter (PM) in the outside air have been conducted but only few data is available on indoor air pollution, even more rare for schools microenvironments**.** Failure to prevent indoor air quality problems can increase short and long-term health outcomes for both teachers and children (Alves et al. 2013).

Therefore, the aim of this experimental study was to assess indoor air quality in schools regarding particulate matter PM10 and PM2.5 influence over indoor concentration levels, the main objective being highlighting particulate matter concentrations evolution during a common school day and identifying possible pollution sources.

2. Materials and methods

Two methods were used: direct measurements with simultaneous indoor and outdoor PM10, PM2,5 , CO_2 temperature and humidity sampling in classrooms and indirect measurements, by applying a checklist for classrooms and calculating the ventilation rate.

2.1 Sampling sites and periods

Particulate matter PM10 and PM2,5 together with CO_2 were collected simultaneously from the indoor and outdoor air of two classrooms. The experimental study was carried out in December 2014, a one day sampling for each.

The classroom S1 was part of a school from a rural area and located in the proximity to high traffic road, being highly exposed to traffic exhaust pollutants and no emissions from industrial sources. The second classroom, S2, was part of a school situated in a mix populated commercial/residential area on a street with high traffic. In the proximity of the school, there was a parking area and a metallurgical plant.

In each classroom, measurements were done during school day.

There had been established 6 sampling periods, starting at 6 a.m. until 12 p.m. for 50 minutes each and 10 minutes ventilation between them, done by opening windows just as normal usage.

Both teachers and children were asked to perform normally all activities.

2.2 Sampling method

The particulate matter PM10 and PM2.5 were measured continuously with three real-time aerosol monitors using a light scattering technique. Indoor particulate matter (both PM10 and PM2.5) was measured with a DustTrak™ II Aerosol Monitor 8530. The instrument was programmed to record every 1 min and 50-min means were calculated.

Outdoor PM10 was measured with EPAM-5000 Environmental Particulate Air Monitor using light scattering with a size selective jet impactor specific for the investigated aerosols and OSHA approved respirable cyclone. PM2.5 on the other hand, was monitored by using Thermo Scientific personalDataRAM 1200 that has an integrated cyclone.

CO_2 sampling was performed by using two gas analyzers IAQ-CALC model 7545 TSI with NIST Certificate included (for simultaneous indoor and outdoor monitoring), using infrared detection of CO_2 (non-dispersive infrared sensor with two wavelengths). These analyzers also monitor temperature and humidity.

2.3 Indirect measurements

For each classroom, a checklist regarding outdoor characteristics, ventilation and cleaning has been filled in; the information followed was related to traffic density, outdoor pollution sources, classroom orientation, frequency of opened windows on a seasonal basis and cleaning arrangements.

The calculation of ventilation rate was made by using CO_2 concentration levels from the end of the sampling period and from the beginning.

2.4 Data analysis

After the description of PM10 and PM2.5 evolution over a school day and the establishment of I/O concentrations relationship, the correlation of particulate matter form indoor with outdoor levels and ventilation rate was evaluated with the Pearson's correlation coefficient "r" by using IBM SPSS Statistics version 22.

3. Results

During school hours in S1, the inside room temperature fluctuated between 17.5 and 19.5 ^{0}C (median: 18.6 ^{0}C), relative humidity ranged between 57 and 70% (median: 62%) and CO_2 concentration levels were between 711 and 1214ppm (median: 1085ppm and standard deviation [SD]: 208). The results for the particulate matter sampling are given in *Figure 1* bellow.

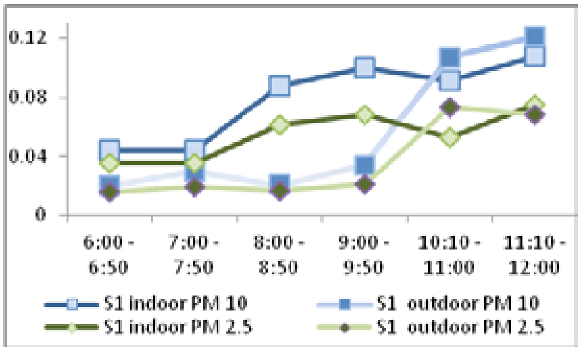

Figure 1. PM $_{10}$ and PM$_{2.5}$ evolution in S1

PM10 fluctuated between 0.044 and 0.108 mg/m^3 (median: 0.079 mg/m^3 and SD: 0.028) inside the classroom and between 0.02 and 0.121 mg/m^3 (median: 0.032 mg/m^3 and SD: 0.046) outside the school. Regarding PM2.5 concentration levels, they ranged between 0.037 and 0.075 mg/m^3 (median: 0.057 mg/m^3 and SD: 0.016) indoor and between 0.016 and 0.073 mg/m^3 (median: 0.02 and SD 0.027 mg/m^3).

The results for the comfort parameters during school hours in inside classroom S2 ranged between 17.1 and 22.9 ^{0}C for temperature (median: 20.9 ^{0}C) and 49 and 63% for the relative humidity (median: 57%). CO_2 concentration levels fluctuated between 825 and 1545ppm (median: 1109ppm and SD: 269). As seen in *Figure 2* bellow, PM10 concentration levels were between 0.011 and 0.088 mg/m^3 (median 0.072 mg/m^3 and SD: 0.033) indoor and 0.012 and 0.064 mg/m^3 (median 0.043 mg/m^3 and SD: 0.019) outdoor, in front of the building. PM 2.5 ranged between 0.011 and 0.068 mg/m^3 (median: 0.053 mg/m^3 and SD: 0.024) inside the classroom and between 0.009 and 0.042 mg/m^3 (median: 0.03 mg/m^3 and SD: 0.012) outside the building.

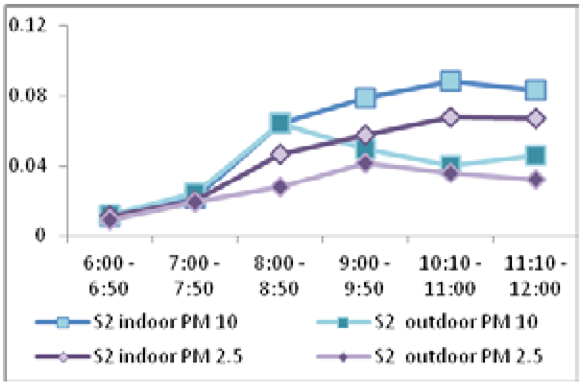

Figure 2. PM$_{10}$ and PM$_{2.5}$ evolution in S2

Correlations between the indoor and outdoor particulate matter concentrations were positive for both schools. For S1, there was a strong correlation (r= 0.6) between indoor PM10 and outdoor concentration and a moderate one (r= 0.4) for PM2.5. In S2, the correlation was strong for PM10 (r= 0.8) and also statistically significant for PM2.5 (r= 0.9 and p= 0.01).

The results for the correlations between indoor air particulate matter concentrations and the ventilation rates were different from the above. In S1, the obtained coefficient was positive and strong (r= 0.7) for PM10 but week for PM2.5 (r= 0.2). In S2 on the other hand, both coefficients were negative, a strong correlation for PM10 (r= 0.6) and moderate (r= 0.4) for PM2.5.

4. Discussions

In this experimental study, for the first time, results on indoor comfort parameters and PM evolution over a school day are presented for two schools from Romania.

According to The American Society of Heating, Refrigerating, and Air- Conditioning Engineers Standard 62-2001, temperatures in S1 are slightly below the recommended values (median: 18.6 ^{0}C; recommended: 19 – 23^{0}C) and the median relative humidity exceeds with 2% the 60% recommended upper limit. For S2, the comfort parameters were in the recommended limits.

In addition to being a useful indicator of inadequate air ventilation (U.S. Environmental Protection Agency, 2000), exposure to elevated CO_2 concentrations, tend to report drowsiness or lethargy (Mahyuddin and Awbi, 2012). The median concentration level for CO_2 in classroom S1 was 1085ppm and 1109ppm in S2, exceeding in both cases the desired levels (700 – 1000ppm) in international guidelines or regulations (Texas Department of State Health Services, 2003; ASHRAE, 2001).

PM monitoring in schools in recent studies showed peak concentrations during teaching hours (Madureira et al. 2012), recording values like 0.157mg/m^3 (Fromme et al. 2008), 0.118mg/m^3 (Simoni et al. 2010) or 0.112mg/m^3 (Jansse et al. 1997). In our study, median concentrations were lower (0.09mg/m^3 in S1 and 0.072mg/m^3).

In a study of Belgian schools, PM2.5 during teaching hours had a value of 0.061mg/m^3 (Stranger et al. 2007) while in Portuguese schools, 0.081mg/m^3 (Madureira et al. 2012), still lower values than identified in the assessed classrooms (0.057mg/m^3 - S1 and 0.053mg/m^3 - S2).

Correlation between indoor particulate matter levels and outdoor concentrations and ventilation was observed, still indoor levels being higher than outside. Same results were identified in recent studies (Fromme et al. 2007; Fromme et al. 2008; Diapouli et al. 2007; Chen and Zhao, 2011). I/O ratio median for PM2.5 was 2.07 and for PM10 1.8 in S1 while in S2 was 1.53 for PM2.5 and 1.29 for PM10, enforcing the statement of the main indoor PM sources (Elbayoumi et al. 2015; Joseph et al. 2010).

Particle generation indoors can result from specific sources or by human activities. Delayed deposition induced by air turbulence and reduced ventilation may also enhance indoor accumulation ((Madureira et al. 2012), jas being the case in this study.

5. Conclusions

The study was conducted in December 2014, in two schools being part of different environments (urban/rural), had different constructions (location, characteristics) and different outdoor exposure sources. For one classroom, comfort parameters did not meet recommended levels. Direct measurements in six sampling periods during a school day showed an increase of PM10 and PM2.5 concentrations from the beginning until the end of classes, the higher concentrations being recorded in the school located in the heavy traffic area (S1). Correlations between indoor pollutants concentrations and outdoor concentrations and the ventilation rate showed that the main PM source was in the classroom, the outdoor air quality still affecting the indoor air. I/O ratios demonstrated that the concentration of indoor pollutants was not necessarily influenced by outdoor sources. Poor ventilation was the factor that determined the existing but low influence of outdoor concentrations.

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