INDOOR AND OUTDOOR DISTRIBUTION OF AIRBORNE POLLUTANTS IN NATURALLY VENTILATED CLASSROOMS

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ABSTRACT

The present study aims at investigating concentration levels of particulate matter PM_{10}, $PM_{2.5}$, PM_1 and UFP as well as of total airborne fungi and their vertical distribution in the indoor and outdoor environment of school classrooms. Measurements were performed in two naturally ventilated high schools in Athens, from January until May 2011. Indoor concentrations of the pollutants will be presented per floor level and indoor to outdoor (I/O) concentration ratios will be estimated as a function of the floor height. The ultimate goal is to create variations' profile of I/O pollutant ratios, so as to understand the contribution of indoor sources and the extent to which the indoor air quality is being affected by the outdoor pollutants.

KEYWORDS

Particulate Matter, Airborne Fungi, Indoor to Outdoor ratios, Vertical distributions

1 INTRODUCTION

Several studies have shown that the outdoor air pollution influences the indoor air quality (Yocom 1982). In particular, focusing on particulate matter (PM), researches have indicated that certain fractions of PM penetrate by a great percentage to the indoor environment (Koutrakis et al., 1992, Özkayanak et al., 1996). Apart from infiltration, indoor sources can also increase significantly the indoor concentrations (Khillare et al., 2004). The indoor to outdoor concentration (I/O) ratios have been studied in several researches (Cao et al., 2005), however it is still not clear the level at which the outdoor environment affects the indoor environment.

Little is also known on how the indoor concentration levels of particulate matter (PM) and airborne fungi are distributed at various floor heights in naturally ventilated buildings. A few studies conducted in that field that are focused on PM, have shown that their rate of change is inconsistent with height due to the complex flow patterns around the buildings, to the vehicle emissions from the adjoining streets and also to particle generation affected by the vertical distribution profiles of PM concentrations (Quang et al., 2012).

The main objectives of this study are to: 1. compare the indoor to outdoor concentrations, 2. evaluate the indoor to outdoor (I/O) ratios of the pollutants and 3. examine the vertical distributions per floor of PM and airborne fungi.

2 METHODOLOGY

2.1 Sampling site description

The experimental campaign was conducted in two high schools from nearby areas just outside the city center of Athens (Dorizas et al., 2013). The first school is located in the Ymittos and the second school located in Kaisariani urban areas, hereafter denoted by Y and K respectively (Figure 1). The adjoining streets of school Y are of moderate traffic, while school K is next to a park. Both schools are naturally ventilated.

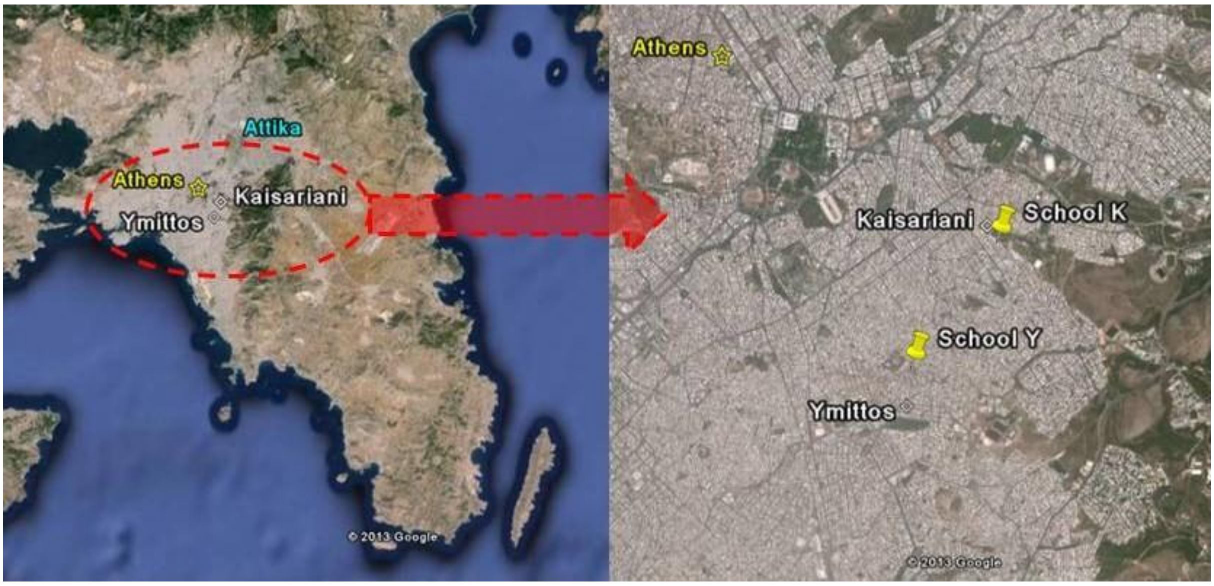

Figure 1: Map of Attica (left) and location of schools (right)

2.2 Sampling strategy

The measurements were conducted from January until May 2011 once every two weeks in each school. Air sample was collected from eight sampling sites per school, including classrooms laboratories and the outdoor environment. The windows kept closed during the measurements.

2.3 Measured parameters and instrumentation

PM_{10}, $PM_{2.5}$ and PM_1 were measured using Osiris (Turnkey Instruments Ltd), an airborne particle monitor in units of mass per unit volume (μg/m3). The ultrafine particle (UFP) concentrations were recorded using P-Trak (TSI, model 8525), a portable counter, in units of particles per unit volume (pt/cm3). Carbon dioxide (CO_2) was measured using IAQ-CALC (TSI, model 8732). Airborne fungi were recovered using a Burkard (Burkard Manufacturing Co. Ltd. Hertfordshire, UK), a portable air sampler for agar plates. Three plates with Malt Agar were exposed consecutively in each sampling site for 3 min/plate and then incubated for 2 weeks at 28 °C. The colony count was corrected and expressed as colony forming units per cubic meter (CFU/m3), a measure of viable spore concentrations. The fungal colonies were identified to genus level and *Penicillium*, *Cladosporium* and *Aspergillus* were the predominant genera.

3 RESULTS & DISCUSSION

3.1 Indoor to outdoor correlations

The indoor concentrations for all of the following cases arose from the averaged value from all of the indoor measurement sites in all of the days of measurement. The correlation coefficients between the indoor and the outdoor concentrations of pollutants are summarized in Table 1. As it can be seen for most of the cases, the correlation coefficients of particles between the indoor and the outdoor environment were high; however the correlations aren't significant. The correlation of $PM_{2.5}$ and PM_1 between the indoor and the outdoor environment are significant at the 0.01 level only in school Y. There was also found significant correlation in the UFP between the indoor and the outdoor environment. The indoor airborne fungi and their prevalent genera did not seem to correlate to the corresponding outdoor concentrations.

Table 1: Pearson and Spearman correlation coefficients of pollutants between the indoor and the outdoor environment

	Ymhttos		**Kaissariani**	
Parameter	**Pearson**	**Spearman**	**Pearson**	**Spearman**
PM_{10}	0.705	0.667	0.628	0.595
$PM_{2.5}$	0.887**	0.857**	0.606	0.690
PM_1	0.909**	0.850**	0.451	0.571
UFP	0.425	0.595	0.866**	0.833*
CO_2	0.565	0.714*	0.337	0.383
Total fungi	0.240	0.405	-0.137	0.5
Aspergillus	-0.118	-0.117	-0.199	-0.067
Cladosporium	-0.114	0.06	0.263	0.396
Penicilium	0.157	0.406	-0.034	0.446

** Correlation is significant at the level 0.01, * Correlation is significant at the level 0.05

3.2 Indoor to outdoor concentration ratios

The indoor to outdoor concentration ratios per pollutant and school are studied in this section. Figure 2 presents the I/O ratios of all the measured pollutants in school Y. As it can be seen, for most of the pollutants, the indoor concentrations are greater than the outdoor ones and most of the ratios were close to 1.5. The indoor UFP concentrations are approximately the same than the outdoor ones. *Cladosporium* was the only pollutant that its concentrations were greater outdoors than indoors. Indoor concentrations of *Aspergillus* and *Penicillium* were by more than two times greater than outdoors.

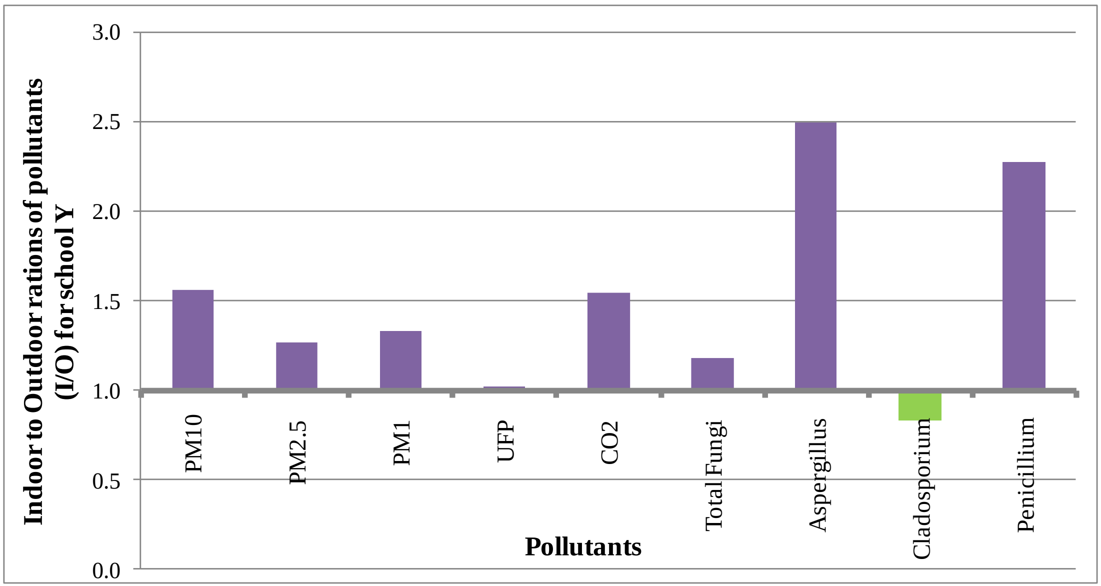

Figure 2: Indoor to outdoor (I/O) concentration ratios of pollutants in school Y

Figure 3 indicates the corresponding I/O ratios of the measured pollutants for school K. The I/O ratios of this school are slightly different than the ones of school Y for certain cases. For school K, PM_1 concentrations indoors were almost the same as outdoors. The outdoor concentrations of UFP for this school exceeded the indoor ones. Also, the indoor concentrations of *Cladosporium* were greater than the outdoor, unlike that found for school Y.

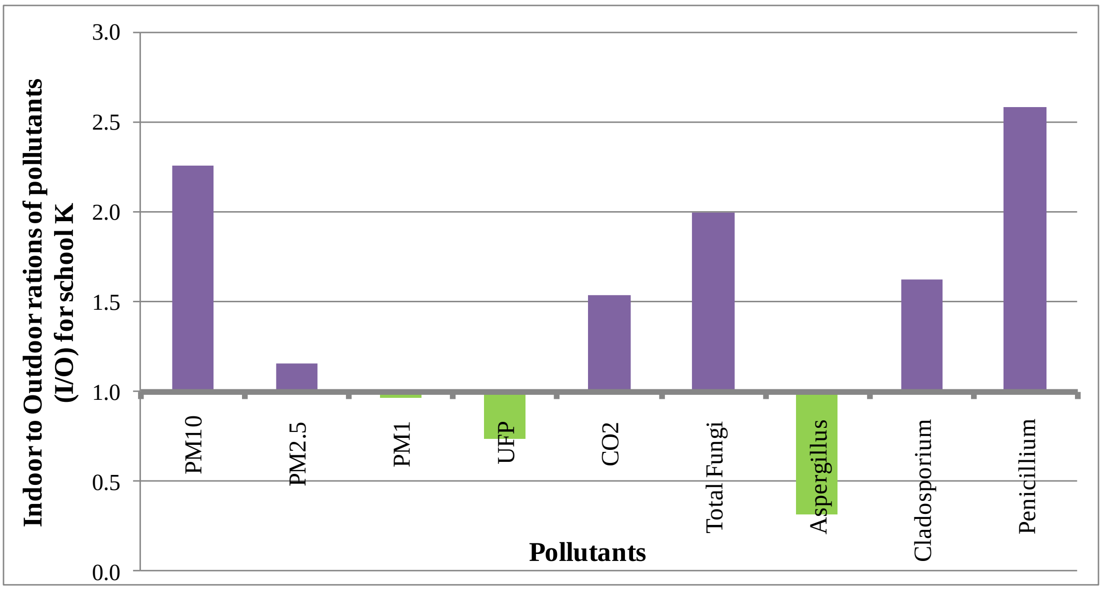

Figure 3: Indoor to outdoor (I/O) concentration ratios of pollutants in school K

The averaged I/O concentrations ratios of the two schools are shown in Figure 4. Overall, the indoor concentrations of the pollutants are greater than outdoor a fact that verifies the presence of indoor air pollutant sources, such as the increased presence of students and inadequate levels of ventilation. Only for the case of UFP concentrations the ratio was found slightly lower than 1, indicating that overall for both schools the outdoor concentrations were greater than indoors.

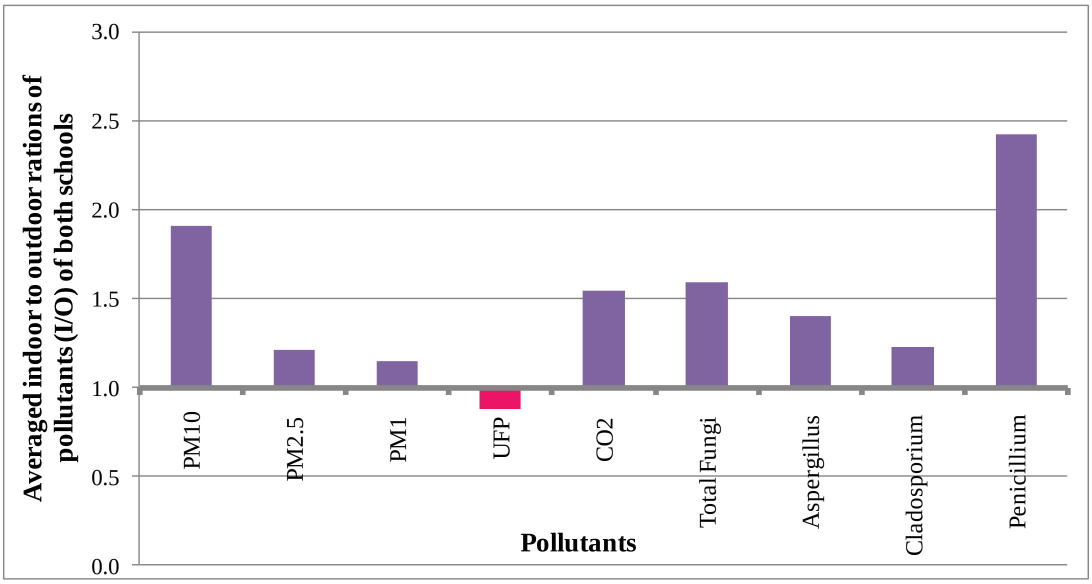

Figure 4: Averaged indoor to outdoor (I/O) concentration ratios of pollutants in both schools

3.3 Pollutant concentrations per floor level in both schools

In this section the vertical distribution of the pollutant concentrations in both schools is studied. The averaged concentrations of the pollutants per floor for all the days of measurement in both schools are presented in figures 5 – 7. The vertical distribution's profile of most of the pollutants is similar. The ground floor concentrations are approaching the outdoor concentrations and are greater than the ones of the first floor, meaning that the ground floor is probably affected by the vehicle emissions from adjoining streets (Kalaiarasan et al., 2009, Quang et al., 2012). The concentrations of the 2nd floor are greater than the ones of the 1st floor. Although the 1st floor is closer to the traffic emissions compared to the 2nd floor, the concentrations of particles and airborne fungi are lower. This fact could be due to the loss of pollutants from deflected traffic polluted air on the 1st floor from the surrounding trees that trap the particles (Cheong et al., 2007). Also, the increased concentration on the 2nd floor compared to the 1st floor could have been overwhelmed by regional sources influences (Jung et al., 2011) The indoor $PM_{2.5}$ (Figure 5, right) and PM_1 (Figure 6, left) concentrations were not greatly affected by the floor level (Jung et al., 2011, Montoya and Hildemann 2005). The airborne fungi of the ground floor were higher than in the 1st floor (Khattab and Levetin 2008).

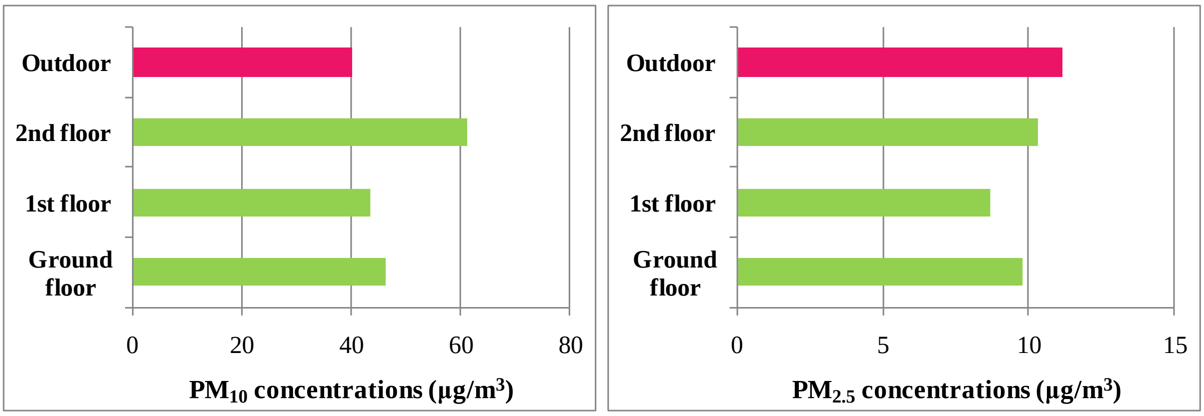

Figure 5: Averaged concentrations of PM10 (left) and PM2.5 (right) per floor in both of the schools

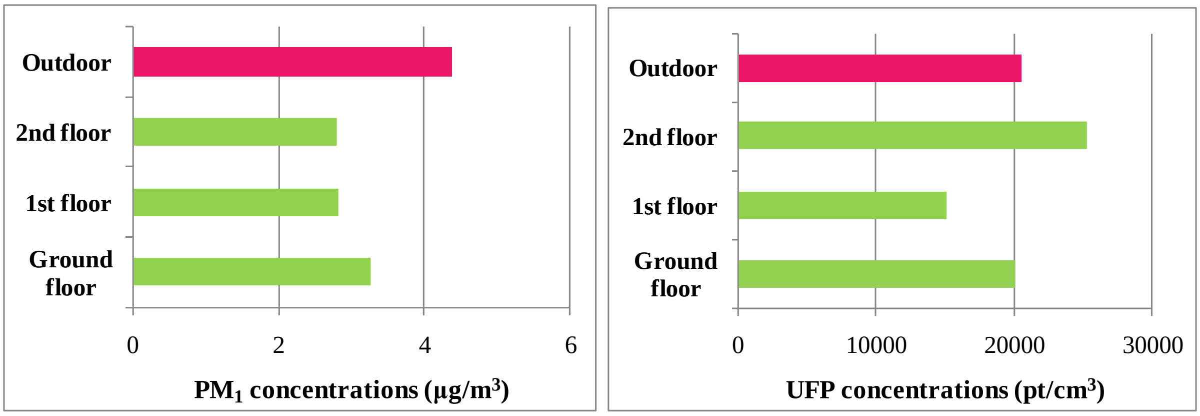

Figure 6: Averaged concentrations of PM1 (left) and UFP (right) per floor in both of the schools

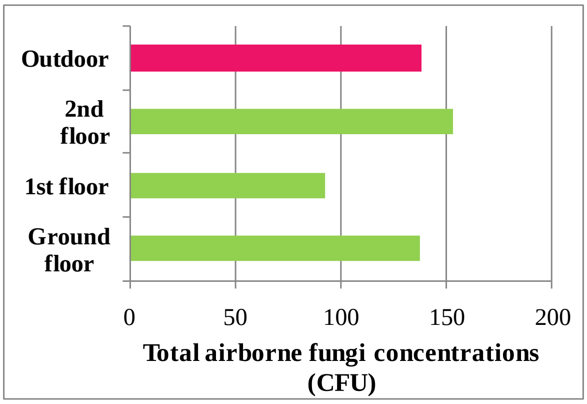

Figure 7: Averaged total airborne fungi concentrations per floor in both of the schools

4 CONCLUSIONS

The main conclusions arisen from this study are: 1. the indoor concentrations of PM correlated to the outdoor concentrations, 2. The indoor airborne fungi and their prevalent genera did not seem to correlate to the outdoor ones, 3. The indoor concentrations were greater than the outdoor concentrations for PM and airborne fungi, indicating the presence of indoor sources, 4. The vertical distribution profile of most of the measured pollutants was identical. The concentrations of the ground floor approached the outdoor levels, the concentrations of the 1st floor were lower compared to the ground floor and the ones of the 2nd floor were greater than the one of the 1st floor and in many cases exceeded the outdoor ones. Regional sources and indoor activities could have influence their vertical distribution profile.

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