Ventilation and particulate levels in dining halls

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ABSTRACT

The dependence of the ventilation on the indoor particulate pollution is highlighted by numerous studies. The aim of the present study is to examine the influence of the ventilation on the levels of the particulate concentrations found in dining halls where a large number of students are accommodated. Indoor particulate sources were also quantified.

Measurements were conducted in four University dining halls, which are located in different parts of the city of Athens. Indoor and outdoor CO_2, PM_1, $PM_{2,5}$ and PM_{10} concentrations along with the number of occupants and smokers were measured in each dining hall during the accommodation of the students. Measurements were repeated for five working days in each dining hall. Ventilation rates were estimated by applying a methodology that involves the solution of the mass balance equation for the CO_2 concentrations. The indoor particulate production rates were estimated by performing consecutive numerical experiments with the Multi Chamber Indoor Air Quality Model (MIAQ).

Median CO_2 concentrations ranged between 1043 μg m^{-3} and 1590 μg m^{-3} and ventilation rates ranged between 0.58 h^{-1} and 5.15 h^{-1}. The respective values for PM_1 ranged between 8.6 μg m^{-3} and 22 μg m^{-3}, for $PM_{2.5}$ between 17 μg m^{-3} and 60 μg m^{-3} and for PM_{10} between 24 μg m^{-3} and 78 μg m^{-3}. The Pearson correlation coefficient between the log transformed ventilation rates and the PM_{10} concentrations were found to be -0.6. Median values of the total production rates were found to range between 100 μg min^{-3} and 5500 μg min^{-3} and are highly correlated with the number of occupants (Pearson correlation coefficient 0.86).

Examination of the origin of the particulate sources indicated that in the majority of cases resuspension is more significant than combustion sources. Significant short-term variation (one hour time interval) of the various sources was also observed. Even though the production rates were significantly elevated, the measured particulate concentrations were moderate due to the high air change rates obtained. These findings supports the results of other studies that highlight the significance of ventilation in environments where indoor sources are prominent.

INTRODUCTION

The importance of indoor air quality in large public places (microenvironments where a large number of people accumulate, such as theatres, athletic halls, clubs, railway stations, etc) is significant due to exposure issues. During the last years several studies were conducted in order to assess indoor air quality in places such as lecture theatres (Cheong and Liu, 2003), night-clubs (Halios et al, 2009), athletic halls (Stathopoulou et al, 2008), railway stations (Kwon et al, 2008). Indoor air quality in hospitality venues such as taverns, restaurants and fast foods was studied in terms of VOCs (Loh et al, 2006, Baek et al, 1996; El-Hougeiri and El Fadel, 2004), classical and photochemical pollutants such as CO, SO_2, O_3 and NO_X (Lee et al, 1999; 2000; 2001; Baek et al, 1996) particulate matter (Migel et al, 1995; Lee et al, 1999; 2000; 2001, Bohanon et al, 2003) and bioaerosols (Zorman and Jersek, 2007). In particular, particulate pollution in restaurants was studied in order to reveal the attendant's exposure to environmental tobacco smoke (ETS) in several studies (Bohanon et al, 2003; Wilson et al, 2006; Ott et al, 1996) and it was established that the ETS levels were significantly reduced when the smoking was minimized. The significance of the ventilation on the improvement of the overall indoor air quality has been sufficiently established in numerous studies (Sfakianaki et al, 2008; Santamouris et al, 2008; Niachou et al, 2008; Halios et al, 2009).

The aim of the present study is to examine the indoor air quality in four dining hall facilities of the university of Athens, and to study the relative contribution of the ventilation and particulate production rates on the attendant's particulate exposure.

METHOD OF APPROACH

For the purposes of the present work we employed measurements of particulate matter (PM_{10}, $PM_{2.5}$ and PM_1) and CO_2 in four dining hall facilities (hereafter DHs). The four DHs are: a. the dining hall of the Faculty of Physical Education and Sport Sciences (hereafter TEFAA) located near a heavy traffic avenue b. the dining hall of the School of Law, Economics and Political Sciences (hereafter LAW) located in a purely residential neighbourhood, c. the dining hall of the School of Philosophy (hereafter PHIL) located in the University Campus at a suburban area and d. the dining hall of the Faculty of Medicine (hereafter MED) located in a residential neighbourhood. The number of occupants as well as the number of smokers was recorded during the experiments. All DHs were naturally ventilated.

Measurements of the PM_1, $PM_{2,5}$ and PM_{10} indoor and outdoor fraction of the atmospheric aerosol were made with a DustTrak portable Aerosol monitor (TSI model 8520). Different impactors are available for the inlet of DustTrak allowing measurements of PM_{10}, $PM_{2.5}$ and PM_1. The time log interval was set to 5 seconds. Then the logged data were averaged to 1-minute values and the outliers (i.e. values greater than the average value plus three times the standard deviation) of each data set were excluded from the data sets. The measurements were scheduled as described in the following: at each DH one set of PM_1, $PM_{2.5}$ and PM_{10} measurements were made in the outdoor environment followed by six sequential sets of measurements into the nightclub. The duration of each set of measurements was about half an hour. The outdoor measurements were made in front of the dining halls, while the indoor measurements were made at the centre of the indoor environments. Measurements were repeated for five working days in each dining hall.

The technique used by the DustTrak aerosol monitor differs substantially from validated gravimetric methods, and the measured $PM_{2.5}$ and PM_1 concentrations were corrected employing empirically derived correction equations. For the correction of the indoor and outdoor PM concentrations we employed the sets of equations described in Halios et al (2009).

Theoretical simulations were conducted with the aid of the indoor air quality model MIAQ (Multichamber Indoor Air Quality model), which is a mathematical model for aerosol dynamics in indoor air. It accounts for the effects of ventilation, filtration, direct emission, deposition onto surfaces, and coagulation for particles. Model results have been validated with experimental data (Nazaroff and Cass, 1987, Nazaroff and Cass, 1989, Drakou et al, 1998). Details regarding the numerical simulations are presented in following section.

RESULTS

CO_2 and PM Concentrations

In Figure 1 the box plots of the measured indoor PM and CO_2 concentrations are presented.

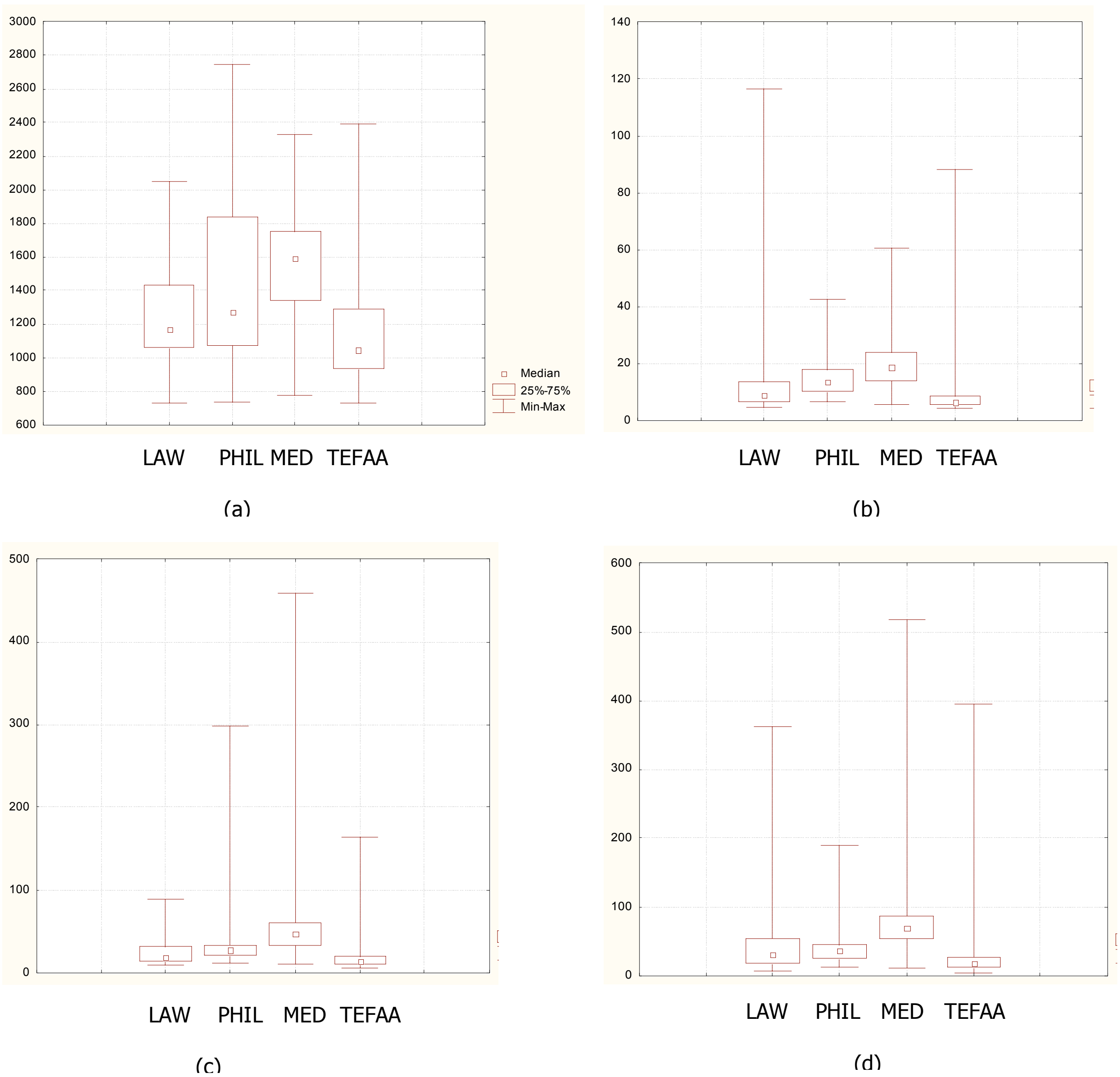


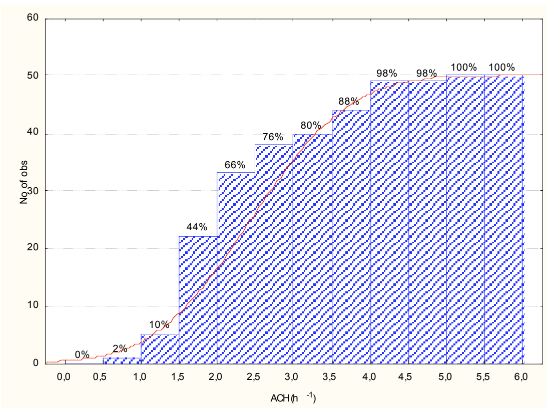
Figure 1: Box Plot of indoor CO_2 in mg m^{-3} (a), PM_1 in μg m^{-3} (b) $PM_{2.5}$ (c) and PM_{10} in μg m^{-3} (d) in μg m^{-3}

Indoor CO_2 concentrations are rather elevated (median value is 1240 mg m^{-3}), apparently due to the high occupancy of the DHs. The highest CO_2 concentrations are observed at MED DH and the lower at TEFAA.

Even though the median values of the PM concentrations are moderate in general (13 µg m^{-3} for PM_1, 23 µg m^{-3} for $PM_{2.5}$ and 33 µg m^{-3} for PM_{10} respectively), the 75th percentile values are rather high, probably indicating the presence of indoor short-term sources (75th percentile values are17 µg m^{-3} for PM_1 38 µg m^{-3} for $PM_{2.5}$ and 58 µg m^{-3} for PM_{10} respectively). Also, high maximum values are observed. It is of interest to notice that the corresponding 75th percentile values for the outdoor concentrations (not shown) are 5.72, 9.8 and 13 for the outdoor PM_1, $PM_{2.5}$ and PM_{10} concentrations respectively. It is noticeable that the highest PMs are observed in MED DH where the highest CO_2 concentrations are also observed. This observation probably indicates that the indoor particulate sources may be attributed to the occupants. This assumption will be further studied in a following section of the study.

Air Change Rates (ACH)

In order to calculate the air change rates in each DH we followed the methodology that is analytically presented in Halios and Helmis (2009). In short, the methodology involves the solution of the mass balance equation for the CO_2 concentrations, considering negligible deposition. The results of the ventilation rates calculations are presented in Figure 2 (a). More specifically, the average calculated ACHs were as follows: 3.31 h^{-1} at TEFAA, 2.08 h^{-1} at PHIL, 2.12 h^{-1} at MED and 2.28 h^{-1} at LAW. The minimum value (0.58 h^{-1}) was calculated at MED, while the highest at TEFAA (5.58 h^{-1}). It should be noticed that for the majority of the time the doors of the DHs were open.



a b

Figure 2: (a) Cumulative frequency distribution of the air change rates for all DHs (b) Box plot of the calculated particulate production rates (µg min^{-1}) in each DH. The y-axis is in a logarithmic scale.

Indoor sources

In order to calculate the strength of the indoor particulate sources (in terms of particulate production rates) within each DH we performed numerical simulations with the Multi Chamber Indoor Air Quality Model (MIAQ). During the numerical experiments the following were taken into account: (a) the measured outdoor PM_1, $PM_{1-2.5}$ and $PM_{2.5-10}$ concentrations were set as input values to the model (b)

Following Lai and Nazaroff (2000) we considered typical values for the particle deposition velocities (0.001 cm s^{-1} for PM_1, 0.005 cm s^{-1} for $PM_{1-2.5}$ and 0.05 cm s^{-1} for $PM_{2.5-10}$) (c) we employed the ventilation rates that were presented in the previous section. Consecutive theoretical calculations with varying indoor particulate production rates were performed, until the model-predicted concentrations coincide with the measured concentrations. In Figure 2 (b) results of these simulations are presented in terms of the total particulate production rates (the sum of the PM_1, $PM_{1-2.5}$ and $PM_{2.5-10}$ production rates). The average value of the indoor production for all DHs is 2,9 mg min^{-1}. It is of importance to notice that the variation between each DH is rather significant (median values 0.59 mg min^{-1}, 0.72 mg min^{-1}, 0.84 min m^{-1} and 5.2 mg min^{-1} for the TEFAA, MED, LAW and PHIL dining halls respectively. The average value of the $PM_{2.5}$ production rates for all DHs is 1.8 mg min^{-1}. The respective value that was calculated in night-clubs where the average $PM_{2.5}$ concentrations were about 20 times higher (484.6 μg m^{-3}) was 9.3 mg min^{-1} (Halios et al, 2009). It is thus apparent that the production rates found here are high, even though the resulting concentrations are rather moderate.

In the section "CO_2 and PM concentrations" it was stated that indoor particulate sources might be attributed to occupants. In order to examine the relationship between the number of occupants and the calculated production rates, the linear regression between these parameters were calculated (not shown). The number of occupants explains about 79% of the total variation of the PM_{10} production rates, (R^2 – value between the number of occupants and the PM_{10} production rates is 0.788). More specifically, the number of people explains 72% of the variation of the PM_1 production rates 83% of the $PM_{1-2.5}$ production rates and 53% of the $PM_{2.5-10}$ production rates. The number of smokers explains 81% of the PM_1 production rates. Thus, it might be deduced that the 18% of the PM_1 production rates, 17% of the $PM_{1-2.5}$ production rates, and 47% of the $PM_{2.5-10}$ production rates could be attributed to other than occupancy sources, such as cooking, or variation of the outdoor concentrations.

Combining indoor sources and ventilation

From the exponential regression between the PM_{10} concentrations and the air change rates (Figure 3) it is apparent that about 36% of the total variation of the PM_{10} concentrations can be explained from the air change rates. Accordingly, from Figure 3 (b) it can be seen that about 47% of the total variation of the PM_{10} concentrations can be explained from the PM_{10} sources (normalized per number of occupants).

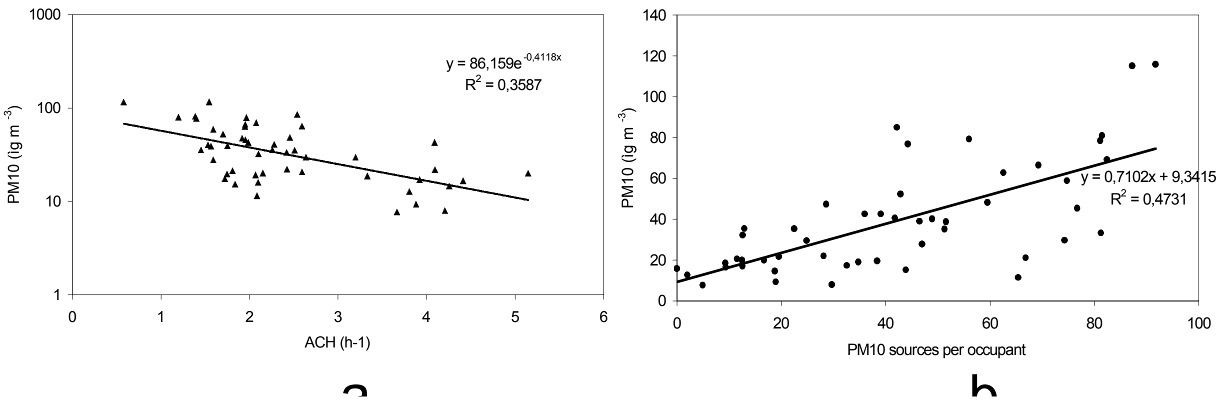


Figure 3: (a) Scatter plot and exponential regression between the PM_{10}, concentrations and the air change rates (b) Scatter plot and linear regression between the PM_{10} concentrations and the PM_{10} production rates normalized to the number of occupants.

CONCLUSIONS

In this study a combination of experimental and theoretical (numerical) methods were employed in order to estimate the combined effect of the ventilation and indoor production rates on the particulate levels of four dining halls in Athens, Greece. The air change rates were calculated with a methodology based on the solution of the mass balance equation for the CO_2 concentrations, and were found to vary between 0.58 h^{-1} and 5.15 h^{-1}. The strength of indoor particulate sources were calculated with the application of a mass balance numerical model. It was found that the indoor PM_1 sources range between 0.05 mg min^{-1} and 3.95 mg min^{-1}, the $PM_{1-2.5}$ sources between 0.01 mg min^{-1} and 7.35 mg min^{-1}, while the $PM_{2.5-10}$ sources between 0.06 mg min^{-1} and 10.75 mg min^{-1}.

Even though the production rates were significantly elevated, the measured particulate concentrations were moderate due to the high air change rates. These findings supports the results of other studies that highlight the significance of ventilation in environments where indoor sources are prominent (Halios et al, 2009). Examination of the origin of the particulate sources indicated that in the majority of cases resuspension is more significant than combustion sources. Significant short-term variation (one hour time interval) of the various sources was also observed.

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