COULD HOUSEPLANTS IMPROVE INDOOR AIR QUALITY IN SCHOOLS?

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Abstract

Previous studies performed by the National Aeronautics Space Administration (NASA) indicated that plants and associated soil microorganisms can be used to reduce indoor pollutant levels. This study investigated the ability of plants to improve indoor air quality in schools. A nine-week intensive monitoring campaign of indoor and outdoor air pollution was carried out in 2011 in a primary school of Aveiro, Portugal. Measurements included temperature, CO_2, CO, concentrations of volatile organic compounds (VOCs), carbonyls and particulate matter (PM_{10}) without and with plants in a classroom. PM_{10} samples were analysed for the water soluble inorganic ions, as well for the carbonaceous fractions. After hanging 6 potted plants from the ceiling, the mean CO_2 concentration decreased from 2004 to 1121 ppm. The total VOC average concentrations in the indoor air during periods of occupancy without and with the presence of potted plants were, respectively, 933 and 249 μg m^{-3}. The daily PM_{10} levels in the classroom during the occupancy periods were always higher than those outdoors. The presence of potted plants likely favoured a decrease of about 30% in PM_{10} concentrations. Our findings corroborate the results of NASA studies suggesting that plants can clean indoor air and make interior breathing spaces healthier.

Key-words: indoor air quality, VOCs, carbonyls, PM_{10}, plants, school.

Introduction

Various studies have demonstrated that plants can be used to remove pollutants from indoor air (e.g. Wolverton et al., 1989; Wood et al., 2006; Liu et al., 2007; Matsumoto and Yamaguchi, 2007). Plants have been pointed out as an attractive and cost effective way to improve indoor air quality (IAQ). Indoor potted-plants have been shown to remove most types of airborne pollutants arising from either outdoor or indoor sources. The benefits of plants on attendance and wellbeing of building occupants has been documented (Berg, 2002; Fjeld, 2002).

This issue arose when the National Aeronautics Space Administration (NASA) tried to find ways to reduce pollutants inside future space habitats (NASA, 1974). Wolverton et al. (1984, 1985, 1989) placed potted plants inside sealed plexiglass chambers, injecting substances commonly found in indoor air. The results showed that leaves, soil, and plant-associated microorganisms have an important function in reducing indoor air pollutants (cigarette smoke, organic solvents, and bioaerosol).

In schools, IAQ is often much worse than outdoor air quality (Kotzias et al., 2009; Pegas et al., 2010; Pegas et al., 2011a, b). Studies carried out by the USA Environmental Protection Agency (EPA) indicate that indoor air pollutant concentrations may be 2-5 times, and occasionally more than 100 times, higher than outdoor levels.

There are several reasons to consider IAQ at primary schools a public concern. One is that children breathe higher volumes of air, relatively to their body weights. Children's physiological vulnerability to air pollution arises from their narrower airways and the fact that their lungs are still developing. Also, many children breathe through their mouths, bypassing the nasal passages' natural defences. Thus, children are more likely to suffer the consequences of indoor pollution. Another reason for environmental deficiencies in schools is due to chronic shortages of funding, which contribute to inadequate operation and maintenance of facilities (Mendell and Heath, 2005).

Previous measurements of particulate matter (PM_{10}), volatile organic compounds (VOCs) and carbonyls carried out in elementary schools in Lisbon revealed indoor/outdoor (I/O) ratios above unity, showing the influence of indoor sources, building conditions and inappropriate ventilation on IAQ, and indicating the need to take decisive remedial actions (Almeida et al., 2011; Pegas et al., 2010; Pegas et al., 2011a, b). The main purpose of the present study was to assess the effectiveness of three common species of houseplants in the fight against rising levels of air pollution in classrooms.

Material and Methods

Study design

This study investigated the effectiveness of potted plants suggested by NASA (NASA, 1974) in reducing the air pollutant concentrations in classrooms. A school located in the city centre of Aveiro, Portugal, was selected to carry out this study. The selected school is located at 40º 38’ 16.76’’N; 8º 39’ 09.85’’W. This school started its activities in the sixties. It is surrounded by commercial and residential buildings and in front of the school there is a car parking and a busy road. The main classroom studied has wood floor, water based paint covering the walls, black board and chalk, white board and markers and five wood windows. The area of the room was 52.5 m^2. The number of students in the classroom is around 25.

Comfort parameters (temperature, relative humidity, CO_2 and CO), VOCs, carbonyls and particulate matter < 10 μm (PM_{10}) concentrations were measured between February and May 2011, 3 weeks without plants (February 28th to March 20th 2011) and 6 weeks with potted plants indoors (March 21st to May 28th 2011).

Dracaena deremensis (Striped dracaena or Janet Craig), *Dracaena marginata* (Red-edge Dracaena, Madagascar dragon tree or Marginata) and *Spathiphyllum* (Mauna loa or Peace lily) were the selected houseplants, since in test-chamber studies (Wolverton et al., 1989; Tarran et al., 2002; Wood et al., 2002; Orwell et al., 2004; Wood et al., 2006) they have been found to be reliably effective in removing benzene, toluene, ethylbenzene and xylenes (BTEX).

The potted-plants were all of similar size, weight and age. In classrooms, they were placed on metallic holders to ensure there was enough height from the floor and a free space under the pot for air circulation (about 30 cm). The number of potted-plants was defined according to the area of the classroom. The Associated Landscape Contractors of America (ALCA) recommendation is one plant per 9.29 m^2. Thus, six potted-plants (300 mm diameter pots) were placed in the selected classroom.

Sampling and analytical methods

Continuous measurements of temperature, relative humidity (RH), CO_2, CO and total VOCs were performed with an automatic portable Indoor Air IQ-610 Quality Probe (Gray Wolf® monitor) and a TSI monitor, simultaneously in the classroom and at the playground, respectively, during 9 weeks.

Every week, during 9 weeks, passive samplers for VOCs and carbonyls (Radiello®) were used to obtain indoor and outdoor average concentrations. Another set of Radiello passive samplers were only exposed from 8:30 AM to 17:30-18 PM to obtain VOC and carbonyl concentrations for the occupancy periods.

VOCs adsorbed in activated charcoal cartridges were extracted with 2 mL of carbon disulfide (CS_2) containing the internal standard, in accordance with the Radiello® procedure. Analyses were performed by gas chromatography (Thermo Scientific Trace GC Ultra) coupled to a flame ionisation detection (GC/FID). The equipment was calibrated before and during the analyses of samples by injecting standard solutions of all compounds identified in CS_2 (Pegas et al., 2010).

Carbonyls were extracted with 2 ml of acetonitrile during 30 minutes and the extract filtered through 0.45 μm membrane disc filters (filtration kit RAD 174) and injected into the high-performance liquid chromatography (HPLC) system. The carbonyl concentrations were quantified with external calibration curves constructed from standard solutions - Aldehyde/ketone-DNPH TO11/IP-6A Mix (USEPA, 1999).

Active sampling of carbonyls was performed during two days in the first period without plants (March 24th and 25th) and during two days in the second period with plants (May 25th and 26th). Carbonyl active collection involved a sampling train consisting of a Thomas pump to draw in air at a flow rate of 2 L min^{-1} for a sampling time of one or two hours in agreement with the classroom cycles, through silica gel cartridges, impregnated with 2,4-dinitrophenylhydrazine reagent (Sep-Pak® DNPH-Silica Cartridges), a dry gas meter to measure the volume of air and ozone scrubbers to minimise ozone interferences. The analytes were extracted with 5 mL of acetonitrile by filtration through gravity feed elution and the extract collected in 3 mL vials and later analysed by high-performance liquid chromatography (HPLC) with UV detection at absorption wavelength at 360 nm (ASTM, 1997).

Two low volume samplers were used to collect simultaneously indoor and outdoor PM_{10} on a daily basis, during the occupancy period, from 8:30 AM to 17:30-18 PM, over a period of 9 weeks. The PM_{10} samples were collected onto pre-baked (6 h at 550ºC) quartz filters 47 mm in diameter. Before weighting, the filters were conditioned in a desiccator at least for 24 hours in a temperature and humidity-controlled room. Before and after sampling, the gravimetric determination was performed with a microbalance Mettler Toledo AG245 (readability 0.1mg/0.01mg). Filter weights were obtained from the average of ten measurements, with weight variations less than 5%.

The elemental and organic carbon (EC and OC) content in PM_{10} was analysed by a home-made thermal-optical transmission system, after passive exposure of sampled filters to HCl vapours to remove carbonate interferences. This procedure was at first developed by Carvalho *et al.* (2006) and recently adapted by Alves *et al.* (2011). Carbonates present in PM_{10} samples were analysed through the release of CO_2, and measured by the same non-dispersive infrared analyser coupled to the thermo-optical system, when a punch of each filter was acidified with orthophosphoric acid (20%) in a free CO_2 gas stream (Alves *et al.* 2011).

For the determination of water soluble inorganic ions (WSII), a filter fraction (2 discs of 13 mm of diameter) were extracted with ultra pure Milli-Q water. Dionex AS14 and CS12 chromatographic columns with Dionex AG14 and CG12 guard columns coupled to Dionex AMMS II and Dionex CMMS III suppressors, respectively for anions and cations, have been used.

To evaluate the significance of differences between variables, the non-parametric Mann-Whitney *U* test was preferred rather than the Student's *t*-test (Browm and Hambley, 2002). A difference between two means was considered to be statistically significant when the *p-value* of the two-tailed Mann-Whitney *U* test was lower than

0.05. All statistical computations were conducted with the R software (*http://www.r-project.org/*).

Results and discussion

The indoor average temperature ranged from18.7±1.99^{o}C in the first period of the study, without plants, to 20.0±2.22^{o}C in the second period, with plants. The RH values did not change appreciably throughout the campaign (55.91±8.32% and 51.73±7.98%). The CO concentrations in the classroom were always low (0.05±0.04 ppm). However, the CO_2 levels (**Figure 1**) were significantly different between the period without (2004±580 ppm) and with plants (1121±600 ppm) in the classroom (*p-value* of 0.0001689). Many studies demonstrated that high levels of CO_2 could cause a negative influence on students' learning ability (Coley and Greeves, 2004; Shendell et al., 2004; Smedje et al., 1996). It should be noted, that during the entire campaign the windows were kept closed. During the hottest days, three exceptions to this condition were registered, when one or two windows were partially opened for a few minutes. Taking into account that these extents of time with higher natural ventilation represented less than 5% of the occupancy period, the possible dilution effect of concentrations was considered negligible.

The National System for Energy and Indoor Air Quality Certification of Buildings establishes an acceptable maximum value (AMV) for the CO_2 concentrations of 1000 ppm in indoor environments in Portugal (RSECE, 2006). Over the period without plants, as well during the week of their acclimatisation, the CO_2 concentrations were always much higher than the AMV. High indoor CO_2 levels are normally considered as indicative of inadequate ventilation. Based on indoor and outdoor CO_2 concentrations, it is possible to estimate ventilation rates under different degrees of window openings or when they are fully closed. When unoccupied there is no CO_2 emission from the tenants, so the ventilation rate can be obtained by:

$$Q = -\frac{V}{t} \times \ln\left(\frac{C_t - C_{ext}}{C_0 - C_{ext}}\right) \quad (1)$$

where C_t is the indoor concentration of CO_2 at time t (ppm), C_{ext} the concentration of CO_2 in the external air (ppm), C_0 the concentration of CO_2 in the indoor air at time 0 (ppm), Q the ventilation rate of air entering the space (m^3 s^{-1}), V the volume of the classroom (m^3) and t is the interval since t=0 (s) (Griffiths and Eftekhari, 2008).

The estimated ventilation rates ranged from 11 to 23 L s^{-1}. The maximum ventilation value, which corresponds to about 0.9 L s^{-1} per person, represented only 35% of the minimum value of 2.5 L s^{-1} per person recommended by the ANSI/ASHRAE Standard 62-1999, and only 10% of that recommended by RSECE (8.33 L s^{-1} per person). The CO_2 levels measured from the 5^{th} week onwards, during the occupancy periods, were not as high as those of the first three weeks, in the absence of plants (**Figure 1**). Tarran et al. (2007), in a study aiming at evaluating the capacity of indoor plants to remove pollutants, reported that CO_2 concentrations were reduced by about 10% in air-conditioned offices and by about 25% in naturally ventilated rooms.

Concentrations of VOCs were always higher indoors than outdoors, including nighttime periods (**Figure 2**). A concentration decrease during the non-occupancy period was observed. Higher indoor levels of many VOC species were also registered in previous studies involving 14 elementary schools of the Portuguese capital, Lisbon (Pegas et al., 2010, 2011a, b). The VOC concentrations during teaching periods ranged from 933 ± 577 μg m^{-3} in the absence to 249 ± 74.2 μg m^{-3} in the presence of plants. The difference between VOC levels without and with plants was statistically significant (*p*-

value of 0.03571). The approximately 73% reduction of VOC concentrations observed in this study is in line with the results of previous investigations in 60 offices by Wood et al. (2006), who tested the effectiveness of potted-plant and root-zone microcosms with and without air-conditioning. It has been observed by these authors that the root-zone microcosm could substantially reduce high concentrations of VOCs within 24 hours. In the current study, the decrease of indoor VOC levels was observed whether in samples obtained during school hours or in weekly samples continuously exposed. The main difference between the two sets of samples is the magnitude of concentrations. VOC levels in weekly samples continuously exposed, as obtained in previous works in Portugal (Pegas et al., 2010, 2011a,b), do not truly reflect the levels of exposure. Outside the room, the VOC levels remained almost uniform over the entire sampling period (**Figure 2**). Methylacetate, 1,1,1-trichloroethane and isopropanol were systematically more abundant in the classroom. Acetone, methanol and 1,1,1-trichloroethane were prevalent outdoors. These compounds may derive from both indoor and outdoor sources, including felt pens, personal care products, PVC cement and primer, various adhesives, contact cement, model cement, degreasers, aerosol penetrating oils, brake cleaner, carburettor cleaner, commercial solvents, electronics cleaners, spray lubricants, etc. (Mendell, 2007).

Among all monitored VOCs, BTEX are of particular interest due to their known carcinogenic effects (Kotzias et al., 2009). Ethylbenzene showed a decrease from levels in the 1.48-2.53 μg m^{-3} range during the period without plants to values below the detection limit during the period with potted-plants indoors. The average toluene concentrations were 7.62 ± 1.73 μg m^{-3} and 4.09 ± 0.66 μg m^{-3}, respectively, when plants were absent or present, showing a decrease of about 57%. A reduction of 80% between the two periods was observed in *m+p*-xylene and *o*-xylene concentrations.

Benzene is a carcinogenic compound to which the WHO has not yet established a guide or safe value (WHO, 2000). The average benzene concentration was 1.09 ± 0.21 μg m^{-3} in the absence of plants, decreasing to 0.84 ± 0.03 μg m^{-3} during the presence of potted vegetation, which represents a decline of almost 15%. Outdoor toluene, ethylbenzene, *m*+*p*-xylene and *o*-xylene levels were significantly lower than air concentrations in the classroom, reflecting the contribution of indoor sources. Although Wolverton (1989) has found a reduction in benzene concentration in controlled chambers of 77.3, 79.5 and 79.0% for the species Janet Craig, Marginata and Peace Lily, respectively, in the classroom, this reduction did not exceed 15%. However, it is important to note that the chamber experiments refer to static testing, where pollutants are injected and then their decay is measured. A classroom is an open system and there are many other cross-factors influencing concentration values. The benzene levels were always within the same order of magnitude or smaller than the outside concentrations, denoting that the major contribution is likely from the outdoor environment.

Carbonyl compounds are the most important chemical contaminants affected by chemical and physical processes in the environment (Cerón et al., 2007). Among the five carbonyls identified in the indoor environment, butyraldehyde (40.8 ± 2.20 μg m^{-3}) and formaldehyde (22.6 ± 3.54 μg m^{-3}) were the most abundant in the classroom in the absence of plants. Formaldehyde is a ubiquitous pollutant that could be found in almost all indoor and outdoor environments. Formaldehyde indoor sources include pressed wood products and furniture, insulation, combustion and tobacco smoke, some textiles and glues. **Figure 3** shows that there was a significant decrease in the sum of carbonyl concentrations after hanging potted plants from the ceiling in the classroom (*p-value* of 0.03571). During the first three weeks without plants, the sum of aldehyde concentrations ranged from 81.3 to 94.3 μg m^{-3} at an average temperature of 18.7 ± 1.90

ºC. Between the fifth and ninth weeks, with plants in the classroom, the concentrations of total carbonyls ranged from 57.4 to 68.7 μg m^{-3} at an average temperature of 24.8 ± 1.35 ºC. Even with increasing temperature, a decrease in carbonyl concentrations of up to 40% was registered. Normally, the carbonyl concentrations increase with increasing temperatures due to evaporation from building materials (Pang and Mu, 2006). In chamber studies with controlled conditions, the decrease in formaldehyde concentration due to the effect of plants ranged from 47 to 70% (Wolverton et al., 1989). Results from active sampling in office environments suggested that achieving an 11% reduction in formaldehyde levels in a real life situation would require the equivalent of one plant to each m^3 or 2.4 plants to every m^2 (Dingle et al., 2000). **Table 1** presents results from active samplings carried out before and after having plants in the classroom. An approximately 40% decrease in the indoor concentrations of the four carbonyl compounds measured by active sampling, whose determination was also done by passive sampling, was observed. The outdoor levels increased with increasing temperature.

Atmospheric particles have been associated with increased respiratory symptoms (Delfino, 2002; Simoni et al., 2002; Weisel, 2002). Indoor PM_{10} may carry toxic pollutants and reaction products into the airways, inducing inflammatory responses through the generation of oxidative stress (Leem et al., 2005). In this experiment, the daily indoor PM_{10} levels were always higher than those outdoors (**Figure 4**), suggesting that the physical activity of the pupils leads to emission/resuspension of coarse particles and greatly contributes to enhanced PM_{10} in classrooms (Almeida et al., 2011). Lohr and Pearson-Mims (1996) reported an approximately 2% reduction in PM_{10} levels in a computer lab and in an office after introducing plants into these building environments. A statistically significant decrease in PM_{10} levels was observed in our study (*p-value* of

0.0001597). The indoor PM_{10} mean values ranged from 137 ± 7.70 μg m^{-3}, without plants, to 91.2 ± 13.2 μg m^{-3}, with plants (**Figure 4**). The outdoor PM_{10} mean values ranged from 28.2 ± 5.78 μg m^{-3} in the first period to 38.2 ± 14.4 μg m^{-3} in the second period of the campaign. Even with an increase of about 35% of outdoor PM_{10} concentration, there was a reduction of about 34% in the indoor levels. This could be related to the gravitational settling of particles onto foliage and potting soil. Lohr and Pearson-Mims (1996) suggested that the plants do not simply block the fall of particles. Plants may also remove particulate matter through impaction of particles carried across their foliage by eddy currents.

On average, the organic carbon represented a mass fraction of PM_{10} of 30.0% indoors. A lower mass fraction was obtained outdoors (OC/PM_{10}=21.3%). The total carbon (TC = OC + EC) levels were higher indoors than outdoors (**Figure 5**). Clearly, OC is enriched in indoor, as compared to outdoor air. An indoor enhancement of OC/EC ratios is likely to be due to indoor sources of organic compounds, such as submicron fragments of paper, skin debris and clothing fibres, among others. A decrease from 36.9 ± 4.81 μg m^{-3} to 24.6 ± 6.32 μg m^{-3} in the OC concentrations have been observed between the periods without and with plants, respectively (*p-value* of 0.001395), whereas no significant difference was found outdoors. There was no significant difference in EC levels between the two periods of the campaign and between the indoor and outdoor air (**Figure 5**).

The water soluble ions contributed, on average, to 20.4% and 14.1% of the particle mass in the classroom and playground, respectively (**Figure 6)**. Carbonate was the dominant ion of indoor-sampled particles, representing, on average, 10.2% of the mass of all analysed ions. Carbonate levels in the indoor air ranged from 21.8 ± 1.33 μg m^{-3}, without plants, to 6.93 ± 2.31 μg m^{-3}, in the presence of plants (*p-value* of 0.00432). The reduction of carbonate levels was followed by a concomitant reduction in calcium levels from 4.25 ± 0.66 μg m^{-3} to 2.78 ± 0.81 μg m^{-3}, without and with plants, respectively (*p-value* of 0.00414). Compared with other soluble ions, the calcium mass fractions were higher in the indoor environment (2.76% of the PM_{10} mass) than those observed outdoors (0.76% of the PM_{10} mass). The higher indoor levels are probably related to the use of chalk crayons on the blackboard. This observation is corroborated by the high carbonate concentrations in the classrooms. The indoor carbonate concentrations were about 10 times the amounts found outdoors during the weekdays. Magnesium represented one of the less abundant ions in the indoor and outdoor environments. The outdoor sodium and chloride levels were about 2 times higher than the indoor levels, probably because these two ions likely have a strong contribution from sea spray. A statistically significant reduction in levels of nitrate, sulphate and ammonia between periods in the absence and presence of plants was observed (*p-value* of 0.0002126, 0.0002688 and 0.0002257, respectively). Atmospheric PM, and especially some of its constituents (e.g. nitrates and ammonium) may affect vegetation directly following deposition on foliar surfaces or indirectly by changing soil chemistry. Indirect effects through the soil, however, are usually the most significant because they can alter nutrient cycling (Grantza et al., 2003; Prajapati, 2012).

Conclusions

This study tried to determine if common houseplants are useful in improving overall indoor air quality. In spite of some possible confounding factors (e.g. variable ventilation rates throughout the monitoring campaign) that could lead to misinterpretation of results, it seems that plants do have the ability to remove ordinary pollutants from the air. After the placement of six potted-plants in the classroom, a statistically significant reduction in CO_2, VOCs, carbonyl, PM_{10}, OC, nitrate, sulphate, ammonia, calcium, and carbonate concentrations was observed. The decrease in indoor air pollutant levels resulting from the use of plants may represent a low-cost solution to reduce exposure to many compounds and lifetime risk, and further improve performance, attendance and welfare of students and teachers in classrooms. This simple measure does not invalidate, however, the adoption of other abatement or preventive strategies, such as to the use low VOC emitting materials and consumer products, lowering the occupancy rates in classrooms, use of air cleaner and humidity control systems, and increasing the ventilation rates (through natural openings or mechanical devices).

Taking into account that the rate at which the plants metabolise the air pollutants depends on the growing conditions and that the removal performance depends on the plant species, further research is needed. This study provides some clues that this is an important issue to pursue, especially as it may relate to potential human health effects.

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Table

Table 1. Active sampling of carbonyls

	Sum of carbonyl concentrations ($\mu g\ m^{-3}$)			
	Without Plants		**With Plants**	
	Average	**STDEV**	**Average**	**STDEV**
Indoor	**52.9**	3.89	**32.1**	11.9
Outdoor	**16.3**	3.86	**27.5**	28.1

Figure Captions

Figure 1. Indoor and outdoor average CO_2 concentration week by week.

Figure 2. Indoor and outdoor concentrations of all VOCs identified.

Figure 3. Indoor and outdoor concentrations of all carbonyls identified (passive sampling).

Figure 4. Indoor and outdoor PM_{10} concentrations week by week.

Figure 5. Indoor and outdoor carbon mass concentration week by week.

Figure 6. Indoor and outdoor soluble ion concentrations week by week.

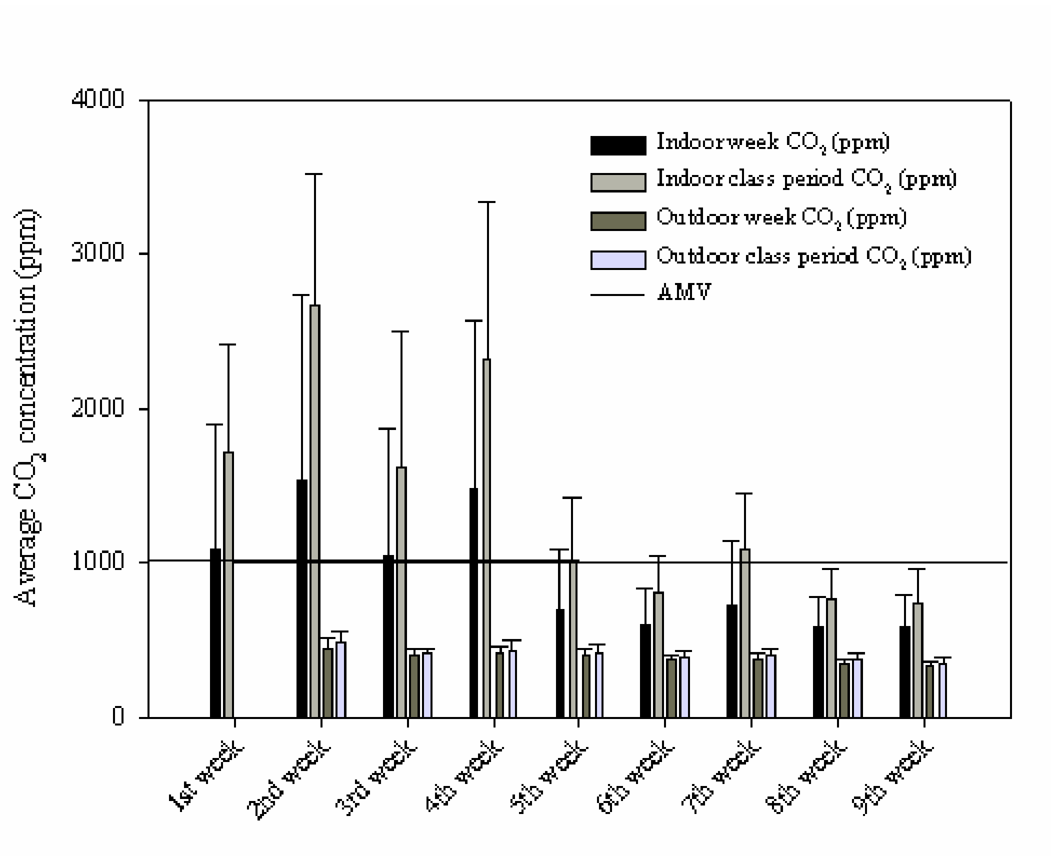


Figure 1

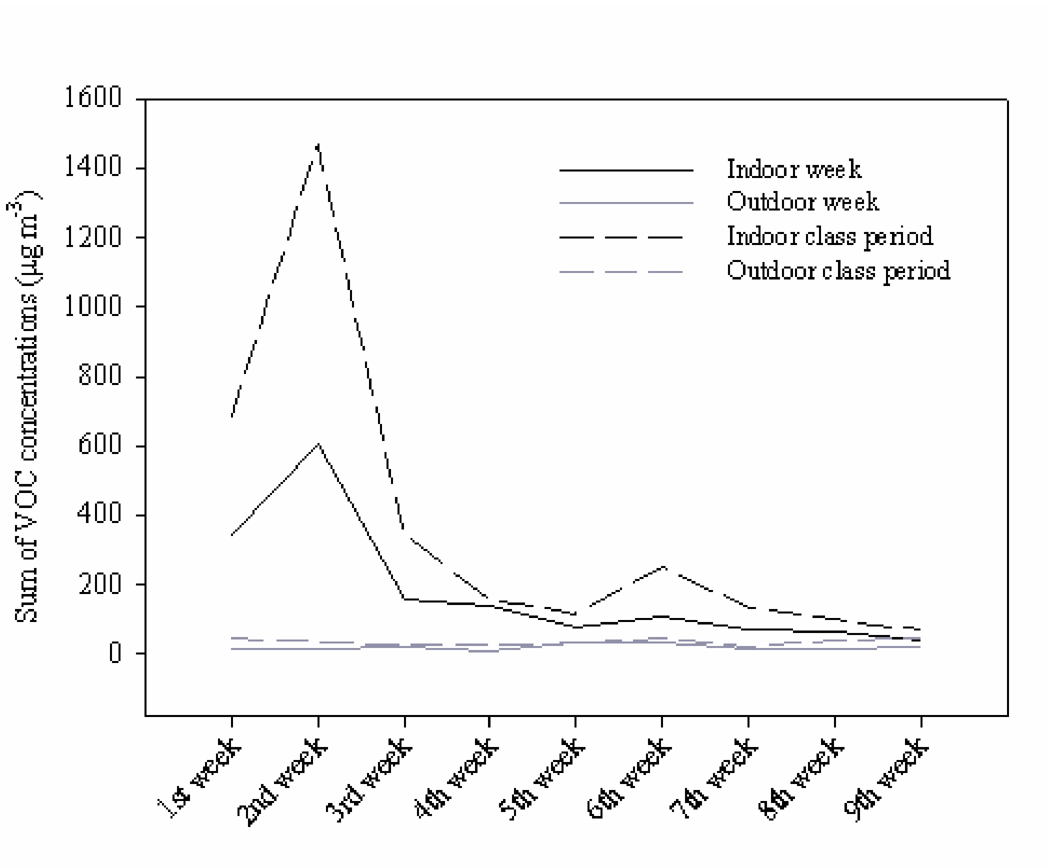

1600
1400
1200
1000
800
600
400
200
0
Sum of VOC concentrations (μg m-3)
Indoor week
Outdoor week
Indoor class period
Outdoor class period
1st week
2nd week
3rd week
4th week
5th week
6th week
7th week
8th week
9th week

Figure 2

120
100
80
60
40
20
0
Sum of carbonyl concentrations (μg m-3)
Indoor week
Outdoor week
Indoor class period
Outdoor class period
1st week
2nd week
3rd week
4th week
5th week
6th week
7th week
8th week
9th week

Figure 3

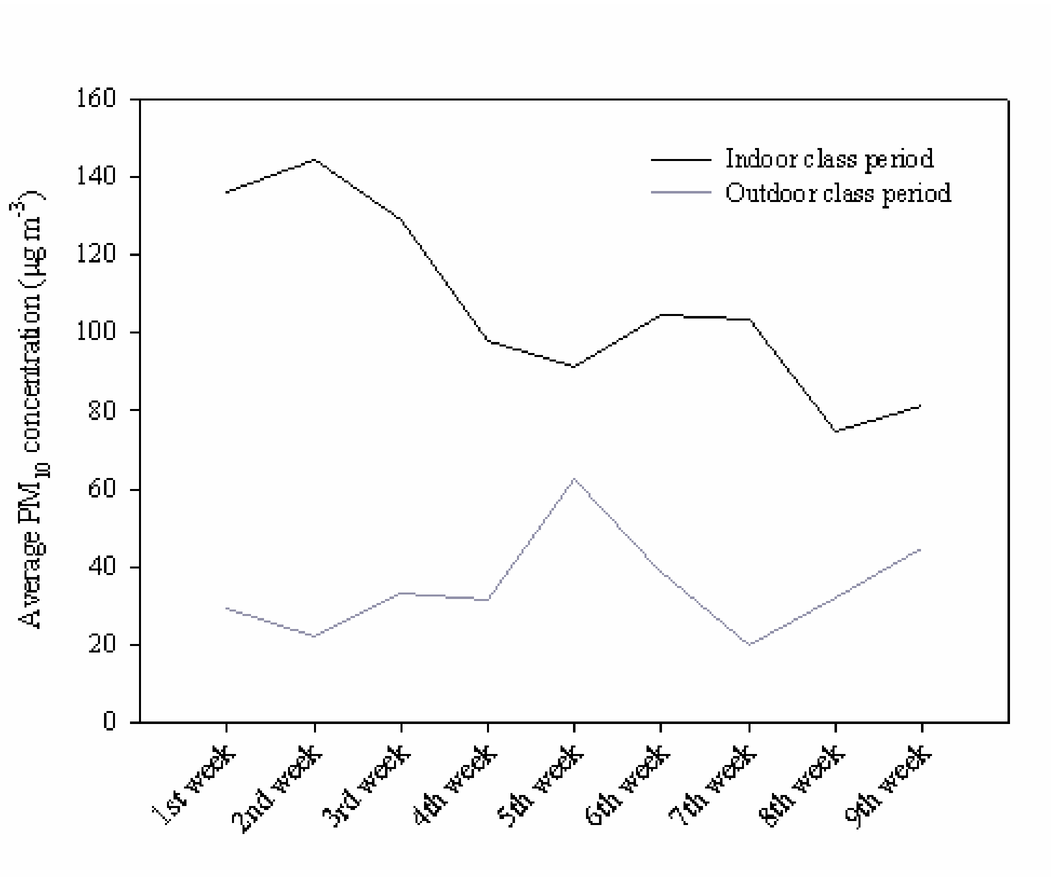
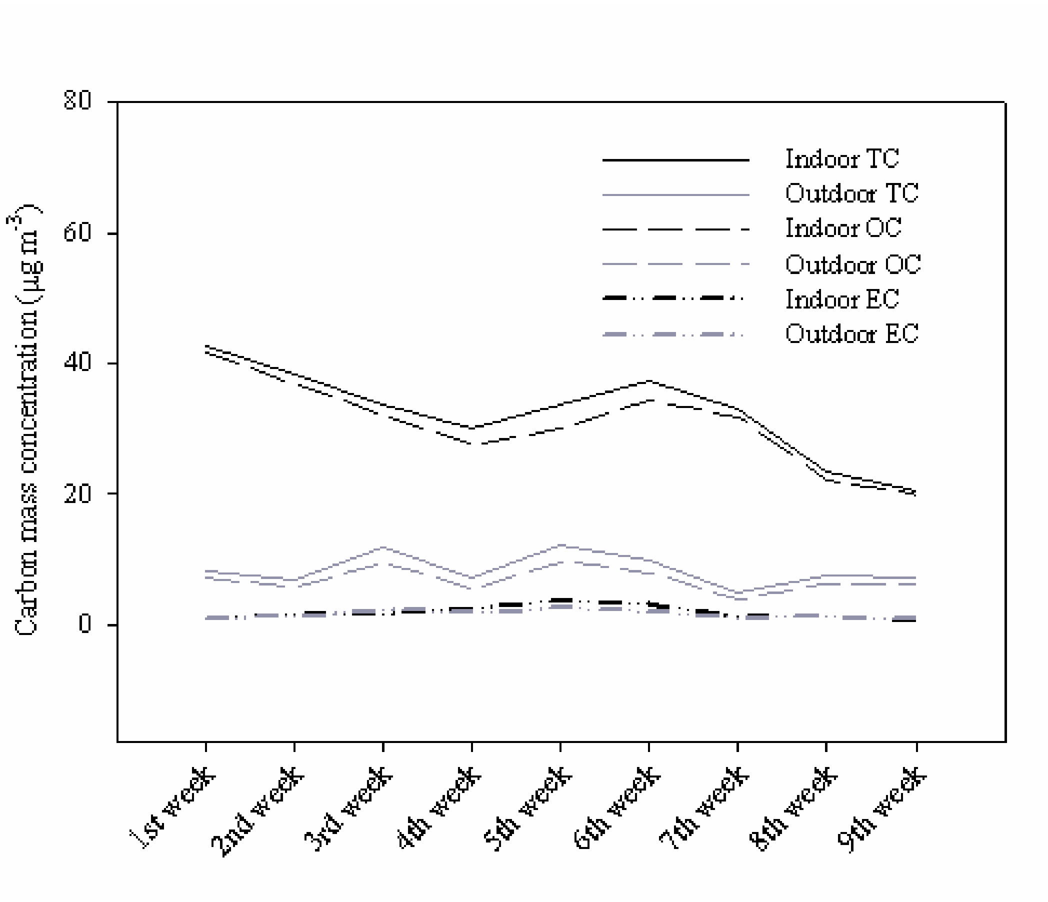
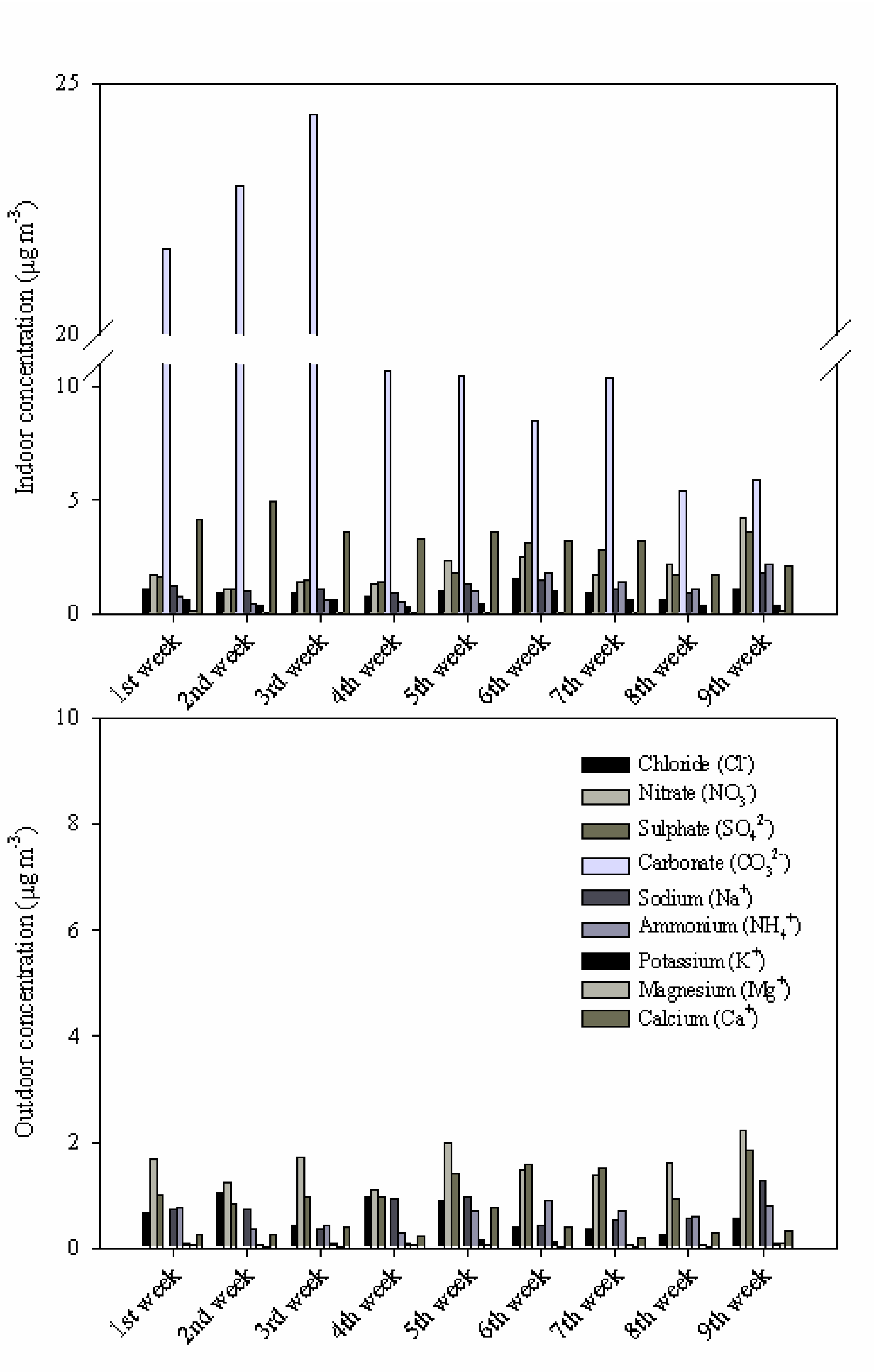

160
140
120
100
80
60
40
20
0
Average PM10 concentration (µg m-3)
Indoor class period
Outdoor class period
1st week
2nd week
3rd week
4th week
5th week
6th week
7th week
8th week
9th week

Figure 4



Carbon mass concentration (μg m-3)
80
60
40
20
0
Indoor TC
Outdoor TC
Indoor OC
Outdoor OC
Indoor EC
Outdoor EC
1st week
2nd week
3rd week
4th week
5th week
6th week
7th week
8th week
9th week

Figure 5



25
20
10
5
0
Indoor concentration (µg m-3)
1st week
2nd week
3rd week
4th week
5th week
6th week
7th week
8th week
9th week
10
8
6
4
2
0
Outdoor concentration (µg m-3)
Chloride (Cl-)
Nitrate (NO3-)
Sulphate (SO42-)
Carbonate (CO32-)
Sodium (Na+)
Ammonium (NH4+)
Potassium (K+)
Magnesium (Mg+)
Calcium (Ca+)
1st week
2nd week
3rd week
4th week
5th week
6th week
7th week
8th week
9th week

Figure 6