Indoor and outdoor air quality in street corner kiosks in a large metropolitan area

Nezis, Ioannis; Biskos, George; Eleftheriadis, Konstantinos; Fetfatzis, Prodromos; Popovicheva, Olga; Kalantzi, Olga Ioanna

DOI
10.1016/j.heliyon.2024.e31340

Publication date
2024

Document Version
Final published version

Published in
Heliyon

Heliyon 10 (2024) e31340

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Indoor and outdoor air quality in street corner kiosks in a large metropolitan area

Ioannis Nezis [a,**], George Biskos [b,c], Konstantinos Eleftheriadis [d], Prodromos Fetfatzis [d,f], Olga Popovicheva [e], Olga-Ioanna Kalantzi [a,*]

[a] Department of Environment, University of the Aegean, Mytilene, 81100, Greece
[b] Climate and Atmosphere Research Center, The Cyprus Institute, Nicosia, 2121, Cyprus
[c] Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, 2628-CN, the Netherlands
[d] Environmental Radioactivity Laboratory, N.C.S.R. "Demokritos", 15310, Ag. Paraskevi, Greece
[e] Institute of Nuclear Physics, Moscow State University, 119991, Moscow, Russia
[f] Department of Industrial Design and Production Engineering, University of West Attica, 12243, Egaleo- Athens, Greece

ARTICLE INFO

Keywords:
Air quality measurements
Black carbon kiosks
Particulate matter
Occupational exposure
Ultrafine particles

ABSTRACT

Poor air quality in workplaces constitutes a great concern on human health as a good fraction of our time is spent at work. In Greece, very unique workplaces are the street corner kiosks, which are freestanding boxes placed on sidewalks next to city streets and vehicular traffic, where one can find many consumer goods. As such, its employees are exposed to both outdoor and indoor air pollutants. Very few studies have examined the occupational exposure of kiosk workers to air pollutants, and thus the magnitude of this unique indoor and outdoor exposure remains unknown. The objective of this study is to investigate and compare the levels of indoor and outdoor particulate matter (PM_{10} and $PM_{2.5}$), ultrafine particles (UFPs) and black carbon (BC) in different kiosks located in Athens, Greece, in urban-traffic and urban-background environments. Continuous measurements of the above-mentioned pollutants were carried out on a 24-h basis over 7 consecutive days at three kiosks from September to October 2019. Indoor PM_{10} concentrations in the urban kiosk ranged from 19.0 to 44.0 μg/m^3, $PM_{2.5}$ values ranged from 14.0 to 33.0 μg/m^3, whereas BC concentrations ranged from 1.2 to 7.0 μg/m^3 and UFPs from almost 9.5 to 47.0 × 10^3 pt/cm^3. Outdoor PM_{10} and $PM_{2.5}$ measurements ranged from 29.0 to 59.0 μg/m^3 and from 22.0 to 39.0 μg/m^3, respectively. BC outdoor concentrations ranged from 1.1 to 2.2 μg/m^3. The mean hazard quotient (HQ) for PM_{10} (4.9) and $PM_{2.5}$ (4.7) among all participants was >1. The health risk of exposure to PM_{10} and $PM_{2.5}$ was found to be at moderate hazard levels, although in some cases we observed HQ values higher than 10 due to high PM_{10} and $PM_{2.5}$ concentrations in the kiosks. Overall our study indicates that people working at kiosks can be exposed to very high concentrations on particulate pollution depending on a number of factors including the traffic that strongly depends on location and the time of the day.

* Corresponding author.
** Corresponding author.
E-mail addresses: ioannisnezis@hotmail.com (I. Nezis), kalantzi@aegean.gr (O.-I. Kalantzi).

https://doi.org/10.1016/j.heliyon.2024.e31340
Received 2 October 2023; Received in revised form 4 May 2024; Accepted 14 May 2024
Available online 16 May 2024

1. Introduction

Air pollution is one of the main risk factors for human health, especially for populations living in urban areas, and an important occupational hazard for outdoor workers [1,2]. Air pollution is both a risk factor for mortality and a cause of indoor and outdoor contamination with chemical and biological agents [3,4]). The most abundant air pollutants are produced by fossil fuel combustion, and industrial activities [5,6,7], with the combustion of diesel being one of the main sources of airborne particulate matter [3,8]. Human exposure to $PM_{2.5}$ (i.e., particulate matter with a diameter smaller than 2.5 μm) concentrations, has been associated with increased mortality and morbidity, due to the fact that smaller particles can penetrate and deposit deeper in our respiratory system where they can cause more harm compared to their larger counterparts [9,10,11,12,13,14]. Several studies have associated adverse health effects related to the lung function (e.g., in the bronchioles and the alveoli), with particulate matter exposure [11,15]. Moreover, significant health risks such as inflammation and related cardiovascular diseases, oxidative stress, dry eyes and nasal symptoms, have been related to exposure to particulate matter [16,17,18,19,20,21,2].

A number of studies published over the last couple of decades have investigated the relationship between indoor and outdoor concentrations of different air pollutants present in various environments [22,23,1,24,25,26,27,28,29]. Many studies have also shown how the inhalable particles can affect the respiratory tract [30,31]. Other studies have also shown that black carbon (BC) can alter isoprostane levels in children [32,33,34]. The majority of these studies focus on individuals who work in vehicular traffic and are heavily exposed to air pollutants, such as traffic police officers [8,28,35–46], street vendors [47,48,42,49,50,51,52], outdoor workers [53,54,55,56,57], and outdoor guards [58]. Several studies also shown that outdoor workers like street vendors, traffic police officers, and newspaper agents commonly report coughing [59,40], and respiratory symptoms [60,61]. A few studies have investigated short-term exposure (over a single day) of kiosk workers [62,59,44]. In contrast to other workers who spend most of their time outdoors or indoors, kiosk employees are equally exposed to both indoor and outdoor air pollutants, which makes them a unique and particularly vulnerable population group.

Kiosks are small free-standing booths that sell a number of products including magazines and newspapers. They are an integral part of the fabric of Greek society since their first appearance in the third decade of the 19th century, shortly after the establishment of the Greek state. Kiosks are placed on sidewalks in the main streets of the cities, often next to bus stops (very close to vehicular traffic), as well as in town

Squares and parks. In urban city centers the majority of kiosks operate 24 h per day, 7 days a week. According to the Hellenic Statistical Authority, there are currently 5700 kiosks operating throughout Greece, employing approximately more than 11.000 employees.

This study aims to investigate and compare the levels of indoor and outdoor particulate matter (PM_{10} and $PM_{2.5}$), UFPs and BC in

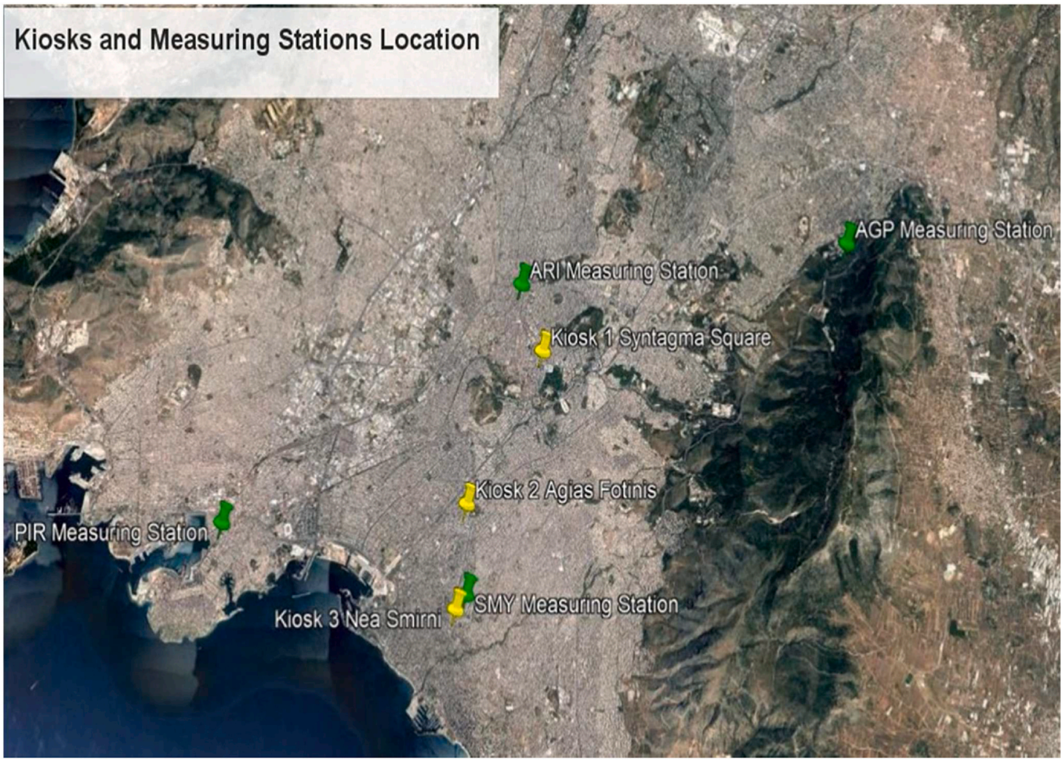

Fig. 1. Kiosk and Measuring Stations location.

three different kiosks located in Athens, Greece, and to estimate the health risk from exposure to these pollutants. We used portable instruments and low-cost air quality monitoring system to measure PM_{10}, $PM_{2.5}$, UFPs and BC concentrations, for 7 consecutive days for each kiosk, on a 24-h basis, from September to October 2019. We also estimated the human health risk arising from exposure to indoor air pollutants according to the age of the kiosk workers.

2. Materials and methods

2.1. Sampling location

The kiosks selected for this survey are located in the center of Athens, which is the largest city in Greece, with a population of 3.8 million inhabitants according to the last census report (Hellenic Statistical Authority, 2011). The city is surrounded by four large mountains, including Mountain Aigaleo (462 m asl) to the west, Mountain Parnitha (1413 m asl) to the north, Mountain Penteli (1109 m asl) to the northeast, Mountain Hymettus (1026 m asl) to the east, and by open sea (the Saronic Gulf) in the south-west. The climate conditions in Athens are unique because the mountainous landscape creates conditions that often trap air pollutants emitted by all human activities in the city, oftentimes resulting to extremely high concentrations of PM [46]. The city center is situated in a valley, where the load of $PM_{2.5}$ is generally well mixed across Athens Metropolitan area [63], exhibiting a gradual improvement in concentration levels over the years [64]. Systematic air pollution measurements are carried in Athens since 2001, under the supervision of Ministry of Environment and Energy, with the contribution of 14 air pollution-measuring stations, which are installed in different areas in Attica.

We selected three kiosks located in different areas in the center of Athens as shown in Fig. 1. The selected kiosks were in a main boulevard close to one of the fourteen air quality monitoring stations. The first kiosk (kiosk 1) is located in the center of Athens at Syntagma square that is one of the most central points of Athens and can thus be characterized as an urban-traffic environment as it where thousands of cars and public means of transportation pass daily. Kiosk 1 is located 1.2 km away from the nearest urban-traffic air quality monitoring station of Aristotelous (ARI). The second kiosk (kiosk 2) is located 4.5 km south-west of the city center of Athens at the suburb of Nea-Smyrni and can be characterized as an urban background area. Kiosk 2 is also 1.2 km from the Nea-Smyrni urban-background air quality monitoring air quality monitoring station (SMY). It should be noted that kiosk 2 is located next to a bus stop on one of the most central streets of the city. The third kiosk (kiosk 3, urban-background) is located at the Southern suburb of Palaio Faliro, 7 km away from the center of Athens along a main avenue. This kiosk is next to the Nea-Smyrni (SMY) urban-background air quality monitoring station.

The outdoor concentrations of $PM_{2.5}$ and PM_{10} used in our study were collected from the air quality monitoring network operated by governmental authorities in Athens. It should be noted that only PM_{10} data were provide by the SMY station, and in order to compare the indoor and outdoor $PM_{2.5}$ concentrations for kiosks 2 and 3, we used data from the closest air quality monitoring stations (Aristotelous and Piraeus). Piraeus (PIR) is an urban-traffic station at the port of Piraeus (Saronic Gulf), the largest port of Greece. Data for outdoor BC concentrations was provided by the NCSR Demokritos ACTRIS/GAW Aerosol Research station located at Agia Paraskevi (AGP) Urban background station typical of suburban air quality Table 1 shows all the details of the measuring stations and the measured pollutants.

2.2. Measurements and data analysis

Taking advantage of new developments in low-cost and portable sensors for monitoring air quality in the urban environment [65], sampling was carried out for 7 consecutive days for each kiosk, on a 24-h basis, from September to October 2019. PM_{10} and $PM_{2.5}$ concentrations were measured with the AirSensis monitor, which is a low-cost air quality monitoring system 30]. Calibration of the AirSensis monitor was carried out using reference instruments and indoor/outdoor samples from a lab environment. More specifically, for the calibration, daily average measurements for PM_{10} and $PM_{2.5}$ collected by the AirSensis monitor were compared to gravimetric 24-h parallel measurements to an indoor workplace environment. Moreover, comparison of Airsensis measurements was made against an Optical Particle Counter (OPC; namely a Grimm OPC Model 107) at Demokritos station [66].

BC concentrations were measured continuously using an custom-made aethalometer developed by the Moscow State University (MSU) and the Central Aerological Observatory (CAO). This aethalometer records light attenuation at three wavelengths (450, 550, and 650 nm) using a detector behind a quartz fiber filter, where the collection of aerosol particles takes place. Their light-attenuation coefficient is then calculated according to previously published literature [67]. To determine the BC concentrations, the calibration parameter was derived from long-term measurements against an AE33 Aethalometer [68] using the paired output of the same wavelength. The instrument filters were manually changed every 24 h. Data corresponding to cumulative attenuation above 100, were

Table 1
Measuring station characteristics.

Athens	Characterization	Altitude (m-asl)	Measured pollutants	
Aristotelous (ARI)	Urban-Traffic	75	PM_{10}	$PM_{2.5}$
Nea Smirni (SMY)	Urban-Background	50	PM_{10}	–
Piraeus (PIR)	Urban-Traffic	4	PM_{10}	$PM_{2.5}$
Agia Paraskevi (AGP)	Suburban-Background	290	BC	

discarded.

UFPs concentrations (sizes ranging from 10 to 300 nm) were recorded with a miniDISC (SN 10166) personal aerosol monitor [69, 70]. Apart from the concentration of UFP, the miniDISC can report the average size and lung-deposited surface area of the samples particles, making it ideal for personal exposure monitoring in different environments. Its detection limit is ideally suited for typical

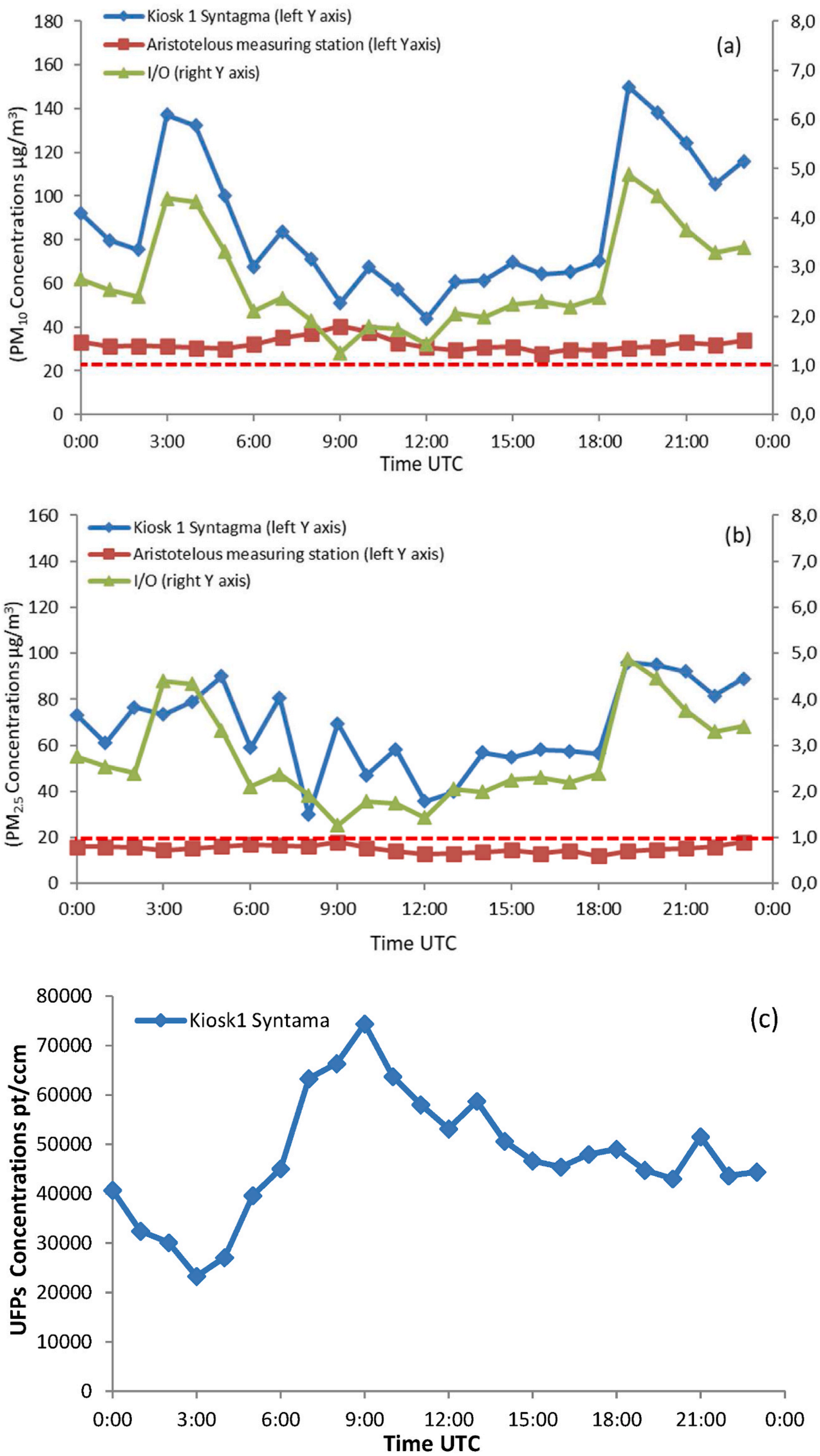

Fig. 2. Hourly average indoor and outdoor concentrations at kiosk 1 (Syntagma) during the sampling period **(a)** PM_{10} concentrations **(b)** $PM_{2.5}$ concentrations **(c)** UFP concentrations.

ambient particle concentrations [69]. The miniDiSC has a lower counting and sizing resolution than traditional aerosol instruments such as the condensation particle counter (CPC; Agarwal & Sem 1980), the scanning mobility particle sizer [58], or the Differential Mobility Spectrometer ([71], but this is compensated by its compact size and ease of handling. In general, measured concentrations and average diameters agree to within 30 % with CPC and SMPS measurements. The data retrieved from the on-line instruments were postprocessed in order to remove outlier values. A value is considered as an outlier if it exceeds its previous value in the time-series by more than 3 times the standard deviation of the last 10 values. If this criterion was met, then the value was removed from the dataset. With this approach, extremely high concentrations attributed to local contamination (e.g., sources momentarily emitting particles close to the instrument, cigarette smoking by passersby etc.) were removed. The outliers were less than 5 % of the total number of values for every kiosk campaign.

2.3. Health risk assessment

To assess the health risk from exposure to indoor PM_{10} and $PM_{2.5}$ in the kiosks we used the hazard quotient (HQ) defined as:

$$HR = \frac{CDI}{RfC} \tag{1}$$

where CDI is the chronic daily intake and RfC the reference concentrations sought from related studies [72,73,74]. The CDI was determined as:

$$CDI = \frac{C \times IR \times ET \times EF \times ED}{BW \times AT} \tag{2}$$

where C is the concentration of PM and IR is the average adult inhalation rate of 0.66 m^3/h (16 m^3/day) [20]. ET, EF, ED, BW, AT, are the exposure time (hours/day), exposure frequency (days/year), exposure duration (years), body weight (kilograms), and average affecting time (365 days), respectively. To evaluate the control level, an HQ < 0.1 represents the non-hazard level, 0.1 to 1.0 represents a low risk level, 1.1 to 10 a moderate hazard level, and HQ > 10 represents a high risk level [75].

3. Results and discussion

3.1. Kiosk 1 (urban-traffic)

As expected, kiosk 1 had the highest indoor and outdoor PM_{10} and $PM_{2.5}$ concentrations. The highest PM_{10} and $PM_{2.5}$ indoor concentrations were recorded from late afternoon until early morning and ranged from 100 to 150 μg/m^3 and 81–96 μg/m^3, respectively (Fig. 2a). During working hours, the outdoor concentrations were at their highest, 41 μg/m^3 for PM_{10} and 18 μg/m^3 for $PM_{2.5}$ (at 9:00 a.m.). The average indoor PM_{10} and $PM_{2.5}$ concentrations, ranged from 44 to 70 μg/m^3, and 36–70 μg/m^3, respectively. These significant differences between indoor and outdoor concentrations, especially in the evening can be attributed to occasional smoking by the employee, as recorded in the diary of activities. The IK/BKG ratio (Indoors Kiosk/Background*) ratio for PM_{10} and $PM_{2.5}$ concentrations, were higher than unity throughout the entire sampling period, which can be attributed to occasional smoking by the employee, who worked the night shift (Fig. 2a and b). UFP concentrations ranged from 23.0 to 74.0 $\times$ 10^3 pt/cm^3, with the maximum concentrations recorded during working hours. The highest daily average concentrations were recorded in the middle of the week, due to the high traffic in the area (Fig. 2c). More specifically, on 18 September and September 25, 2019 the daily indoor PM_{10} concentrations were 120.3 μg/m^3 and 125.7 μg/m^3, while the outdoor concentrations were 46.9 and 30.8120.3 μg/m^3, respectively. The daily IK/BKG ratio for PM_{10} rates, were 2.6 on September 18th and 4.1 on September 25th.

Regarding the $PM_{2.5}$ daily concentrations, the maximum values were recorded on Wednesday the 25th of September. The average $PM_{2.5}$ indoor values, were 108.3 μg/m^3 and the corresponding outdoor was 15.1 μg/m^3. The IK/BKG ratio was 7.2. Finally, UFP concentrations reached their highest values on September 19, 2019 (60 $\times$ 10^3 pt/cm^3). The daily indoor and outdoor rates for PM_{10}, $PM_{2.5}$ and UFPs concentrations, are shown in Fig. 6a,b,c. At this kiosk, due to the malfunction of the aethalometer, we do not have BC concentration data.

3.2. Kiosk 2 (urban-background)

Kiosk 2 had the second highest indoor concentrations of PM_{10} and $PM_{2.5}$. The sampling period started at October 13, 2019 and lasted 8 days. The highest average indoor concentrations ranged from 19 to 44 μg/m^3 for PM_{10} and 14–33 μg/m^3 for $PM_{2.5}$, with the maximum indoor concentrations measured during working hours. Comparing the hourly average outdoor and indoor concentrations for PM_{10} and $PM_{2.5,}$ we observed that the outdoor concentrations were greater than indoors throughout the entire sampling period. During working hours, the hourly outdoor concentrations were slightly higher than indoors. The IK/BKG ratio for PM_{10} and $PM_{2.5}$ concentrations, was <1 throughout the survey, with some exceptions late in the afternoon, due to activities like shopping and rush hour car traffic, that took place during that time in the area around the kiosk. The maximum daily indoor PM_{10} concentrations, were recorded on Friday October 18, 2019. The average daily rate was 75.5 μg/m^3 (Fig. 7a). The average $PM_{2.5}$ indoor concentrations reached their higher values (59.9 μg/m^3) on the same day (Fig. 7b). The corresponding average outdoor PM_{10} and $PM_{2.5}$ concentrations, were 48.9 and 37.9 μg/m^3 respectively.

BC concentrations ranged from 1.2 to 7 μg/m^3 with the maximum concentrations recorded during working hours. More specifically, from 8:00 to 16:00 the average hourly indoor concentrations ranged between 1.3 and 7 μg/m^3. During the working hours, indoor concentrations were higher than outdoors, however, late in the afternoon, after the working shift, the outdoor values were higher due to higher traffic next to the air quality monitoring station. The average IK/BKG ratio for BC was >1 during working hours (Fig. 7c). The IK/BKG* ratio for PM and BC concentrations was <1, possibly due to the transport of pollutant from the outdoor environment. In fact, during working hours (particularly between 8:00 and 11:00), the IK/BKG ratio for both PM and BC reached its highest values, which according to the daily diary that was kept during the study by the employee, that was the time of the day where a lot of people visit the kiosk to buy some essentials. At this point we should mention that the employees were non-smokers. The UFPs concentrations ranged from 9407 to 46 × 10^3 pt/cm^3. The maximum concentrations were recorded between 8:00 and 9:00 a.m. (28,438 and 46 × 10^3 pt/cm^3 respectively). The average hourly concentrations for all the pollutants at kiosk 2, throughout the duration of the measurements, are shown in Fig. 3a,b,c,d. Finally, Fig. 7d shows the average daily UFPs concentrations with the maximum concentrations to be recorded on Monday October 14, 2019 (26 × 10^3 pt/cm^3).

3.3. Kiosk 3 (urban-background)

PM_{10}, $PM_{2.5}$, BC and UFP measurements in Kiosk 3 lasted for 8 days from October 25, 2019 to November 1, 2019. The PM_{10} indoor values ranged between 6.0 and 33.0 μg/m^3 with the maximum concentrations recorded during the working hours. Similarly, $PM_{2.5}$ indoor concentrations ranged from 4.0 to 24.0 μg/m^3, with the maximum concentration recorded at 20:00 (24 μg/m^3). For both pollutants (PM_{10} and $PM_{2.5}$) the IK/BKG ratio was mostly <1, with a few exceptions in the afternoon hours. BC concentrations ranged from 2.0 to 6.0 μg/m^3, with the highest ones being recorded during working hours (6.0 μg/m^3 at 8:00 a.m.). The IK/BKG ratio for BC concentrations, remained higher than unity throughout the entire measurements period. The IK/BKG correlation for both PM and BC concentrations were >1 during all measurements, possibly due to the transport of pollutants from the outdoor environment and the fact that the window was always open according the workers. Finally, the UFP concentrations ranged from 10.0 to 24.0 × 10^3 pt/cm^3 with the highest concentrations recorded early in the morning (8:00 a.m.). The average hourly concentrations for all the pollutants at kiosk 3 are shown in Fig. 4a,b,c,d. For PM_{10} and $PM_{2.5}$ the highest daily indoor concentrations were measured mid-week. More specifically, on the 29th of October, the average daily PM_{10} and $PM_{2.5}$ rate was 31.2 μg/m^3 and 22.5 μg/m^3, and on the 30th of October

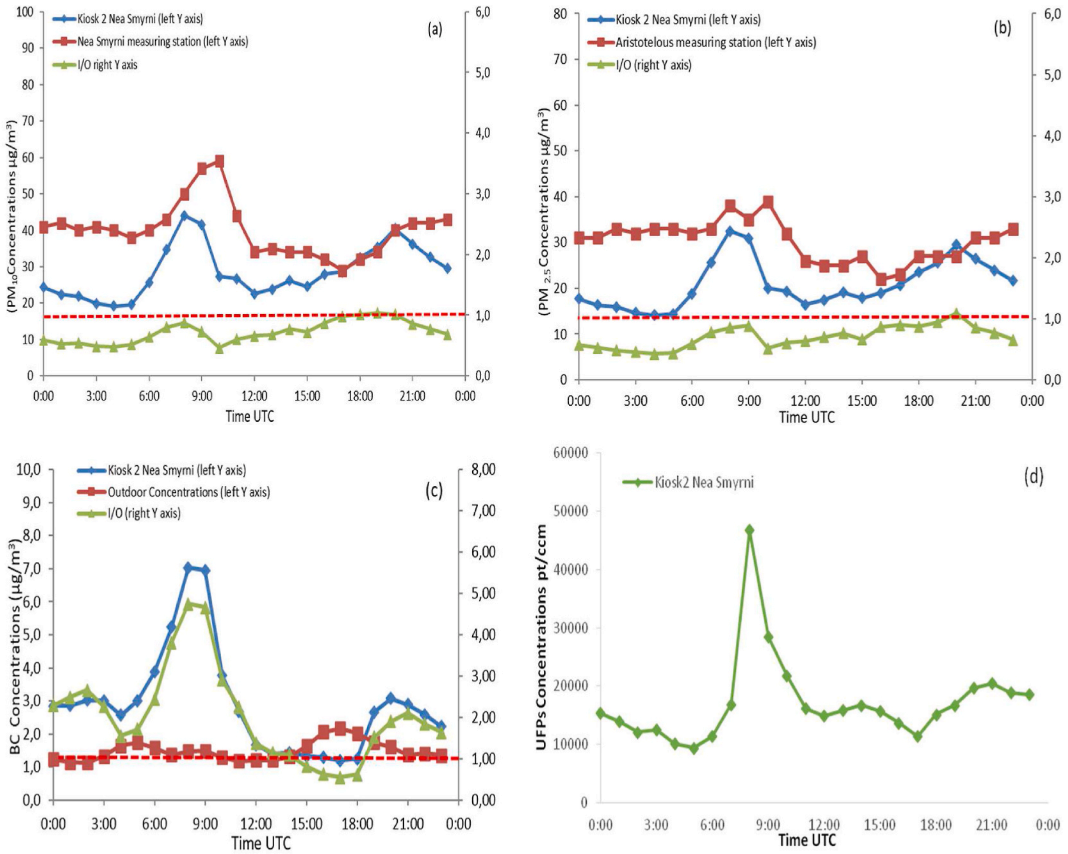

Fig. 3. Hourly average indoor and outdoor concentrations at kiosk 2 (Nea Smyrni) during the sampling period: **(a)** PM_{10} concentrations **(b)** $PM_{2.5}$ concentrations **(c)** BC concentrations **(d)** UFP concentrations.

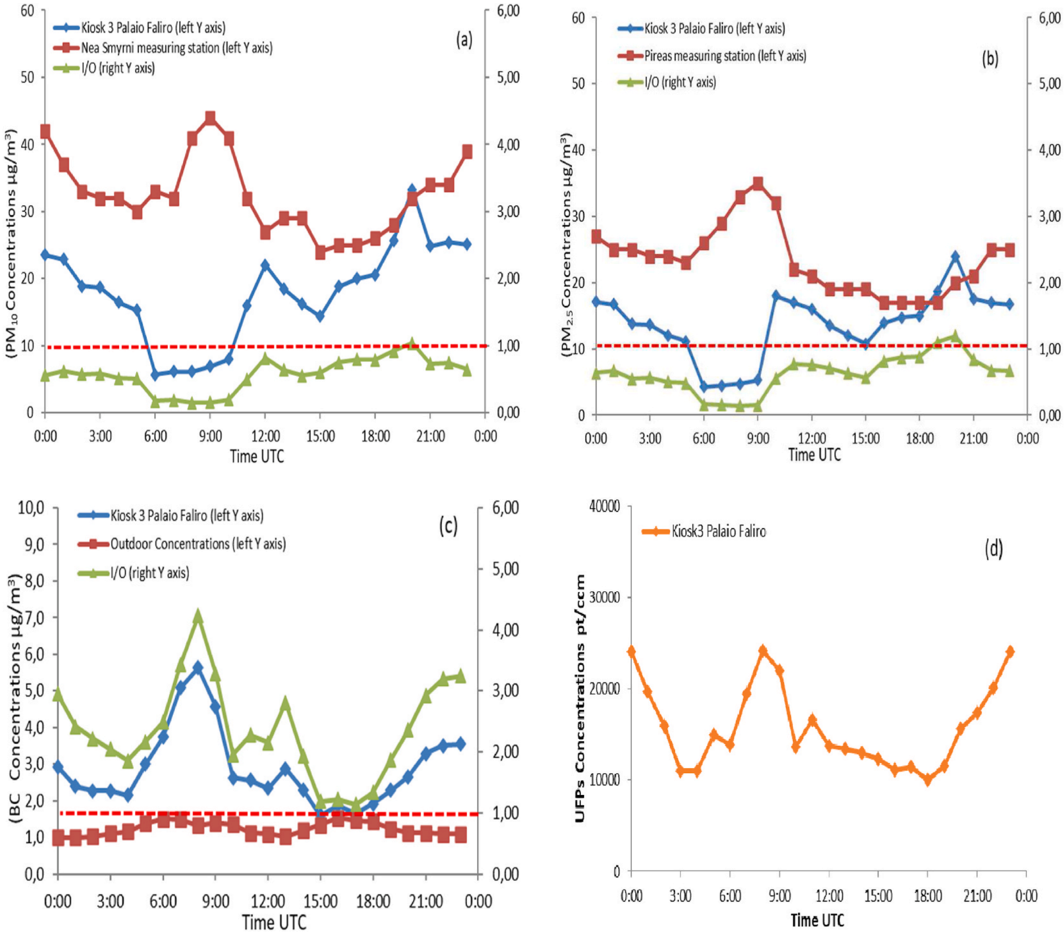

Fig. 4. Hourly average indoor and outdoor concentrations at kiosk 3 (Palaio Faliro) during the sampling period **(a)** PM_{10} concentrations **(b)** $PM_{2.5}$ concentrations **(c)** BC concentrations **(d)** UFP concentrations.

34.8 μg/m^3 and 25.2 μg/m^3. During the entire sampling period, outdoor PM_{10} and $PM_{2.5}$ concentrations were higher than indoor concentrations. Regarding the BC daily average concentrations, we observed that the highest values were also recorded mid-week (up to 4.9 μg/m^3). As with particulate matter, these values were higher than the corresponding outdoor ones. This fact could be explained from the number of people who visit the kiosk and the employees' smoking behavior. Finally, the highest UFPs levels were recorded on the 30 of October 42.9 pt/cm^3 at 8.00 a.m. The daily concentrations for all the pollutants at this kiosk are presented in Fig. 8a,b,c,d.

Compared with other measuring stations in Athens, we can observe that PM_{10} concentrations in Eleusina suburban-industrial air quality monitoring station were higher than the two suburban-background air quality monitoring stations of Agia Paraskevi and Lykovrisi (ELE: 22–43 μg/m^3; AGP:16–21 μg/m^3; LYK: 18–34 μg/m^3). Similarly, the corresponding $PM_{2.5}$ concentrations at Eleusina station ranged from 18 to 23 μg/m^3. At Agia Paraskevi and Lykovrisi station the $PM_{2.5}$ concentrations were noticeably lower (AGP:13–16 μg/m^3; LYK: 11–17 μg/m^3). Fig. 5a,b shows the PM_{10} and $PM_{2.5}$ concentrations of local measuring stations. This difference in pollutant concentrations is a result of different meteorological conditions in the wider area of Athens caused by te mountainous landscape that traps air pollutants emitted by vehicular traffic, which in turn affect air pollution levels in each area. Moreover, kiosks are characterized by their small size and as such, atmospheric pollution can lead to increased indoor air pollutant concentrations due to poor pollutant dispersion. Kiosks, are generally situated close to high traffic avenues (on the ground level), thus the contribution of vehicle emissions is expected to be significant. The results also showed that there is a number of factors that contribute to the level of respirable particles, such as the kiosk's location, the background area, the existence of strong anthropogenic activities such as smoking, as well as vehicular emissions, that affect kiosk employees' health.

4. Human health risk assesment

The working behavior of the 6 employees who worked in the three kiosks were collected to determine their risk of exposure. The workers' age ranged from 48 to 57 years for the males and 22 to 30 for the females. The average working hours and years was 12 h per day and 11.8 years of work, respectively. The average working days and body weight were calculated to be 312 days and 72 kg,

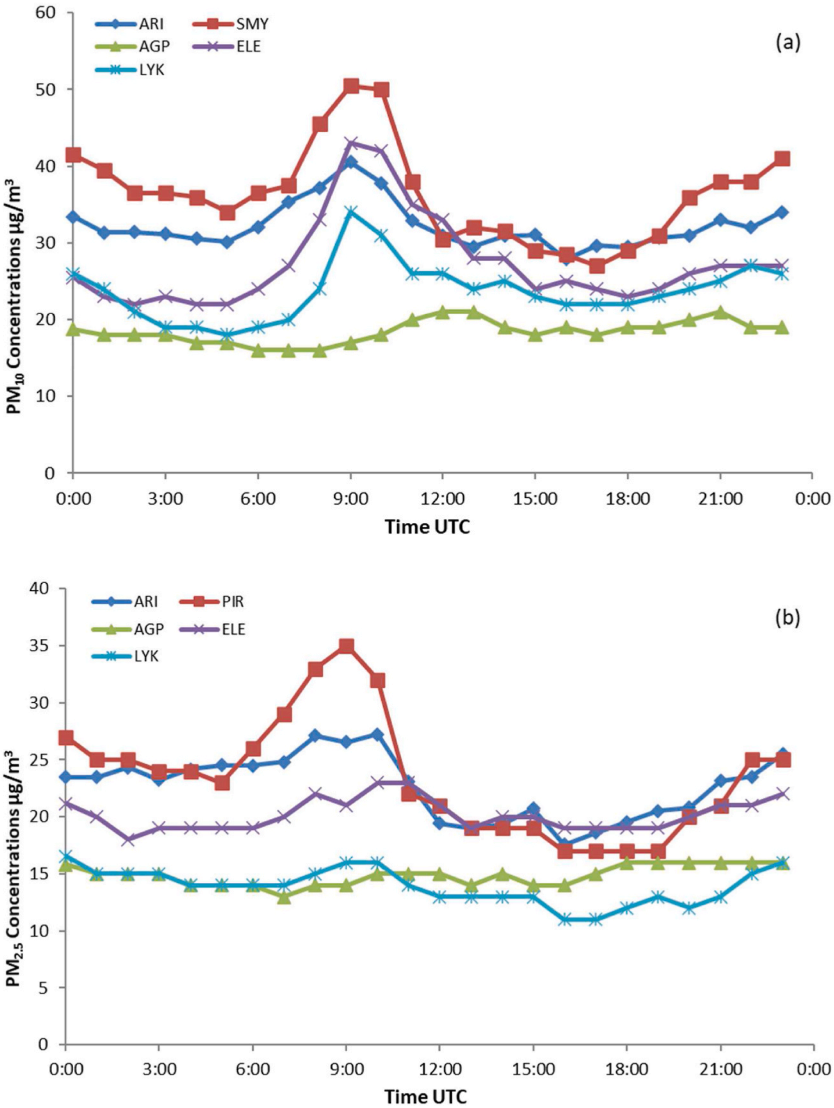

Fig. 5. Hourly average concentrations of local measuring stations: **(a)** PM_{10} concentrations **(b)** $PM_{2.5}$ concentrations.

respectively. For the health risk assessment we used the RfC for PM_{10} and $PM_{2.5}$ (0.011 and 0.005 mg/kg/capita, respectively) [73]. The CDI for PM_{10} and $PM_{2.5,}$ was 0.068 ± 0.039 and 0.048 ± 0.029 mg/kg/day, respectively. The PM_{10} (4.9 μg/m^3) and $PM_{2.5}$ (4.7 μg/m^3) mean hazard quotient (HQ) among all participants was >1, indicating a significant risk factor for human health. These values are in the medium hazard level between 1.1 and 10, although in some cases we observed HQ values higher than 10 due to high PM_{10} and $PM_{2.5}$ concentrations levels in the kiosks. However, PM_{10} and $PM_{2.5}$ concentrations for the under-study kiosks do not exceed air quality standards, but the health impacts from exposure to air pollution are still an important issue. Chalvatzaki et al. [72], estimate that health risk effects are caused by the inhalation of particulate matter (PM) and particle-mound metals to adult males in three European cities (Athens, Kuopio, Lisbon). In this study we did not measure other compounds (such as metals) that may be present in PM_{10} and $PM_{2.5}$, however they may be harmful to kiosk employees' health and increase their health risk.

5. Conclusions

We examined the indoor and outdoor concentrations of $PM_{2.5,}$ PM_{10}, BC and UFPs in three kiosks with different characteristics (with respect to traffic and human presence) at three locations in Athens, Greece. As expected, the most centrally located kiosk in downtown Athens (#1) with the highest trafic, had significantly higher PM_{10} and $PM_{2.5}$ hourly average indoor than outdoor concentrations throughout the entire study period. The concentrations in that kiosk were also the highest among of all three kiosks, and higher than the recommended indoor 24-h mean PM standard. PM_{10} and $PM_{2.5}$ outdoor concentrations in the other two kiosks were higher than those indoors, with some exceptions late in the afternoons. The outdoor concentrations were always well below the

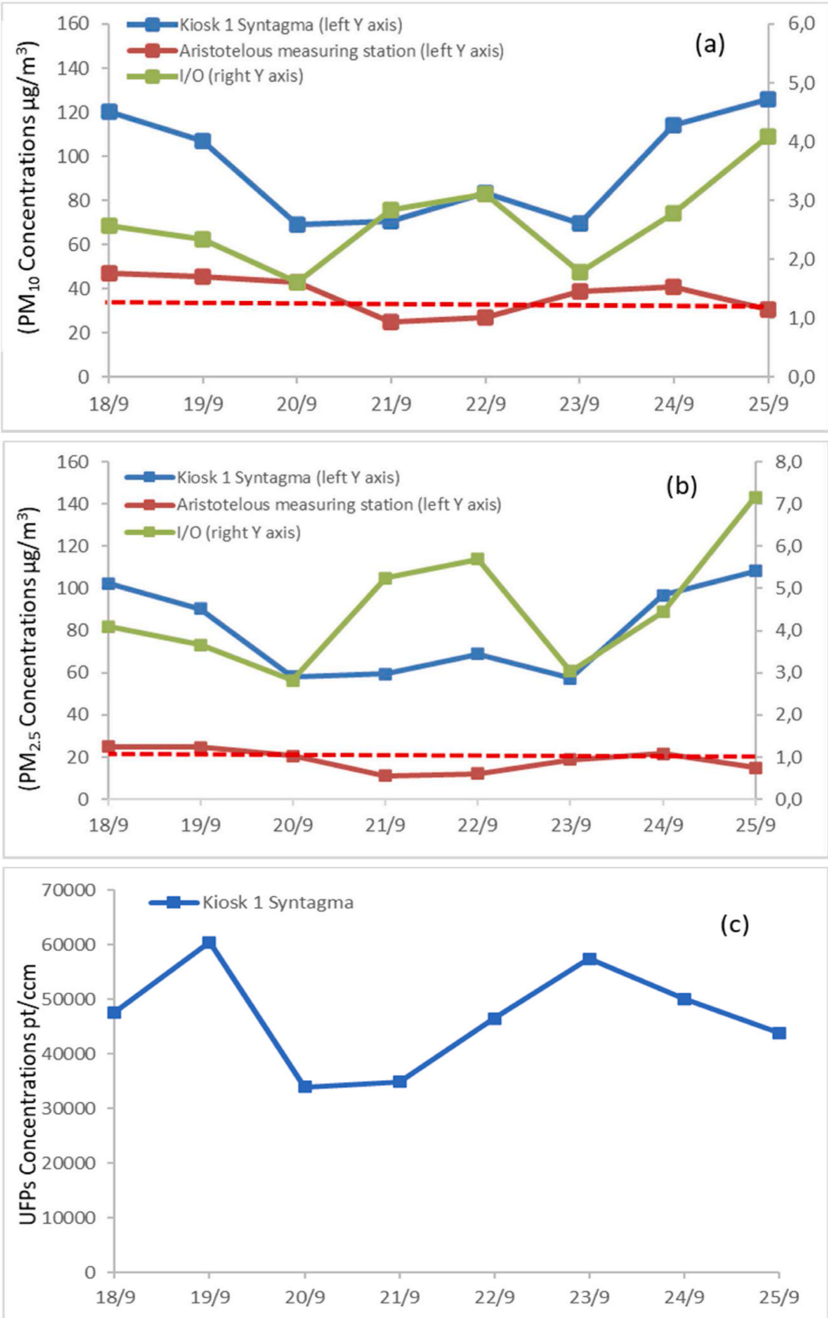

Fig. 6. Daily average concentrations recorded indoors in the Kiosk 1 (Syntagma) and outdoors during the sampling period **(a)** PM_{10} concentrations **(b)** $PM_{2.5}$ concentrations **(c)** UFPs concentrations.

recommended indoor 24-h mean PM standard [76]. The average measured indoor BC concentrations during working hours in kiosk 3 were comparable to typical European urban background levels [63,26]. Compared to previously published studies, occupational exposure to BC in Greece is lower than in other countries. A similar study in Nairobi, Kenya [49] showed that after 11 h of personal exposure the average mean BC concentrations to bus drivers were 63.9 μg/m^3, and to street vendors were 30 μg/m^3. In our study BC outdoor concentrations were similar with the BC concentrations in highways in New York [12].

According to Brigs and Long [77], many European studies showed that during the winter burning biomass is responsible for the high BC concentrations, especially in villages and rural areas. The majority of these studies show that fossil fuel composition is a result of wood burning for heating. Moreover, in urban European areas diesel sources are responsible for the high levels of BC concentrations especially for those areas closer to highways and high traffic areas. Similarly, US studies showed that in urban sites the main source of

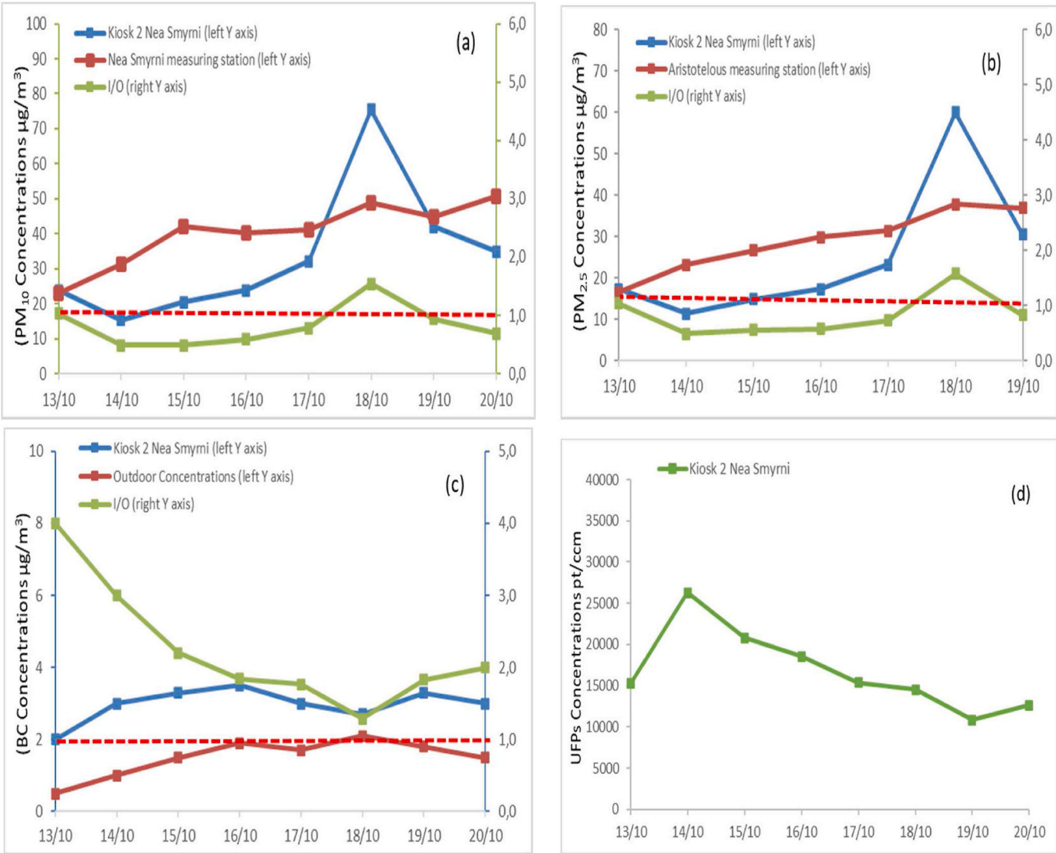

Fig. 7. Daily average concentrations recorded indoors in the Kiosk 2 (Nea Smyrni) and outdoors during the sampling period **(a)** PM10 concentrations **(b)** $PM_{2.5}$ concentrations **(c)** BC concentrations **(d)** UFPs concentrations.

BC concentrations are diesel and gasoline emissions, particularly in heavily trafficked surface streets.

Regarding the daily average indoor concentrations, we observed that the maximum values were recorded on days in the middle of the week for all the pollutants in all three kiosks. This could be explained by the fact that kiosks get supplies during the week, and as a result, keep their windows and doors open longer than during the weekend. Notably, the HQ values for PM_{10} and $PM_{2.5}$ were at moderate health hazard level, indicating a significant risk from inhalation exposure to these indoor air pollutants. Moreover, indoor concentrations of PM_{10} p.m.$_{2.5}$ BC and UFPs showed a strong variation among the different kiosks, as several contributing factors such as their location, employee habits and the number of customers who visit the kiosks, appear to play a key factor. In cases of relatively low indoor concentrations and absence of strong indoor sources (such as smoking), we observed that the outdoor environment mainly contributes to the high particle levels, especially when air renewal (i.e., by having an open window) is frequent. Despite that the PM_{10} and $PM_{2.5}$ concentrations were high.

Our pilot study is the first to investigate exposure of kiosk workers to major air pollutants PM_{10}, $PM_{2.5}$, UFPs and BC over a period of one week. However, there are some limitations to our work, the most notable one being the small number of locations and the sampling during one season. Future studies should include measurements at more kiosks in different areas of the city with a longer duration and repeatability. It would also be useful to carry out these measurements during different time periods (e.g., summer and winter), taking into account seasonal changes in pollutant concentration. It would also be useful to combine the estimations of inhalation intake for kiosk workers and their health effects, by using separate dose-response approaches for $PM_{2.5}$ and BC. In this way it will be possible to provide guidelines for improving indoor air quality in kiosks, and thus the working standards of employees who spend much of their time inside them.

Ethics approval

The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Fig. 8. Daily average concentrations recorded indoors in the Kiosk 3 (Palaio Faliro) and outdoors during the sampling period **(a)** PM_{10} concentrations **(b)** $PM_{2.5}$ concentrations **(c)** BC concentrations **(d)** UFPs concentrations.

Consent for publication

Informed consent was obtained from all individuals who participated in this study.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

Funding

O.P. thanks the RSF project №19-77-30004-П for support of custom-made aethalometer and BC methodology developing.

CRediT authorship contribution statement

Ioannis Nezis: Writing – original draft, Methodology, Investigation, Formal analysis. **George Biskos:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Konstantinos Eleftheriadis:** Writing – review & editing, Writing – original draft, Supervision, Resources, Methodology, Conceptualization. **Prodromos Fetfatzis:** Writing – original draft, Resources, Methodology. **Olga Popovicheva:** Resources, Methodology. **Olga-Ioanna Kalantzi:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Olga-Ioanna Kalantzi was an Associate Editor of Heliyon Environment until March 2024.

Acknowledgements

The custom-made aethalometer and BC methodology was developed under Russian Science Foundation (RSF) support, project number 19-77-3004- П.

References

[1] M.H. Dehghani, et al., The data on the dispersion modeling of traffic related PM_{10} and CO emissions using CALINE3; A case study in Tehran,Iran, Data Brief 19 (2018) 2284–2290, https://doi.org/10.1016/j.dib.2018.07.019.
[2] P. Wolkoff, K. Azuma, P. Carrer, Health, work performance, and risk of infection in office-like environments: the role of indoor temperature, air humidity, and ventilation, Int. J. Hyg Environ. Health 233 (2021) 113709, https://doi.org/10.1016/j.ijheh.2021.113709.
[3] S.S. Lim, et al., A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor cluster in 21 regions, 1999–2010: a systematic analysis for the Global Burden of Disease Study 2010, Lancet 380 (2012) 2224–2260, https://doi.org/10.1016/S0140-6736(12)61766-8.
[4] WHO, Health relevance of particulate matter from various sources, in: Report on a WHO Workshop; EU/07/5067587; World Health Organization Regional Office for Europe: Copenhagen, Denmark, 2007. https://apps.who.int/iris/handle/10665/107846.
[5] A. Koulova, W.H. Frishman, Air pollution exposure as a risk factor for cardiovascular disease morbidity and mortality, Cardiol. Rev. 22 (1) (2014) 30–36, https://doi.org/10.1097/CRD.0000000000000000. Jan-Feb.
[6] R. Nabizadeha, M. Yousefia, F. Azimia, Study of particle number size distributions at Azadi terminal in Tehran, comparing high-traffic and no traffic area, MethodsX 5 (2018) 1549–1555, https://doi.org/10.1016/j.mex.2018.11.013.
[7] M. Zheng, et al., Sources of primary and secondary organic aerosol and their diurnal variations, J Hazard Mater. pii: S0304-3894 (13) (2013), https://doi.org/10.1016/j.jhazmat.2013.10.047, 00796-6.
[8] S.S. Salvi, A. Frew, S. Holgate, Is diesel exhaust a cause for increasing allergies? Clin. Exp. Allergy 29 (1999) 4–8, https://doi.org/10.1046/j.1365-2222.1999.00465.x.
[9] M. Anderson, M. Svartengren, K. Philipson, P. Camner, Regional human lung deposition studied by repeated investigations, J. Aerosol Sci. 25 (1994) 567–581, https://doi.org/10.3109/01902148609061494.
[10] A. Churg, M. Brauer, Human lung parenchyma retains $PM_{2.5}$, Am. J. Respir. Crit. Care Med. 155 (1997) 2109–2111, https://doi.org/10.1164/ajrccm.155.6.9196123.
[11] D.W. Dockery, Pope III CAAcute respiratory effects of particulate air pollution, Annu. Rev. Publ. Health 15 (1994) 107–132, https://doi.org/10.1146/annurev.pu.15.050194.000543.
[12] F.J. Kelly, J.C. Fussell, Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter', Atmos. Environ. 60 (2012) 504–526, https://doi.org/10.1016/j.atmosenv.2012.06.039.
[13] I.I.I.C.A. Pope, M.J. Thun, M.M. Namboodiri, et al., Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults, Am. J. Respir. Crit. Care Med. 151 (1995) 669–674, https://doi.org/10.1164/ajrccm/151.3_Pt_1.669.
[14] I.I.I.C.A. Pope, R.T. Burnett, G.D. Thurston, et al., Cardiovascular Mortality and Long-Term Exposure to Particulate Air Pollution: Epidemiological Evidence of General Pathophysiological Pathways of Disease Circulation, vol. 109, 2004, pp. 71–77, https://doi.org/10.1161/01.CIR.0000108927.80044.7F.
[15] T. Gotschi, J. Heinrich, J. Sunyer, N. Kunzli, Long-term effects of ambient air pollution on lung function, Epidemiology 19 (2008) 690–701, https://doi.org/10.1097/EDE.0b013e318181650f.
[16] V. Ashok, T. Gupta, S. Dubey, R. Jat, Personal exposure measurement of students to various microenvironments inside and outside the college campus', Environ. Monit. Assess. 186 (2014) 735–750, https://doi.org/10.1007/s10661-013-3413-y.
[17] C.A. Pope, et al., Lung cancer, cardiopulmonary mortality, and long–term exposure to fine particulate air pollution, JAMA, J. Am. Med. Assoc. 287 (2002) 1132–1141, https://doi.org/10.1001/jama.287.9.1132.
[18] C.A. Pope, D.W. Dockery, Health effects of fine particulate air pollution: lines that connect, J. Air Waste Manag. Assoc. 54 (2006) 709–742, https://doi.org/10.1080/10473289.2006.10464485.
[19] M. Sehgal, et al., Assessment of outdoor workers' exposure to air pollution in Delhi (India), Int. J. Environ. Stud. 72 (1) (2015) 99–116, https://doi.org/10.1080/00207233.2014.965937.
[20] U.S. Environmental Protection Agency, Exposure Factors Handbook (Final Report), Author, Washington, DC, 2011.
[21] P. Wolkoff, Dry Eye Symptoms in Offices and Deteriorated Work Performance -A Perspective Building and Environment, vol. 172, 2020 106704, https://doi.org/10.1016/j.buildenv.2020.106704.
[22] G. Buonanno, L. Stabile, L. Morawska, Personal exposure to ultrafine particles: the influence of time–activity patterns, Sci. Total Environ. 468 (2014) 903–907, https://doi.org/10.1016/j.scitotenv.2013.09.016.
[23] A. Chaloulakou, I. Mavroidis, A. Duci, Indoor and Outdoor Carbon Monoxide Concentration Relationships at Different Microenvironments in the Athens areaChemosphere, vol. 52, 2003, pp. 1007–1019, https://doi.org/10.1016/S0045-6535(03)00263-7.
[24] C. Halios, C. Helmis, K. Eleftheriadis, A comparative study of the main mechanisms controlling indoor air pollution in residential flats water air, Soil Pollut 204 (2009) 333–350, https://doi.org/10.1007/s11270-009-0048-2.
[25] J. Jones, S. Stick, P. Dingle, P. Franklin, Spatial variability of particulates in homes: implications for infant exposure, Sci. Total Environ. 376 (2007) 317–323, https://doi.org/10.1016/j.scitotenv.2007.01.060.
[26] I. Nezis, et al., Linking indoor particulate matter and black carbon with sick building syndrome symptoms in a public office building, Atmos. Pollut. Res. 13 (2022) 101292, https://doi.org/10.1016/j.apr.2021.101292.
[27] S.E. Sarnat, et al., The influences of ambient particle composition and size on particle infiltration in Los Angeles, CA, residences, J. Air Waste Manag. Assoc. (2006) 186–196.
[28] H. Siddiqui, et al., Industrial hygiene and toxicity studies in unorganized bone–based industrial units, Environ. Monit. Assess. 176 (2011) 213–223, https://doi.org/10.1007/s10661-010-1577-2.
[29] P. Wolkoff, Indoor air humidity, air quality, and health – an overviewInternational, Journal of Hygiene and Environmental Health 221 (2018) 376–390, https://doi.org/10.1016/j.ijheh.2018.01.015.
[30] H.S. Choi, et al., Rapid translocation of nanoparticles from the lung airspaces to the body, Nat. Biotechnol. 28 (2010) 1300–1303, https://doi.org/10.1038/nbt.1696.
[31] T. Hussein, et al., Indoor aerosol modeling for assessment of exposure and respiratory tract deposited dose, Atmos. Environ. 106 (2015) 402–411, https://doi.org/10.1016/j.atmosenv.2014.07.034.
[32] Fenger, J. Urban air quality. Atmos. Environ., 33, pp. 4877–4900 https://doi.org/10.1016/S1352-2310(99)00290-3.
[33] W.J. Gauderman, et al., The effect of air pollution on lung development from 10 to 18 years of age, N. Engl. J. Med. 351 (2004) 1057–1067, https://doi.org/10.1056/NEJMoa040610.
[34] U. Gehring, et al., Traffic-related air pollution and dry night cough during the first 8 years of life, Pediatr. Allergy Immunol. 22 (2011) 85–86, https://doi.org/10.1111/j.1399-3038.2010.01100.x.
[35] A. Cattaneo, et al., Personal exposure of traffic police officers to particulate matter, carbon monoxide, and benzene in the city of milan, Italy Journal of Occupational and Environmental Hygiene (7) (2010) 342–351, https://doi.org/10.1080/15459621003729966.
[36] H.-R. Chao, et al., Inflammatory response and $PM_{2.5}$ exposure of urban traffic conductors, Aerosol Air Qual. Res. 18 (2018) 2633–2642, https://doi.org/10.4209/aaqr.2018.04.0132.

[37] Y.-C. Chen, et al., Particulate matter exposure in a police station located near a highway, Int. J. Environ. Res. Publ. Health 12 (2015) 14541–14556, https://doi.org/10.3390/ijerph121114541.
[38] J. Estévez-García, N. Rojas-Roa, A. Rodríguez-Pulido, Occupational exposure to air pollutants: particulate matter and respiratory symptoms affecting traffic-police in Bogotá, Revista de salud publica 15 (6) (2014) 889–902.
[39] T. Hussein, et al., Regional inhaled deposited dose of urban aerosols in an eastern mediterranean city, Atmosphere 10 (2019) 530, https://doi.org/10.3390/atmos10090530.
[40] M. Jamil, et al., Respiratory effects of exposure to high levels of particulate among Malaysian traffic police mal, J Med Health Sci 15 (4) (2019) 136–140.
[41] R.K. Jazani, et al., Influence of traffic-related noise and air pollution on self-reported fatigue' International, Journal of Occupational Safety and Ergonomics 21 (2) (2015) 193–200, https://doi.org/10.1080/10803548.2015.1029288.
[42] E.G. Maina, et al., Demonstrating $PM_{2.5}$ and road-side dust pollution by heavy metals along Thika superhighway in Kenya, sub-Saharan Africa, Environ. Monit. Assess. 190 (2018) 251, https://doi.org/10.1007/s10661-018-6629-z.
[43] G. Mona, et al., A Systematic Review on Occupational Hazards, Injuries and Diseases Among Police Officers Worldwide: Policy Implications for the South African Police Service Journal of Occupational Medicine and Toxicology, vol. 14, 2019, p. 2, https://doi.org/10.1186/s12995-018-0221-x.
[44] D. Saraga, et al., Workplace personal exposure to respirable PM fraction: a study in sixteen indoor environments, Atmos. Pollut. Res. 5 (2014) 431–437, https://doi.org/10.5094/APR.2014.050.
[45] P.A. Syahira, et al., Impacts of $PM_{2.5}$ on respiratory system among traffic policemen, Work 66 (1) (2020) 25–29, https://doi.org/10.3233/WOR-203147.
[46] E. Triantafyllou, G. Biskos, Overview of the temporal variation of PM_{10} mass concentrations in the two major cities in Greece: Athens and Thessaloniki, Global NEST Journal 14 (4) (2012) 431–441, https://doi.org/10.30955/gnj.000845.
[47] E.C. Cozza, et al., An approach to using heart rate monitoring to estimate the ventilation and load of air pollution exposure, Sci. Total Environ. 520 (2015) 160–167, https://doi.org/10.1016/j.scitotenv.2015.03.049.
[48] P. Kongtip, et al., Health effects of metropolitan traffic-related air pollutants on street vendors, Atmos. Environ. 40 (2006) 7138–7145, https://doi.org/10.1016/j.atmosenv.2006.06.025.
[49] N. Ngo, et al., Occupational exposure to roadway emissions and inside informal settlements in sub-Saharan Africa: a pilot study in Nairobi, Kenya Atmospheric Environment 111 (2015) 179–184, https://doi.org/10.1016/j.atmosenv.2015.04.008.
[50] S. Noomnual, et al., Young adult street vendors and adverse respiratory health outcomes in bangkok, Thailand Safety and Health at Work 8 (2017) 407–409, https://doi.org/10.1016/j.shaw.2017.02.002.
[51] V. Prabhu, et al., Exposure to atmospheric particulates and associated respirable deposition dose to street vendors at the residential and commercial sites in dehradun city, exposure to atmospheric particulates and associated respirable deposition dose to street vendors at the residential and commercial sites in dehradun city', Safety and Health at Work 10 (2019) 237–244.
[52] U.S. Environmental Protection Agency, Indoor particulate matter, Retrieved from, https://www.epa.gov/indoorairqualityiaq/indoorparticulatematter, 2019.
[53] M. Kulkarni, R. Patil, Monitoring of daily integrated exposure of outdoor workers to respirable Particulate Matter in an urban region of India, Environ. Monit. Assess. 56 (1999) 129–146.
[54] M. Matsuda, et al., Lacrimal Cytokines Assessment in Subjects Exposed to Different Levels of Ambient Air Pollution in a Large Metropolitan Area Lacrimal Cytokines and Air Pollution, 2015, pp. 1–11, https://doi.org/10.1371/journal.pone.0143131.
[55] U.P. Santos, et al., Association between Traffic Air Pollution and Reduced Forced Vital Capacity: A Study Using Personal Monitors for Outdoor Workers Traffic Air Pollution and Lung Function, 2016, pp. 1–12, https://doi.org/10.1371/journal.pone.0163225.
[56] K. Shakya, et al., Respiratory effects of high levels of particulate exposure in a cohort of traffic police in kathmandu, Nepal JOEM 58 (6) (2017) 218–225, https://doi.org/10.1097/JOM.0000000000000753.
[57] T. Stoeger, et al., Instillation of six different ultrafine carbon particles indicates a surface area threshold dose for acute lung inflammation in mice, Environ. Health Perspect. 114 (2005) 328–333, https://doi.org/10.1289/ehp.8266.
[58] S. Wang, R. Flagan, Scanning electrical mobility spectrometer, Aerosol. Sci. Technol. 13 (1990) 230–240, https://doi.org/10.1080/02786829008959441.
[59] A. Gerber, et Airborne particulate matter in public transport: a field study at major intersection points in Frankfurt am Main (Germany) Gerber et al, J. Occup. Med. Toxicol. 9 (13) (2014) 1–4.
[60] A. DeToni, F.F. Larese, L. Finotto, Respiratory diseases in a group of traffic police officers: results of a 5-year follow-up, Giornale italiano di medicina del lavoro ed ergonomia 27 (3) (2005) 380–382.
[61] M. Riediker, Cardiovascular effects of fine particulate matter components in highway patrol officers inhalation, Toxicology 19 (1) (2007) 99–105, https://doi.org/10.1080/08958370701495238.
[62] P. De Marchis, et al., Cardiovascular Effects of Occupational Exposure to Urban Airborne Pollution on a Group of Newsagents in the City of Palermo Acta Medica Mediterranea, vol. 30, 2014, pp. 347–353.
[63] K. Eleftheriadis, K.M. Ochsenkuhn, T. Lymperopoulou, A. Karanasiou, P. Razos, M. Ochsenkuhn-Petropoulou, Influence of local and regional sources on the observed spatial and temporal variability of size resolved atmospheric aerosol mass concentrations and water-soluble species in the Athens metropolitan area, Atmos. Environ. 97 (2014) pp252–261, https://doi.org/10.1016/j.atmosenv.2014.08.013.
[64] K. Eleftheriadis, Long-term variability of the air pollution sources reflected on the state of mixing of the urban aerosol Current, Opinion in Environmental Science & Health 8 (2019) 36–39, https://doi.org/10.1016/j.coesh.2019.04.001.
[65] P. Kumar, et al., The rise of low-cost sensing for managing air pollution in cities, Environ. Int. 75 (2015) 199–205, https://doi.org/10.1016/j.envint.2014.11.019.
[66] P. Fetfatzis, et al., Air Sensis: Low-Cost Air Quality Monitoring System European Aerosol Conference, 2019.
[67] I. Rasdi, The Association of Works Demands, Air Pollution and Noise with Mental Health and Work Absences Among Traffic Police Officers in Urban and Rural Malaysia (Unpublished Doctoral Thesis), La Trobe University, Melbourne, 2013.
[68] L. Drinovec, G. Močnik, P. Zotter, A.S.H. Prévôt, C. Ruckstuhl, E. Coz, M. Rupakheti, J. Sciare, T. Müller, A. Wiedensohler, A. Hansen, The "dual-spot" Aethalometer: an improved measurement of aerosol black carbon with real-time loading compensation, Atmos. Meas. Tech. 8 (5) (2015) 1965–1979, https://doi.org/10.5194/amt-8-1965-2015,2015.
[69] M. Fierz, et al., Design, calibration, and field performance of a miniature diffusion size classifier, Aerosol. Sci. Technol. 45 (2011) 1–10, https://doi.org/10.1080/02786826.2010.516283.
[70] M. Fierz, et al., Field measurement of particle size and number concentration with the diffusion size classifier (DiSC). SAE 2008-01-1179. https://doi.org/10.4271/2008-01-1179, 2008.
[71] G. Biskos, K. Reavell, N. Collings, Description and theoretical analysis of a differential mobility spectrometer, Aerosol. Sci. Technol. 39 (2005) 527–541, https://doi.org/10.1080/027868291004832.
[72] E. Chalvatzaki, et al., Characterization of Human Health Risks from Particulate Air Pollution in Selected European Cities Atmosphere, vol. 10, 2019, p. 96, https://doi.org/10.3390/atmos10020096.
[73] Department of Health, Guidelines for Surveillance of Risk Areas from Air Pollution Bangkok, Author, Thailand, 2011. Retrieved from, http://www.oic.go.th/FILEWEB/CABINFOCENTER17/DRAWER002/GENERAL/DATA0000/00000200.PDF.
[74] T. Neamhom, et al., Health risk and predictive equation for $PM_{2.5}$ using TSP and PM_{10} Songklanakarin, J. Sci. Technol. 43 (3) (2021) 834–839, https://doi.org/10.3390/ijerph182312354.
[75] A. Dennis Lemly, Evaluation of the hazard quotient method for risk assessment of selenium Ecotoxicology and Environmental Safety 35 (2) (1996) 156–162, https://doi.org/10.1006/eesa.1996.0095.
[76] WHO, Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. https://apps.who.int/iris/handle/10665/69477, 2005.
[77] N. Briggs, C. Long, Critical review of black carbon and elemental carbon source apportionment in Europe and the United States, Atmos. Environ. 144 (2016) 409–427, https://doi.org/10.1016/j.atmosenv.2016.09.002.