Corrigendum to “Linking indoor particulate matter and black carbon with sick building syndrome symptoms in a public office building” [Atmos. Pollut. Res. 13 (2022) 101292] (Atmospheric Pollution Research (2022) 13(1), (S1309104221003548), (10.1016/j.apr.2021.101292))

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DOI
10.1016/j.apr.2022.101507

Publication date
2022

Document Version
Final published version

Published in
Atmospheric Pollution Research

Atmospheric Pollution Research 13 (2022) 101292

Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: www.elsevier.com/locate/apr

Linking indoor particulate matter and black carbon with sick building syndrome symptoms in a public office building

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ARTICLE INFO

Keywords:
$PM_{2.5}$
Black carbon
Indoor air quality
Human exposure
Indoor air pollution
Office
Sick building syndrome symptoms
Saharan dust event

ABSTRACT

Poor indoor air quality is an important issue for public and occupational health worldwide. Location, air-tightness of the building, ventilation rate and resident activities play an important role on the concentration of indoor pollutants and subsequently on their effects on human health. While indoor air pollution in working environments has been widely studied, the association between specific pollutants and Sick Building Syndrome (SBS) symptoms is still not clear. The objective of this study is to explore the association between $PM_{2.5}$ and BC with SBS symptoms reported by employees working in a public building in the center of Athens, Greece. Continuous indoor air quality measurements were carried out from March until May 2016 (24 h, 7 days per week), including days during a Saharan dust event in March 2016. The measurements took place in four different types of spaces, including an office, a printer room and two archiving rooms, representing both high and low exposure environments. Indoor $PM_{2.5}$ and BC concentrations in the office ranged from 5.9 to 14.3 μg/m^3 and 1.1–1.9 μg/m^3, respectively, whereas outdoor $PM_{2.5}$ and BC concentrations were in the range of 6.5–21.7 μg/m^3 and 1.4–2.6 μg/m^3, respectively. We observed diurnal variations in indoor/outdoor ratios of $PM_{2.5}$ and BC in most rooms that were >1 during working hours, that subsequently fell to below unity after working hours. Data collected via a questionnaire to 73 employees showed that the most commonly reported SBS symptoms were irritation of the eyes, a stuffy or runny nose, headache and drowsiness. Female employees were more likely to report SBS symptoms than male employees, especially nonspecific symptoms, including "unusual tiredness or fatigue" and "feeling depressed".

1. Introduction

Indoor air pollution is a major problem for industrially developed countries, where people spend on average 90% of their time in closed spaces (Dimitroulopoulou et al., 2001; McCreddin et al., 2013). Individuals working from home, elderly people and preschoolers spend the majority of their time at home, whereas workers split their time between their home and their workplace (Karakatsani et al., 2010; Baccarelli et al., 2011). The recent COVID-19 pandemic has exacerbated the situation, forcing many people to work from home following mobility restrictions and social isolation. While outdoor air pollution in urban city centers is one of the world's largest health and environmental problems, indoor air can carry a higher pollution burden, particularly at the workplace and in buildings of large and industrialized cities (e.g., Perez et al., 2010; Cheung et al., 2011 Salmatonidis et al., 2019; Lasithiotakis et al., 2020). The problem is intensified in buildings that are designed to be insulated and recycle the air using only a small fraction of fresh air (Quang et al., 2013; Jurado et al., 2014).

A number of parameters can be used for assessing indoor air quality (IAQ), including humidity and temperature (Wolkoff and Kjaergaard,

Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.
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https://doi.org/10.1016/j.apr.2021.101292
Received 1 May 2021; Received in revised form 23 November 2021; Accepted 1 December 2021
Available online 4 December 2021

2007), particulate matter (PM) (Horemans and Van Grieken, 2010) and organic compounds (Fraser et al., 2013; Watkins et al., 2013; Lappalainen et al., 2013; Salonen et al., 2009). In addition, many studies have assessed IAQ in office buildings in combination with building operation parameters such as ventilation and energy efficiency (Bluyssen, 1996; Perez et al., 2010; Baccarelli et al., 2011; Cheung et al., 2011). The type of ventilation and the way it is used defines to a great extent the concentration of indoor air pollutants, and can give valuable information on IAQ levels (Jamriska et al., 2003). Three different ventilation systems are employed in office and commercial buildings. The first is natural ventilation through windows and doors. The second type of ventilation is mechanical, where temperature and humidity are regulated by heating and ventilating air conditioning (HVAC) systems. The third type is mixed-mode ventilation that combines both natural and mechanical ventilation, e.g., through the use of window air conditioners in combination with open windows and doors (Irga and Torpy, 2016).

Technological advances over the last decades have changed the way that individuals work and the quality and quantity of office equipment they use. Personal computers, printers, fax machines and photocopiers are basic equipment in offices nowadays. There are, however, growing concerns about the levels of potentially harmful pollutants that are emitted from office materials and equipment such as particulate matter (PM) and volatile organic compounds (VOCs) as well as secondary pollutants such as ozone (Destaillats et al., 2008; Kalantzi and Siskos, 2011). Poor indoor air quality due to infiltration of pollutants from outdoor air or from production within the indoor working environment may result in significant exposure levels, causing numerous health problems such as rhinitis, eye and skin irritation, dry throat, asthma, allergic inflammations, headaches and cardiovascular diseases, thereby reducing quality of life (Mitsakou et al., 2007; Tang et al., 2012). In addition, certain microclimatic and ventilation conditions encountered in offices can have a negative impact on IAQ and employees' health. The consensus from recent studies is that location, air-tightness of office buildings, as well as ventilation rate and employee activities, play an important role on the concentration of indoor pollutants and subsequently on their health (Nezis et al., 2019).

Many epidemiological studies have reported that PM has a strong effect on human health. Elevated PM and BC concentrations have been associated with adverse health effects such as irritation of the respiratory tract, as well as pulmonary and cardiovascular diseases (Ostro et al., 2015; Ragazzi et al., 2014; Makri and Stilianakis, 2008; WHO 2007). Based on a systematic review on PM and BC exposure and the associated health effects, Janssen et al. (2011) proposed the use of BC as an important air quality indicator for health impact assessments. To investigate the impacts so of these two parameters in the context of IAQ, a number of studies have assessed the relationship between health effects with ratios of indoor/outdoor PM and BC concentrations in houses (Van Vliet et al., 2013; Downward et al., 2016; Gould et al., 2018; Tang et al., 2018; Lai et al., 2019; Rickenbacker et al., 2016; Yuan et al., 2020; Arif and Parveen, 2021; Lee et al., 2021), schools (Rivas et al., 2015; Gaffin et al., 2017; Artinano et al., 2019; Isiugo et al., 2019; Zhou et al., 2020; Li et al., 2020; Pacitto et al., 2020; Rejc et al., 2020; Fernandes et al., 2021; Portela et al., 2021) as well as non-residential indoor environments close to major traffic highways in urban and suburban areas worldwide (Viana et al., 2011; Fujita et al., 2014; Tunno et al., 2015; Underhill et al., 2015; Pant et al., 2017; Jeong et al., 2019; Shakya et al., 2017; Selokar et al., 2020).

Indoor air quality depends on the way buildings are built and operated, which in turn can vary significantly with geographical location. In northern European countries for instance, where houses and offices are better isolated from the outside environment and natural ventilation is not so frequent, outdoor PM and BC concentrations do not contribute much compared to those in the indoor air (Mandin et al., 2017; Vilcekova et al., 2017; Szigeti et al., 2014; Lappalainen et al., 2013; Traistaru et al., 2013; Tang et al., 2012; Horemans and Van Grieken, 2010; Branis et al., 2005; Gotschi et al., 2002). On the other hand, in southern European countries where buildings are not required to be highly isolated from the outdoor environamnt, indoor PM and BC can be strongly influenced by outdoor concentrations (Pacitto et al., 2020; Ragazzi et al., 2014).

Diapouli et al. (2009) characterized PM $_{10}$, $PM_{2.5}$ and BC mass concentration in residential environments in Athens and examined the relative contribution of indoor and outdoor sources. Residential indoor air pollution was also assessed by Halios et al. (2009, 2004), while Loupa et al. (2016) investigated the elemental composition and diurnal variations of indoor $PM_{2.5}$ and BC in a hospital. Relatively fewer studies have evaluated IAQ in commercial buildings and offices, assessing both indoor and outdoor concentrations of $PM_{2.5}$ and BC in rooms with different exposure characteristics in terms of ventilation, human activity, and presence of electronic equipment such as printers (Klinmalee et al., 2009; Horemans and Van Grieken, 2010; Wu et al., 2012; Rickenbacker et al., 2016; Chatoutsidou et al., 2017; Lin et al., 2019). Despite this growing number of reported observations, no previous study has investigated the association between PM and BC with health effects in naturally ventilated office environments to the best of our knowledge (Nezis et al., 2019).

The objective of this work is to explore the link between outdoor and indoor air $PM_{2.5}$ and BC concentrations with Sick Building Syndrome (SBS) symptoms reported by people working in office buildings. Indoor and outdoor $PM_{2.5}$ and BC concentrations were simultaneously monitored, whereas the measurement were compared with air quality limit values, and associated with SBS symptoms reported by employees working in the building.

2. Materials and methods

2.1. Sampling location

The building is located in the center of Athens, next to a busy traffic road, and houses the Ministry of Environment and Energy. Athens city center is situated in a valley, where the $PM_{2.5}$ load is generally well mixed across the Athens Metropolitan area (Eleftheriadis et al., 2014), with a gradual improvement in concentration levels over the years (Triantafyllou and Biskos 2012; Eleftheriadis, 2019). The building has 10 floors, of which only the first four are occupied. The majority of the offices have a surface area of 20–40 m^2. The building has 21 offices on the 1st floor, 19 on the 2nd floor, 21 on the 3rd floor and 16 on the 4th floor. It has natural ventilation and central heating, while every office has a separate air-conditioning (A/C) unit that is used during the summer for cooling. The office rooms selected for measurements were 3 on the 1st floor, and 1 on the 2nd floor. The first office (low exposure room) is a typical office room with 3 employees. The second office is a printing room (high exposure room), in which printing and photocopying activity takes place. The third office (medium exposure room) is an archiving office with no employees, but it is frequently visited throughout the working day (7:30 a.m. until 3:30 p.m.) for document archiving. The fourth room is a maps archiving office, located on the 2nd floor of the building, containing all the topographical maps of Greece. There is no permanent employee in this room and thus it represents the reference room. Table 1 shows the characteristics of each office.

2.2. Questionnaires

The first part of the questionnaire included basic demographic and work-related information, such as gender, age, marital status, education, working hours, commute time and mode, smoking, alcohol consumption and medical history. The second part of the questionnaire included questions on the employees' perception of indoor air quality in their offices, and questions regarding typical SBS symptoms such as nose, eyes, skin, upper and lower respiratory irritation, observed during the preceding 4 weeks. The second part of the questionnaire was based on the NIOSH Indoor Air Quality and Work Environment Symptoms

Table 1
Characteristics of the offices.

Room	Floor	Surface Area (m^2)	Number of Employees	Electronic equipment	Type of Ventilation
Office room	1st	40	3	2 PCs, 2 laser printers, 1 fax machine	Natural
Printer room	1st	60	3	4 photocopy machines, 2 plotters, 3 PCs, 3 laser printers, 2 fax machines	Natural
Archiving room	1st	70	0[a]	–	Natural
Maps file room	2nd	140	0[b]	–	Natural

[a] Frequently visited throughout the workday for archiving.
[b] Occasionally visited by an employee for archiving.

Survey, which has questions related to 13 symptoms. In our study the SBS symptoms were defined under the following two criteria: (1) whether the symptoms appeared when the study employees entered the study office and disappeared when they left it, and (2) whether such symptoms occurred at least once per week. We collected data from 73 employees, which represent 40% of the total number of employees working in the building. Informed consent was obtained from all individuals who participated in this study.

2.3. Environmental measurements

Sampling was carried out over 14 consecutive days for each office room on a 24-h basis, from March to May 2016. Due to the availability of one set of instruments to operate for simultaneous indoor/outdoor sampling, the measurements were carried out in each office in different periods during springtime 2016. More specifically, the measurements in the office room were realized in two phases: the first phase lasted 4 days from 22/3to 24/3, and the second phase lasted 5 days staring from 28/3 to 1/4. In the printing room measurements were carried out from 2/4 to 15/4, in the archiving room from 16/4 to 25/4 and in the maps file room from 10/5 until May 20, 2016.

Temperature and relative humidity were measured with a HOBO U12-013 data logger that has a built-in temperature and relative humidity sensor along with two external channels for a wide range of energy and environmental sensors. $PM_{2.5}$ concentrations were measured with a DataRAM 4000 particle monitor, a high-sensitivity, two-wavelength nephelometric monitor that has been optimized for the measurement of the fine particle fraction of airborne dust, smoke, fumes, and mists in ambient, atmospheric, industrial, research, and indoor environments. BC concentrations were measured on a 24-h basis using a custom-made aethalometer developed by Moscow State University (MSU) and Central Aerological Observatory (CAO). The instrument records light attenuation at three wavelengths (450, 550, and 650 nm) using a detector behind a quartz fiber filter, where aerosol particles are collected. The light-attenuation coefficient of the collected aerosol is calculated according to Hansen and Rosen (1985) and Popovicheva et al. (2017a). Although for practical reasons the commonly used term BC is employed through the document, the measured mass concentration of Black Carbon obtained by this method is better described by the term "equivalent Black Carbon" (eBC). This is determined by converting the time-resolved light attenuation to an equivalent mass of light absorbing carbon that would cause the same attenuation at 650 nm, and is characterized by a specific mean mass attenuation coefficient as described elsewhere (Popovicheva et al., 2017b). The specific calibration parameter for this aethalometer to quantify eBC was derived during parallel long-term measurements against an AE33 Aethalometer Magee Scientific (Drinovec et al., 2015) using the paired output for the same wavelength. Aethalometer filters were manually changed every 24 h. Data corresponding to cumulative attenuation above 100 were discarded.

The instruments were placed on a table close to the breathing height of a sitting person (0.80 m from the floor), in the middle of the 1st floor office where two employees worked on desks. In all the other rooms (printer office, archiving office and maps archiving room) the instruments were placed higher (1.75 m from the floor) in order to be closer the breathing zone of the employees who work standing upright. Finally, all the instruments were connected to an automatic sampling system. The role of this pump was to provide indoor air for 50 min every hour and outdoor air for the remaining 10 min of each hour. Indoor and outdoor sampling was carried out through a 2-m long conductive tubing (3 cm ID) connected to the sampling system. The DataRam4000 was calibrated at the beginning of the study against the reference gravimetric method EN12341 in the same manner performed earlier for other automatic semi continuous PM monitoring instruments (Triantafyllou et al., 2016). All the instruments were zero-checked on a daily basis.

2.4. Statistical analysis

Linear relationships among quantitative variables were explored by multiple regression analysis. A *t*-test was used to determine the continuous variables and examine the relationship between SBS symptoms and risk factors. We estimated the odds ratio (OR) of SBS Symptoms along with its 95% confidence interval (CI) by using a conditional logistic regression model between age, sex, allergic history and smoking habit of the employees in order to determine the associations between risk factors and SBS symptoms. The models were configured with the binomial error distribution and logit link function. Statistical significance was set at $p > 0.05$. The statistical package used was SPSS (v.23, SPSS Inc.).

3. Results and discussion

3.1. p.m.$_{2.5}$ and black carbon

3.1.1. Printing room

The highest $PM_{2.5}$ indoor average concentrations were measured in the printing room during working hours, and ranged from 32.0 μg/m^3 at 10:00 (maximum 73.0 μg/m^3), to 63.2 μg/m^3 at 14:00 (maximum 93.2 μg/m^3). During the night and on weekends, outdoor $PM_{2.5}$ concentrations were greater than indoor concentrations (the ratio of indoor to outdoor concentrations, I/O, was <1; cf. Fig. 1a). On the other hand, during the day (mainly during working hours), the I/O ratio was >1, with the highest values recorded during peak printing hours (12:00 to 15:00). BC concentrations were generally lower than $PM_{2.5}$, with the highest indoor concentration being 9.4 μg/m^3 at 11:00 and 6.1 μg/m^3 at 14:00, respectively. Comparing the average indoor and outdoor BC concentrations during the sampling period (Fig. 1b), we can observe that the hourly indoor concentrations were slightly higher than the outdoor concentrations. During working hours (10:00 and 15:00) the I/O correlation for $PM_{2.5}$ and BC in the printer room was >1, because indoor air concentrations were mainly influenced by activities such as printing and photocopying (Fig. 5a). Indoor temperature and humidity ranged from 20.0 to 23.7 °C and 47–64%, respectively, throughout the entire sampling period.

3.1.2. Archiving room

The file storage room exhibited the second highest concentrations of $PM_{2.5}$. The I/O was higher than unity during working hours and less than unity during non-working hours. The highest average indoor concentrations (ranging from 36.8 to 51.5 μg/m^3) were recorded between 12:00 and 13:00. The average hourly $PM_{2.5}$ indoor and outdoor concentrations are shown in Fig. 2a. BC concentrations were lower than $PM_{2.5}$, ranging from 1.3 to 10.2 μg/m^3. The average hourly indoor and outdoor BC concentrations (Fig. 2b) exhibited an I/O ratio >1 during

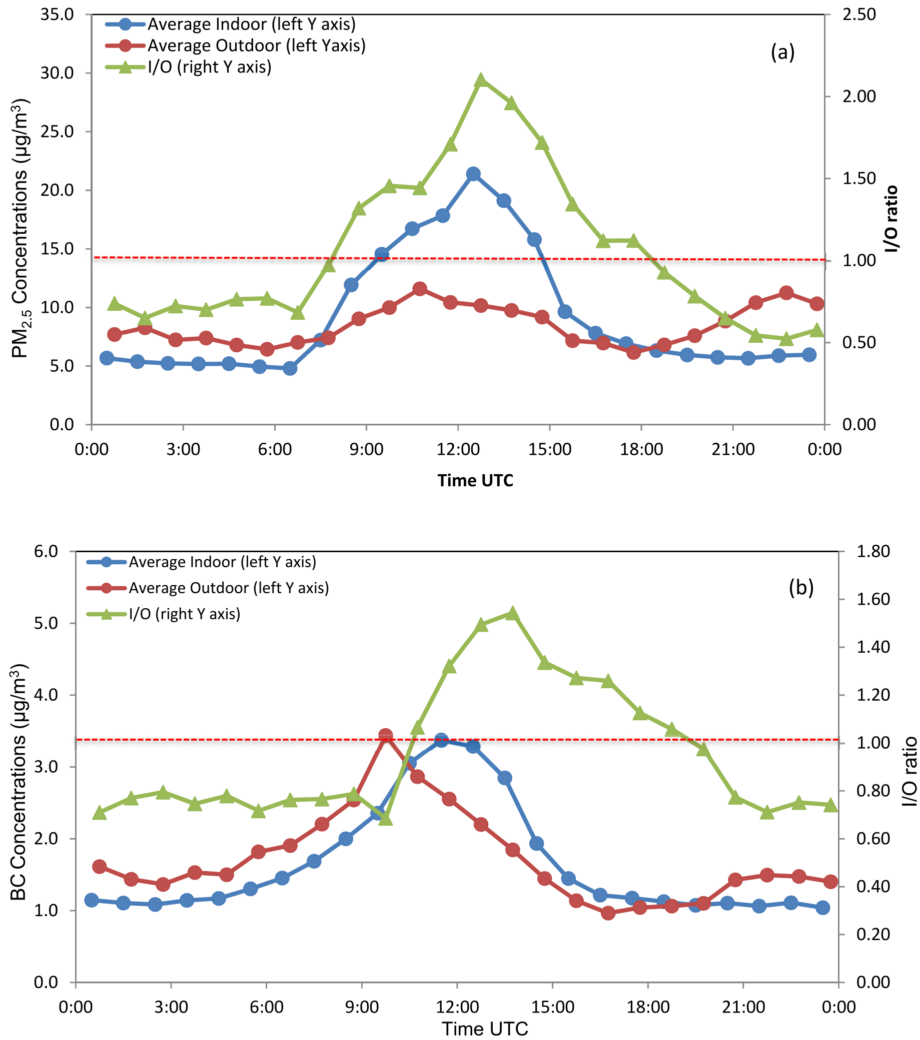

Fig. 1. Hourly average indoor and outdoor $PM_{2.5}$ (a) and BC (b) concentrations in the printing room.

working hours, with the highest values being observed between 10:30 and 16:30. The I/O correlation for $PM_{2.5}$ and BC was >1 (Fig. 5b), which can be attributed to the indoor activities of the employees; according to the activity diary some individuals used the adjacent room as a smoking area. The temperature and humidity in the archiving room ranged from 22.5 to 25.8 °C and 49.6–61.1%, respectively throughout the duration of the measurements.

3.1.3. Office room

The measurements conducted in the 1st floor office throughout the 8-h working day were realized in two phases. The first phase lasted for 4 days from March 21, 2016 to March 24, 2016, and the second phase lasted for 5 days, from March 28, 2016 to April 1, 2016. In contrast to the other rooms, the office is naturally ventilated through windows. While it was recommended that during sampling all windows be kept closed in order to achieve distinctness between indoor and outdoor measurements, the windows were occasionally opened by the employees (according to the activity diary they kept during the study). The concentrations of $PM_{2.5}$ during both phases of the measurements were greater outdoors than indoors, with average indoor concentrations ranging from 5.4 to 17.6 μg/m^3 (Fig. 3a). The I/O ratio was <1 during both working and non-working hours, including the weekends. The average indoor and outdoor BC concentrations during working hours ranged from 1.4 to 6.6 μg/m^3 and 1.3–6.1 μg/m^3, respectively. The average I/O ratio for BC throughout the duration of the study was >1, especially during working hours (Fig. 3b). The I/O correlation for $PM_{2.5}$ and BC was <1, possibly due to pollutant transport from the outdoor environment (Fig. 5c). In fact during working hours (particularly after 12:00), the I/O ratio for both $PM_{2.5}$ and BC reached its highest values, which according to the activity diary that was kept during the study by the employees, is when the windows were opened. In general, where major indoor sources were absent, the I/O ratios were typical of the range found in previous studies in the Athens urban area residential buildings (Diapouli et al., 2011). The temperature ranged between 14.1 and 27.8 °C and humidity from 45.3 to 69.3%.

It is worth noting that a Saharan dust event occurred on March 23, 2016, during which maximum $PM_{2.5}$ concentrations of 530.2 and 374.7 μg/m^3 were recorded at 18:00 outdoors and indoors, respectively. Fig. 3c shows the $PM_{2.5}$ concentrations during the Saharan dust event. Indoor BC concentrations ranged from 0.7 to 3.1 μg/m^3 (average: 1.9 μg/m^3), while the outdoor concentrations ranged from 0.5 to 3.6 μg/m^3 (average: 2.2 μg/m^3) during the event (data not shown).

3.1.4. Maps file room

The $PM_{2.5}$ and BC measurements in the maps file room lasted for 9 days; from May 11, 2016 to May 19, 2016. Throughout the duration of these measurements the windows remained closed. This room was characterized as a reference room because no human activities took place during the study. Average indoor $PM_{2.5}$ concentrations ranged from 3.7 to 7.1 μg/m^3 and the highest concentration that was recorded during the entire sampling period was 17.7 μg/m^3. It is worth noting that the average outdoor air $PM_{2.5}$ concentrations were between 9.6 and

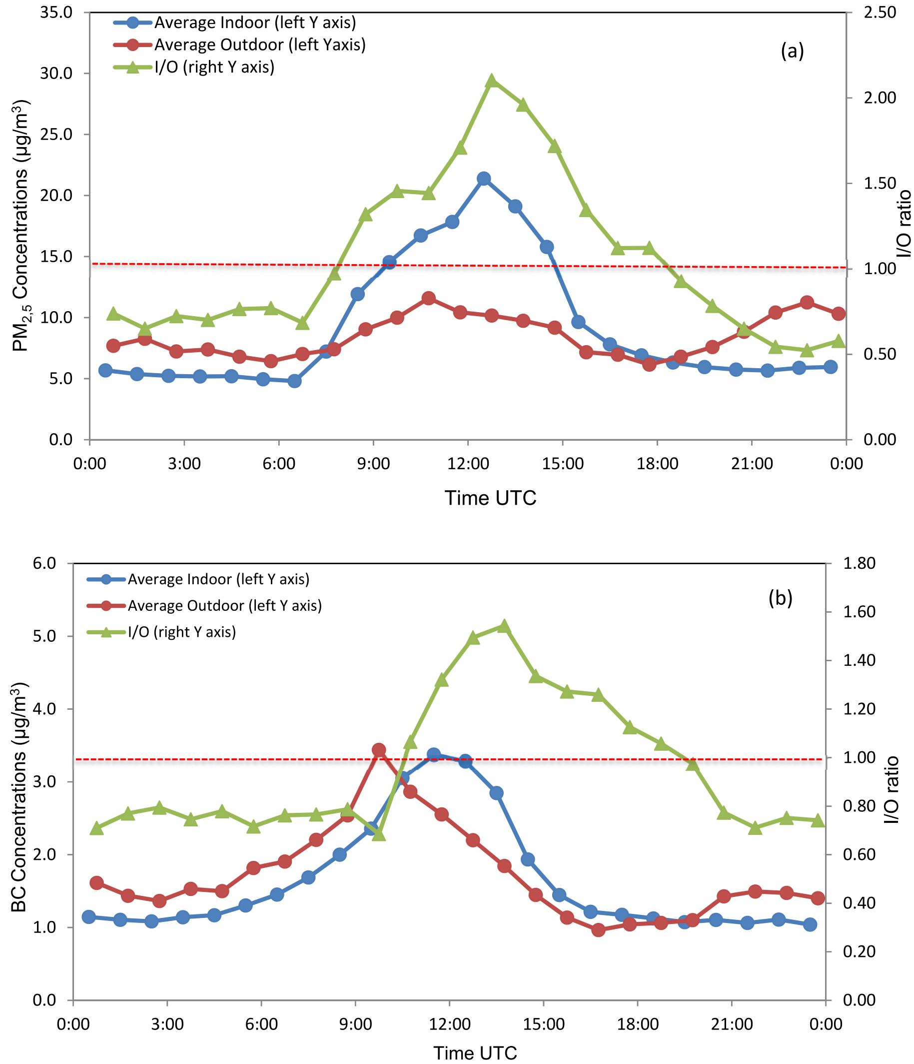

Fig. 2. Hourly average indoor and outdoor $PM_{2.5}$ (a) and BC (b) concentrations in the archiving room.

16.4 μg/m^3 (with the highest recorded outdoor concentration being 88.6 μg/m^3). The average indoor and outdoor $PM_{2.5}$ concentrations are shown in Fig. 4a. The I/O ratio during working hours was <1. Regarding BC measurements, the average indoor concentration during working hours ranged from 1.2 to 1.9 μg/m^3, while outdoor BC concentrations ranged from 1.4 to 2.6 μg/m^3. The I/O ratio was <1 throughout the duration of the study (Fig. 4b). The I/O correlation between $PM_{2.5}$ and BC was <1, because the windows remained closed, and as a result indoor $PM_{2.5}$ and BC concentrations were not affected from the outdoor environment (Fig. 5d). The temperature and humidity ranged from 22.5 to 25.9 °C and 49.7%–61.1%, respectively.

In general, I/O ratios for BC were lower than 1 with the exception of the printing room, where printers act as a source for indoor BC. For all other indoor spaces results point towards the reduced penetration of BC particles from outdoors where their main source (traffic) is active during the day. The observed weaker (Fig. 1a) or stronger (Fig. 1c) relationship between I/O for $PM_{2.5}$ and BC reveals that they may co-vary due to similar sources in the outdoor atmosphere and a common dependence to a short term variability of the ventilation rate; however BC has a lower penetration rate than $PM_{2.5}$ and/or $PM_{2.5}$ indoors is less affected by indoor sources compared to outdoor air.

Variations between I/O ratios of $PM_{2.5}$ and BC can be explained if one considers the removal/deposition and the emission rates of the particles, which varied substantially among the different rooms and experimental periods, mainly depending on the types of ventilation and construction characteristics of each room. The calculated removal/deposition rates during the entire measurement period are provided in Table 2.

In general, the larger the room, the smaller its surface to volume ratio; as a result, particulate pollutant concentrations will fall faster in a smaller office room when the other parameters (outdoor pollution, ventilation rates) are kept constant due to particle deposition on the walls. The deposition rates of $PM_{2.5}$ and BC were calculated with a methodology based on the solution of the mass balance equation applied for each office room, assuming steady-state conditions which are not far from reality when the ventilation rate is constant (Yang et al., 2004; Matson, 2005). The controlling parameters of $PM_{2.5}$ and BC transport between the indoor and outdoor environments (i.e., through ventilation and the use of external openings) were calculated based on our measurements. We calculated the ventilation rate using this equation $\alpha = {}^{\lambda}/_{(\lambda + k_\tau)}$. Details of the methodology are described in Appendix 1. The ventilation rates required for these calculations are presented in Table 2.

3.2. Questionnaire data

The demographic characteristics of the employees are shown in Table 3. Of all the respondents, 95% were over 35 years old, 63% were female and 62% had a university (undergraduate or higher) degree. 62%

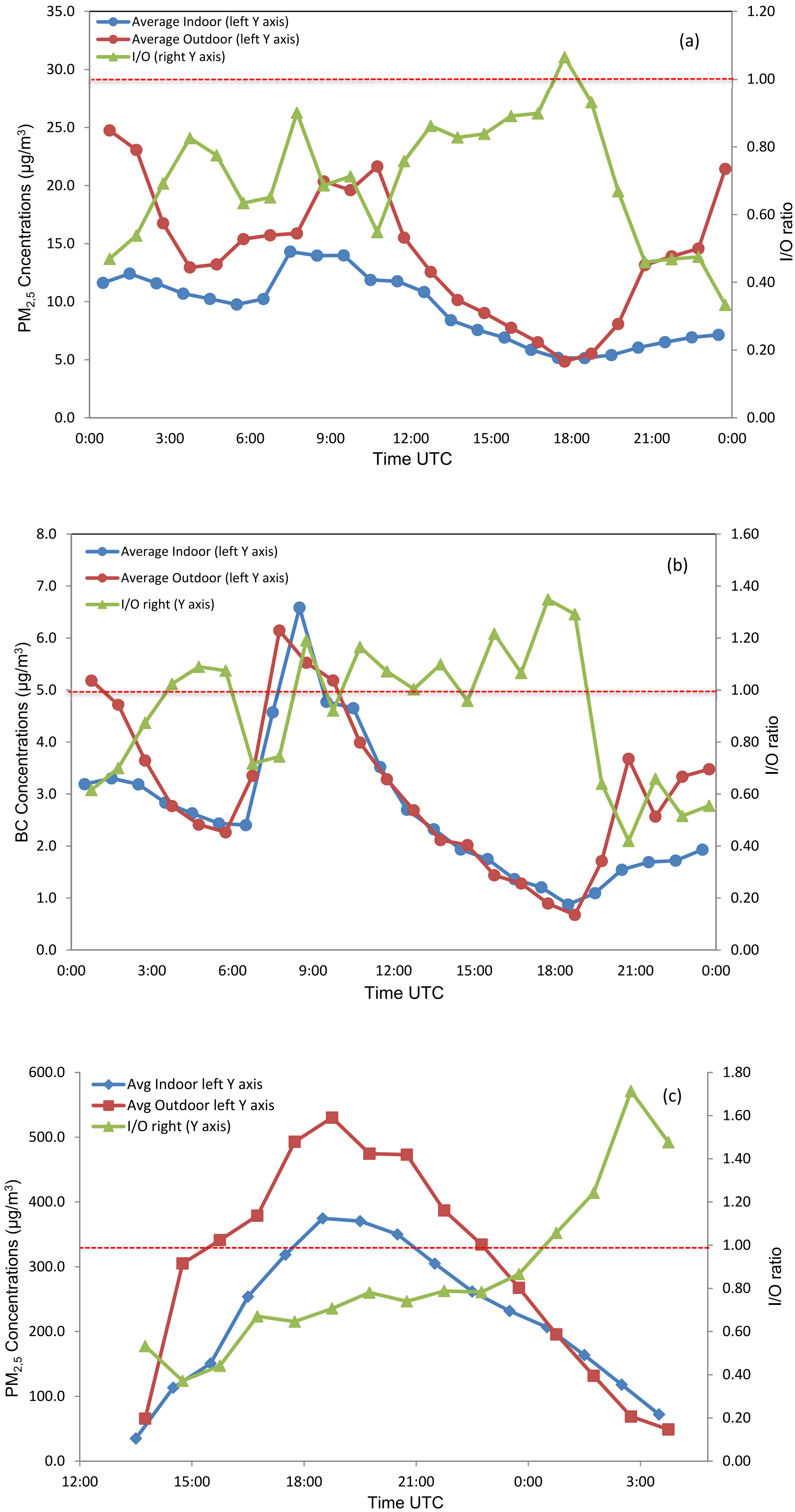

Fig. 3. Hourly average indoor and outdoor $PM_{2.5}$ (a), BC (b) and $PM_{2.5}$ during a Saharan dust event (c) concentration in the office room.

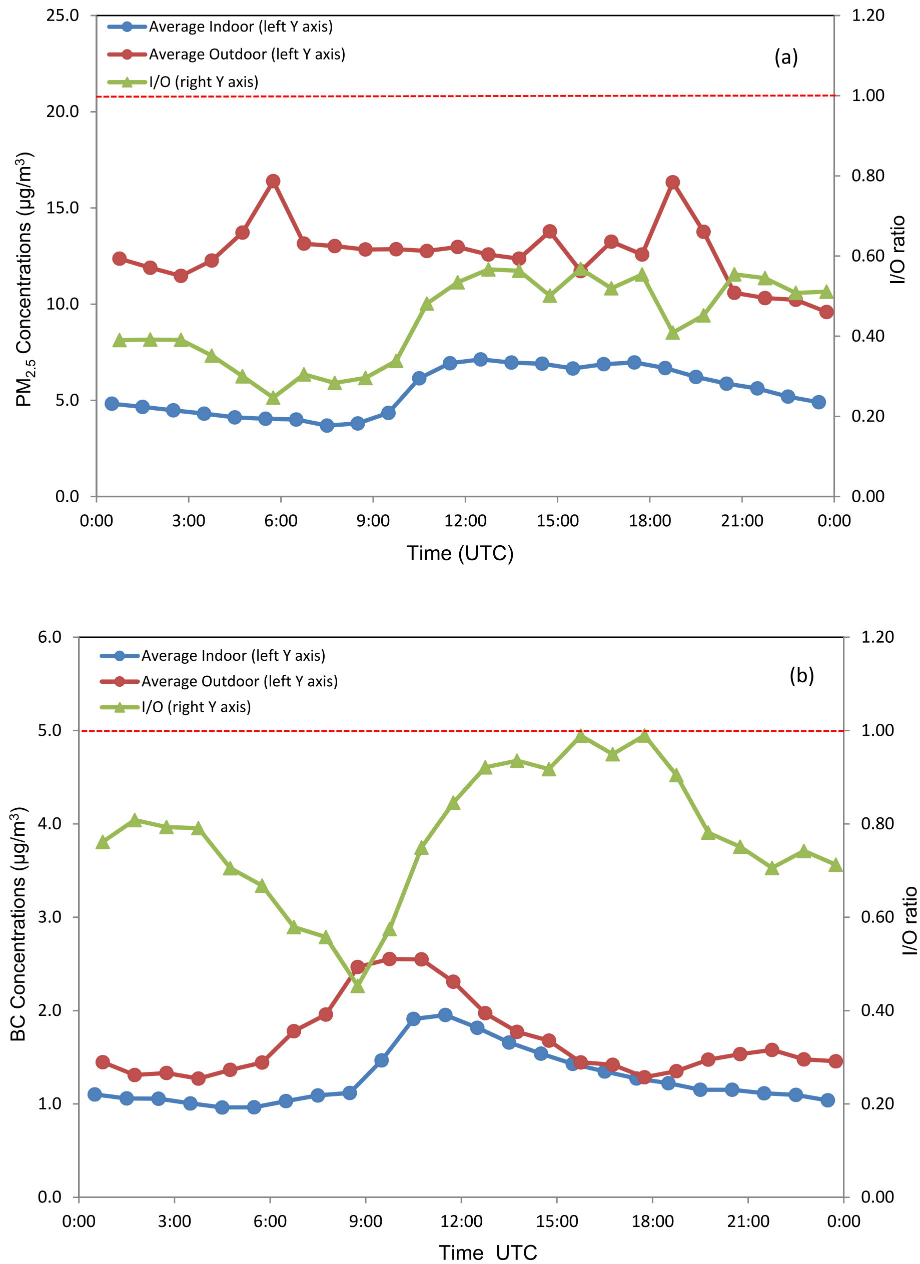

Fig. 4. Hourly average indoor and outdoor $PM_{2.5}$ (a) and BC (b) concentrations in the maps file room.

were casual or everyday smokers, 25% reported suffering from allergies and 11% reported suffering from rhinitis. 86% of the employees had been working for 11 years or more at the same post and 44% worked more than 8 h per day. The majority of the respondents commute to work by public transport (52%) or car (29%), with their commute time ranging from <40 min (43%) to > 40 min (22%). Most of them worked on the 1st (23 employees), 2nd (20 employees), and 3rd (10 employees) floor of the building. Their offices share the same characteristics with the office we sampled: i.e., they have a surface area up to 40 m^2 where 2 to 4 employees work. About a third were smokers, all of them use a computer for 6–8 h, and >80% of them use the printer in their office to print more than 10 pages per hour. Three employees worked in the printer room, two of which aware ex-smokers and one was a non-smoker. They worked 6–8 h per day, using the computer more than 6 h a day and print on average 1000 pages per hour on the photocopy machines. The eight employees who work in the archiving room frequently visit it through their 8-h shift for document archiving. The majority were smokers between 45 and 54 years old, and have been working there for 11–20 years.

The self-reported perceived SBS symptoms were categorized into the following five groups according to the classifications outlined in previous studies (Eriksson et al., 1996; Redlich et al., 1997; Tsai et al., 2012): (1) eye irritation, (2) nonspecific symptoms ("headache," "tiredness, fatigue," "difficulty in concentrating"), (3) upper respiratory symptoms ("sore or dry throat," "stuffy or runny nose, and "cough"), and (4) skin irritation ("dryness or rash"). The SBS symptoms in this study were defined under the following two criteria: (1) whether they appeared when the study employees entered their office and disappeared when they left, and (2) whether such symptoms occurred at least once per week (Tsai et al., 2012). Table 4 presents the prevalence of SBS symptoms among the 73 participants who work in offices that have the same characteristics with the sampled office. The questionnaire results showed that the offices are naturally ventilated through windows, they are being cleaned once a week and, according to the respondents'

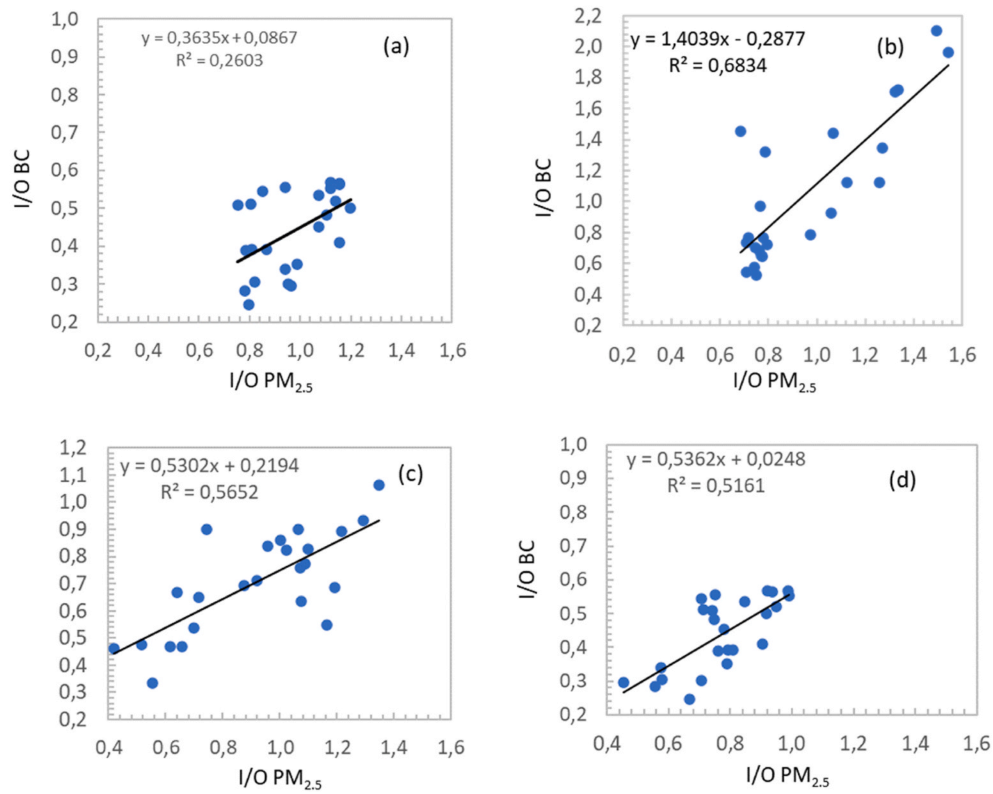

Fig. 5. Average I/O correlation of $PM_{2.5}$ and BC in the **(a)** printing room, **(b)** archiving room, **(c)** office room, and **(d)** maps file room.

Table 2
Calculated deposition rates (h^{-1}) of $PM_{2.5}$ and BC.

Room	BC Dep. rate (h^{-1})	$PM_{2.5}$ Dep. rate (h^{-1})
Office room[a]	0.21	0.31
Printing room[b]	0.15	0.12
Archiving room[b]	0.14	0.10
Maps file room[b]	0.11	0.06

[a] The windows were occasionally opened during working hours.
[b] The windows were closed throughout the duration of the measurements.

answers, they do not have a steady temperature during the year. Each floor is disinfected once a year and the air-conditioning units are also being serviced once every year. 43% of the employees occasionally feel tired or dizzy, 51% reported having a dry throat during working hours and 50% of them occasionally suffer from headaches during their shift. Finally, 54% reported sometimes feeling tired and 64% of them felt better upon leaving the building. In the printer room two of the three employees reported suffering from allergies and rhinitis and the third one reported having hypertension and taking medication.

Table 5 shows the OR of the four SBS groups of symptoms, with respect to age, sex, allergic history, and smoking habit as variables. Results show that female employees were more likely to report SBS symptoms than male employees, with regards to nonspecific symptoms ("Unusual tiredness or fatigue" ORs = 5.4; 95% CI = 0.9–30.9, "feeling depressed" OR = 4.1; 95% CI = 0.6–24.5). Smokers were more likely to report "eye irritation,"(OR = 2.0; 95% CI = 0.6–6.4) "stuffy or runny nose,"(OR = 1.9; 95% CI = 0.6–5.6) and "respiratory symptoms" (cough OR = 2.4; 95% CI = 0.8–7.2) than non-smokers. The most commonly reported symptoms were irritation of the eyes, a stuffy or runny nose, headache and drowsiness. About a half of the participants complained of skin and throat dryness, as well as nose stuffiness. The questionnaire analysis revealed that the employees experienced a variety of symptoms that occurred 'often' or 'always' and subsequently disappeared after leaving the building. Fatigue was an independent risk factor for all summary symptoms. Fatigue, difficulty concentrating, and tiredness are typical components of SBS symptoms and could be intermediate variables between adverse physical and occupational exposures and physical symptoms. Fatigue is also a strong independent predictor of physical symptoms. Finally, employees with allergies also reported more work-

Table 3
Demographic characteristics of the participants (n = 73).

Variables	Study Sample	
	No.	%
Gender		
Male	27	37
Female	46	63
Education		
Postgraduate	21	28.8
Undergraduate	16	21.9
Technological Institute	8	11
High school or Secondary school	28	38.4
Average Daily Working Hours		
less or equal to 6 h	2	2.7
6-8 h	37	50.7
More than 8 h	34	46.6
Way of accessing their workplace		
On foot	8	11
Transportation	38	52.1
Car/Motorbike	27	36.9
Smoking		
Smoker	26	35.6
Former smoker	20	27.4
Never	26	35.6
History of Allergies		
Yes	18	24.7
No	54	74
History of Rhinitis		
Yes	11	15.1
No	62	84.9

Table 4
Prevalence of SBS symptoms reported by the participants (n = 73).

SBS Groups and Individual Symptoms[1]	No.	%
Eye Irritation	43	70.4
Nonspecific Symptoms		
Headache	47	77
Unusual tiredness or fatigue	54	88.5
Drowsiness	47	77
Difficulty in remembering things or in concentrating	45	73.8
Dizziness or lightheadedness	36	59
Upper Respiratory Symptoms		
Sore throat	24	39.3
Dry throat	37	60.6
Stuffy or runny nose	34	55.7
Sinus congestion	34	55.8
Cough	39	63.9
Skin Irritation		
Skin dryness or rash	28	45.9

An SBS group was regarded as being present if any subject reported at least one building-related symptom from that group.

related symptoms than those who did not have allergies. The most significant differences concerned nose- and eye-related symptoms, as well as throat dryness and irritation.

4. Conclusions

We examined the indoor and outdoor concentrations of $PM_{2.5}$ and BC in four types of office rooms with different characteristics (ventilation, human traffic, and presence of electronic equipment such as printers). The diurnal variations in indoor to outdoor ratio for $PM_{2.5}$ and BC in the printing and archiving rooms was >1 during working hours. In the printing room the high I/O ratio for $PM_{2.5}$ and BC can be attributed to indoor activities such as printing and photocopying. In contrast, the high I/O ratios for $PM_{2.5}$ and BC in the archiving room were due to occasional smoking in the adjacent room. The office room exhibited higher I/O ratios for $PM_{2.5}$, indicating pollutant transport from outdoors due to the occasional opening of the windows for ventilation by the employees. Finally, the low I/O ratio in the maps file room can be attributed to the closed windows and the lack of pollutant transport from the outdoor environment. The office room, which had the same characteristics with the majority of the offices in the building and housed the majority of employees, had indoor $PM_{2.5}$ concentrations during working hours that were always well below the recommended indoor 24 h mean PM standards (5.9–14 μg/m^3; WHO 2005). The average indoor BC concentrations during working hours ranged from 1.2 to 1.9 μg/m^3 and were comparable to typical European urban background levels (Harrison et al., 2012; Fuller et al., 2014; Diapouli et al., 2017). Smoking, employee density, outdoor pollutant concentrations, temperature and humidity were the most common determinants of PM in offices. Deposition rates also varied substantially between office rooms and experimental periods, which may be attributed to different types of rooms (ventilation, surface area), construction characteristics and different employee indoor activities.

The most commonly reported SBS symptoms were irritation of the eyes, a stuffy or runny nose, headache and drowsiness. About half of the participants reported skin and throat dryness, as well as nose stuffiness. The questionnaire analysis revealed that the employees experienced a variety of symptoms that occurred "often" or "always" and subsequently disappeared after leaving the building. Results also showed that female employees were more likely to report SBS symptoms than male employees, with regards to nonspecific symptoms ("unusual tiredness or fatigue", "feeling depressed"). As expected, the majority of smokers reported "eye irritation", "stuffy or runny nose" and "respiratory symptoms" (cough) than non-smokers. Those who worked in the printing room were more likely to report eye irritation, upper respiratory and non-specific symptoms than employees working in the office and archiving rooms.

Our findings provide useful insights for linking IAQ with SBS syndrome symptoms, highlighting the necessity for improving air quality in public office buildings. To protect the health of office employees it is recommended to place instruments such as photocopiers and printers away from the employees' breathing zone (and if possible in separate rooms), keep office rooms well ventilated, and perform regular maintenance on office equipment and ventilation systems. Additional pollution control measures will be useful to improve indoor air quality in offices worldwide, particularly in developing nations and countries where regular indoor air pollution monitoring does not occur. Future studies in public buildings and offices should include parameters such as concentrations of ultrafine particles and carbon dioxide. The analysis of these pollutants in combination with PM and BC concentrations will be useful to better understand the contribution of indoor air quality to employee health and SBS symptoms.

Author contributions

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

Table 5
Odds ratios (OR) and 95% confidence intervals for associations between risk factors and SBS symptoms.

	Sex Female vs Male		Age ≥45 Years vs < 45		Allergic History[a] Yes vs No		Smoking Yes vs No	
SBS Groups and Individual Symptoms	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Eye Irritation	1.6	0.5–5.1	1.3	0.4–4.1	0.3	0.1–1.8	2.0	0.6–6.4
Nonspecific Symptoms								
Headache	1.4	0.4–4.9	0.6	0.1–2.1	0.5	0.1–2.8	1.7	0.5–6.0
Dizziness or lightheadedness	0.9	0.3–2.8	0.9	0.3–2.7	0.3	0.8–1.4	1.2	0.4–3.7
Difficulty in remembering things or in concentrating	1.0	0.3–3.5	0.4	0.1–1.5	0.1	0.1–1.5	0.9	0.2–3.0
Unusual tiredness or fatigue	5.4	0.9–30.9	0.9	0.1–4.6	0.5	0.1–5.3	1.6	0.3–8.1
Drowsiness	0.6	0.1–2.3	0.6	0.1–2.1	0.5	0.1–2.8	1.7	0.5–6.0
Feeling depressed	4.1	0.6–24.5	0.6	0.1–3.5	1.1	1.0–1.2	1.0	0.1–6.1
Upper Respiratory Symptoms								
Nose Irritation	1.1	0.3–3.1	0.4	0.1–1.2	0.3	0.1–1.2	1.4	0.4–4.1
Stuffy or runny nose	0.8	0.2–2.3	0.3	0.1–0.9	0.3	0.1–1.2	1.9	0.6–5.6
Sore throat	0.9	0.3–2.6	0.5	0.1–1.4	0.3	0.1–1.1	1.3	0.4–3.9
Dry throat	0.4	0.1–1.3	0.6	0.2–1.8	0.2	0.1–1.0	1.4	0.4–4.2
Cough	0.7	0.2–2.2	0.4	0.1–0.3	0.2	0.1–1.2	2.4	0.8–7.2
Skin Irritation	1.1	0.3–2.1	0.4	0.1–1.3	0.1	0.1–0.3	1.0	0.3–3.0

[a] Allergic history refers to asthma, eczema, sinusitis, hay fever, allergies to dust and mold.

Resources. Nikolay Sitnikov: Methodology, Resources. Olga-Ioanna Kalantzi: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. All authors read and approved the final manuscript.

Declarations

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.

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

No funding was received for this work.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The aethalometer was developed under Russian Science Foundation (RSF) support, project number 19773004. Methodological work was partly supported by Russian Ministry of Education and Science (14. W03.31.0008).

Appendix A. Calculation of the Deposition Rates

This APPENDIX describes the methodology and the calculation of the deposition rates of PM (Halios et al., 2009). To estimate the deposition rates we use a mass balance equation expressed as:

$$\frac{dC_i}{dt} = m\lambda C_o - \alpha m\lambda C_o - m\lambda C_i - K_\tau C_i + \frac{S}{V} \quad (1)$$

where V is the volume of the space, C_i is the indoor concentration (μg m^{-3}), C_o is the outdoor concentration (μg m^{-3}), α is the fraction of pollutants filtered from air entering the room (nondimensional), m is the mixing factor (nondimensional), λ is the ventilation rate (h^{-1}), K_τ is the deposition rate (h^{-1}), and S is the source or sink strength (μg m^{-3} h^{-1}). For relatively small rooms, as the ones in which this work was carried out, we can assume homogeneity; i.e., that the concentration is the same in every part of the room. A penetration factor is usually employed for aerosol particles in order to account for losses during particle exchange between indoors and outdoors. However, black carbon is found to reside in a size mode (0.1–0.5 μm), where penetration is maximum (Sarnat et al., 2006). Under these assumptions, the mass balance equation can be re-expressed as:

$$\frac{dC_i}{dt} = \lambda C_o - \lambda C_i - k_\tau C_i + \frac{S}{V} \quad (2)$$

Assuming steady-state conditions (i.e., $dC_i/dt = 0$), and that the ventilation rate is constant, Eq. (2) becomes:

$$C_i = \left[\lambda/(\lambda + k_\tau)\right] C_o + S/V(\lambda + k_\tau) \quad (3)$$

which can be expressed as:

$$C_i = \alpha C_o + b \quad (4)$$

where values of *a and b* can be determined by regression. In the case of outdoor pollution, $b = 0$. As a result, the slope of the linear regression model between indoor and outdoor values gives:

$$\alpha = \lambda/(\lambda + k_\tau) \quad (5)$$

and thus the deposition rate is given by:

$$k_\tau = \lambda\left(1/\alpha - 1\right) \quad (6)$$

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