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Size distribution and chemical composition of indoor and outdoor particles in lab building

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ABSTRACT:

Introduction: Exposure to toxic components in indoor PM is associated with a wide spectrum of adverse respiratory and cardiovascular health effects. The fine PM pollution in ambient air is currently a major health concern in Iran and is driving increasing research interest. Due to air pollution in Tehran metropolitan, it is necessary to study the concentration and size distribution of particles inside and outside the building.

Materials and methods: Hence, for this study, concentration and size distribution of particles matter was calculated with diameters of $PM_{\leq 0.4}$, $PM_{0.4-0.7}$, $PM_{0.7-1.1}$, $PM_{1.1-2.1}$, $PM_{2.1-3.3}$, $PM_{3.3-4.7}$, $PM_{4.7-7}$, PM_{7-11}, $PM_{\geq 11}$ and TSP during two seasons in the lab building in the Tehran. Measurements on the aerodynamic size of atmospheric aerosols carried with Anderson type 1-ACFM Cascade Impactor with six-stage. The length of each collection period was about 24 h.

Results: The results show that the effect of outdoor air pollution on the concentration of particles in the indoor environment is significant. According to these results, the lowest value is for particles with a diameter greater than 11 µm. the highest value of this ratio is dedicated to $PM_{\leq 0.4}$ and with the increase of the aerodynamic diameter of the particles, the I/O decreases as well. A similar trend was recorded for concentration of TSP. The highest difference in the concentration of TSP in indoor and outdoor was 60.25 and 188.36 µg/m^3, respectively.

Conclusion: This effect is due to factors such as the lack of standard ventilation, old doors and windows and the life of the building.

Introduction

Several studies have been conducted on the impact of air pollution on health. This studies indicated a significant relationship between air particles and different diseases such as respiratory and cardiovascular diseases [1, 2]. The recent studies indicated that $PM_{2.5}$ is responsible for 30 million early deaths in 2010 all around the world [3]. The particles lower than $PM_{2.5}$ have the highest impact on human health. Since they can penetrate into the deepest parts of respiratory system and lungs, and cause harmful ef-

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fects [1, 4]. Recently, the World Health Organization introduced outdoor air pollution as a class 1 carcinogen on a global scale. The guideline of the World Health Organization in 2005 considered maximum annual and daily mean amount of $PM_{2.5}$ as 10 and 25 µg/m^3, respectively [5, 6]. In order to identify the health impact and exposures, identifying the relationship between indoor and outdoor air pollutions is necessary. One of the indicators which are widely used for evaluating the impacts of indoor pollutions resulted from outdoor pollutions is the ratio of indoor to outdoor air pollution (I/O ratio) [7, 8]. In the absence of severe resources of indoor pollutions, different studies indicated higher concentrations of outdoor pollutions. Moreover, spatial and temporal fluctuations of outdoor particles can affect the I/O ratio. Seasonal fluctuations and ventilation mode, along with the behavior of residents, can affect the I/O ratio [9 - 12]. Some factors, such as distance from polluting resources, climate, the life of the building, and its architectural characteristics can affect indoor air pollution which is resulted from outdoor air pollution. In indoor environments, smoking, cooking, and particles resuspension due to the presence of people play an important role in the particle; concentration [13 - 15].

The previous study indicated that indoor and outdoor resources affect indoor air pollution and he mentioned that traffic as the outdoor reason of 50% of the combustion pollutants in urban environments. According to the fact that people spend most of their times in indoor environments, the impacts of outdoor pollutants on human health as a problematic issue [16 - 18]. The results of I/O ratios are different in various studies so that those modem building that has mechanical ventilators without any indoor activity has a ratio equal to zero or near to zero. For occupational environments or residential building with high amounts of smoking and activity is higher than 10 [19, 20]. In the last two decades, PM_{10} and $PM_{2.5}$ indicators are used for I/O ratios determination [21, 22]. Certain researchers reported that the concentration of indoor PM_{10} is higher than outdoor PM_{10} in a commercial building with natural ventilation [23]. Other researchers reported higher PM_{10} concentrations in indoor environment for work hours if comparison with non-working hours [24 - 29, 7]. The finding in Xian Jiaotong University, about residential and commercial buildings of Beijing, is obviously indicative of a wide change in PM_{10} concentrations [29]. The higher concentrations are reported to be restaurants, dormitories, and classrooms and lower concentrations are reported to be in supermarkets, computer rooms, offices, and laboratories. Some researchers in their studies, used the PM_4 indicator in determining the I/O ratio [30]. The utilization of PM_1, $PM_{2.5}$, PM_{10} and TSP indicators is reported in three studies, which are done on schools and universities of central Europe and other places [26, 29, 31 – 33]. In a research that was conducted in Xian Jiaotong University, studied the effects of difference in indoor and outdoor temperatures on the penetrability of outdoor particles [34]. Their results indicated that the difference in indoor and outdoor temperatures widely affect the penetrability of small particles; if the amount of this difference increases, penetrability increases as well. Moreover, temperature differences affect the I/O ratio. These effects are more intense on $PM_{2.5}$ in comparison with PM_{10}. A significant number of these studies have also been conducted in schools and educational centers. In another study in Texas, it was calculated pollutant of NO_2 for twenty schools in 1999 [35]. In the Netherlands, the pollutant of NO_2 evaluated for six schools including three schools were in areas varying degrees of urbanization and three other schools in located near highways with varying traffic density for a year from 1997 to 1998 [36]. Also, in California at 10 schools was measured the concentration of NO_2 for spring and fall 2004 [37]. In Pennsylvania State, was measured the pollutant rate of NO_2, CO, O_3 and number concentration of sub-micrometer particles (<1.0 μm) for four schools in the area with differing traffic levels for 17 days of spring 2005 [38]. In Australia (Brisbane city) in the same study, was measured the concentration of sub-micrometer particles (<1.0 μm) for a school located in a small village with low levels of traffic in 1996 [39]. Also in another study was calculated concentration of NO_2 and PM_{10} for thirteen schools in the Netherlands [40]. Similar to the research in East Harlem of New York; in Istanbul of Turkey, and in Prague of Czech Republic, were calculated the concentration of $PM_{2.5}$ in schools [41 – 43]. Also, in Hong Kong, were measured the concentration of aerosols (such as: PM_{10}, $PM_{2.5}$, NO_2, O_3) in schools buildings [44]. In a study recently conducted done in exercise centers, entry of aerosol particles from the outside into the building was evaluated [45]. Tehran as the capital of Iran suffers from serious air pollution problems because of rapid industrialization and urbanization. High traffic, transportation vehicles, and industrial activities affect residential, commercial, and official building in this city, which are widely under the influence of outdoor air pollution. However, limited data on particulate pollution in indoor and outdoor environments in Tehran are available. In addition, the effects of climatic conditions and building characteristics on the relationship between indoor and outdoor pollution should be determined for different geographic locations [22, 46, 47]. Contamination in different environments such as the laboratory, in addition to human health, can also affect the test results. The evaluated changes in the concentration and size distribution of particles in the lab building was the goals of this research. In this research, was selected the safety and environment Lab in Nuclear Science and Technology Research Institute in Amirabad, Tehran for sampling site. Therefore, contrary to other studies, extensive size of $PM_{\leq 0.4}$, $PM_{0.4–0.7}$, $PM_{0.7–1.1}$, $PM_{1.1–2.1}$, $PM_{2.1-3.3}$, $PM_{3.3-4.7}$, $PM_{4.7–7}$, $PM_{7–11}$, $PM_{\geq 11}$ and TSP particles along with I/O ratios are assessed for lab building.

Materials and methods

The monitoring of the particles was carried out all the two seasons in summer 2018 and winter 2019. The concentration of $PM_{\leq 0.4}$, $PM_{0.4–0.7}$, $PM_{0.7–1.1}$, $PM_{1.1–2.1}$, $PM_{2.1–3.3}$, $PM_{3.1–4.7}$, $PM_{4.7–7}$, $PM_{7–11}$, $PM_{\geq 11}$ and TSP, was measurement. Sampler device was with 1.5 m distance from the earth surface and inside lab buildings. The sampling process was conducted on three labs. Measurements on aerodynamic size of atmospheric aerosols carried with Anderson type 1-ACFM Cascade Impactor with six-stage. The 1-ACFM design operated at 28.3 L/min (1 ft^3/min). In the Anderson Cascade Impactor the particles are carried by a flow in a curvilinear trajectory and depending on their stokes number they are collected in different stages according to their aerodynamic size. The particles in each stage can be counted by weight (weighting the collected particles) [46]. The difference in weight of steel stages before and after sampling will indicate the rate of PM collected. The length of each collection period was about 24 h. Because of this, the sampling process was selected in four seasons to determine the effect of student's presence and absence on particle concentration. Before sampling, the stages of Impactor were pre-heated in a muffle furnace at 500ºC for h to remove organic impurities. In each sampling period, the preparation process was performed for each stage of the impactor. For data analysis, SPSS 18 and the related tests, such as correlation coefficient test, were used for determining the relationship between I/O ratio and atmospheric variables. The ratio of I/O in Tehran was studied for a different condition, and its relationship with environmental indicators was analyzed. For I/O ratio determination, use the Equation; $I/O = C_{in} / C_{out}$, that C_{in} is a concentration of particles indoor and C_{out} is a concentration of particles outdoor [22].

Results and discussion

The changing trends for the concentration of $PM_{\leq 0.4}$, $PM_{0.4-0.7}$, $PM_{0.7-1.1}$, $PM_{1.1-2.1}$, $PM_{2.1-3.3}$, $PM_{3.3-4.7}$, $PM_{4.7-7}$, PM_{7-11}, $PM_{\geq 11}$ and TSP particles in indoor and outdoor environments for summer and winter indicted in Figs. 1 and 2. As can be seen in all the figures, the condition of indoor particles is under the influence of outdoor particles, this influence is more observable in smaller particles. According to these results, particles with diameters larger than 11 μm ($PM_{\geq 11}$) had a high mean concentration difference with the measured values the indoor and outdoor environments. As well as the average concentration of a particle with a diameter of 0.4 μm ($PM_{\leq 0.4}$) was low during the seasons. A similar trend was recorded for concentration of TSP. The highest difference in the concentration of TSP in indoor and outdoor was 60.25 and 188.36 μg/m^3, respectively. The mean indoor/outdoor concentration of TSP for summer and winter was indicated in Fig. 3.

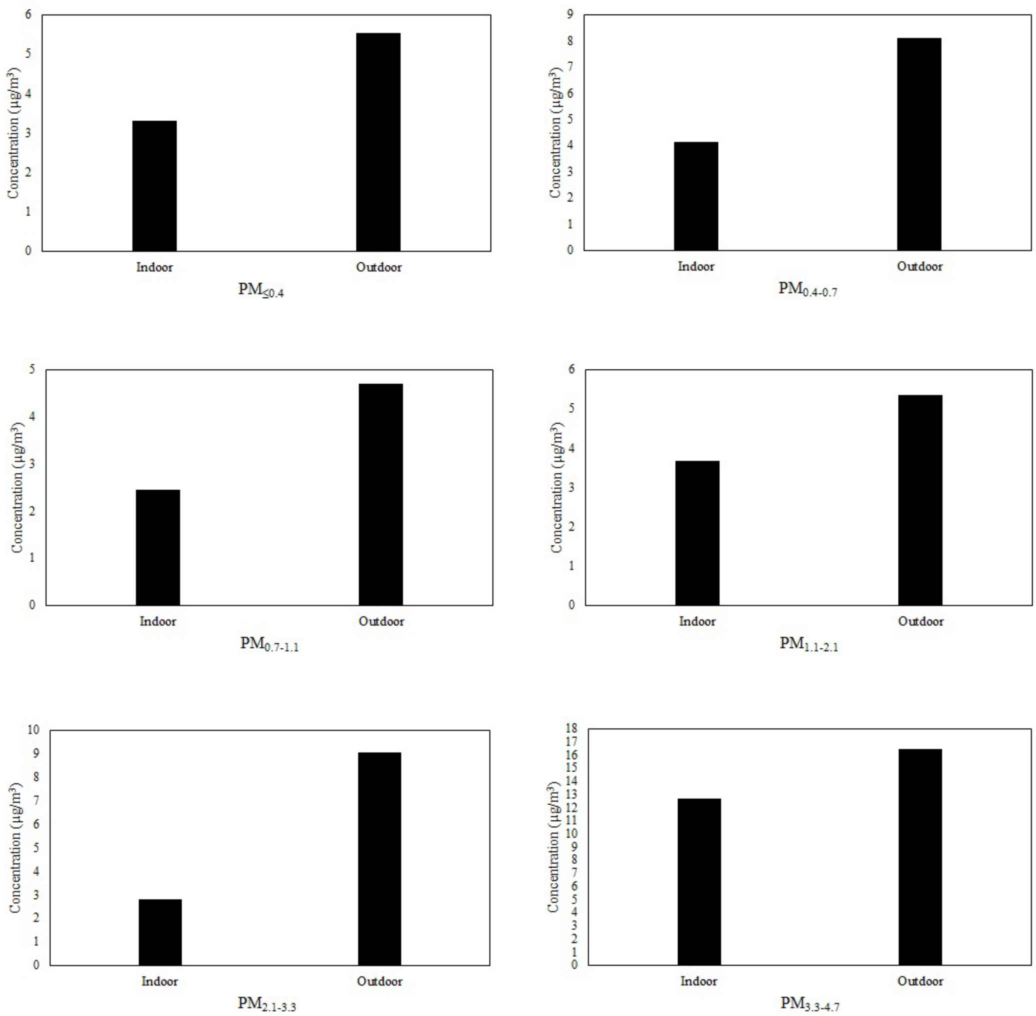
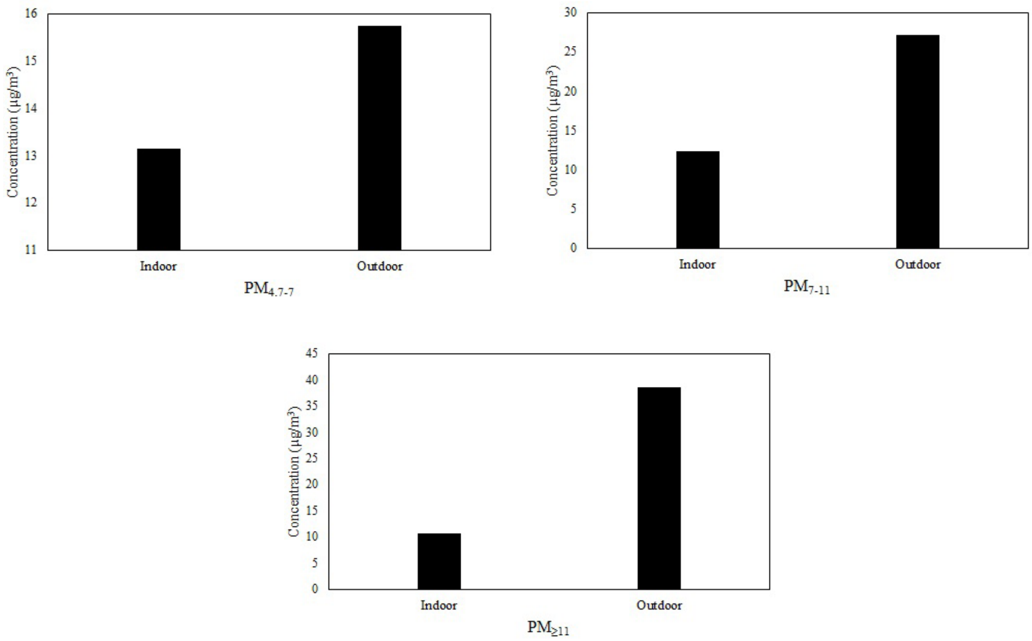


Fig. 1. The concentration of aerosols in indoor and outdoor environments in summer



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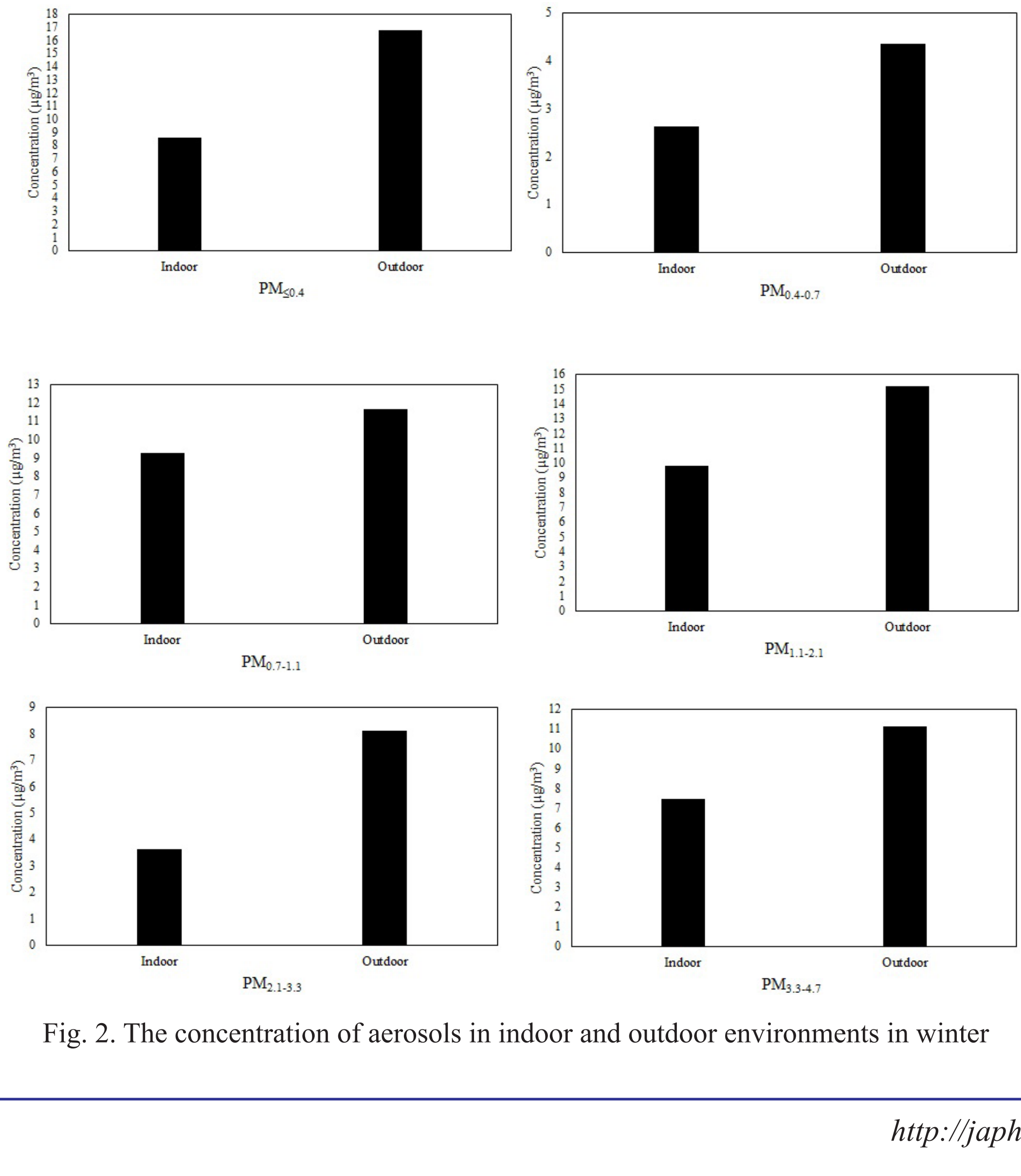

Fig. 2. The concentration of aerosols in indoor and outdoor environments in winter

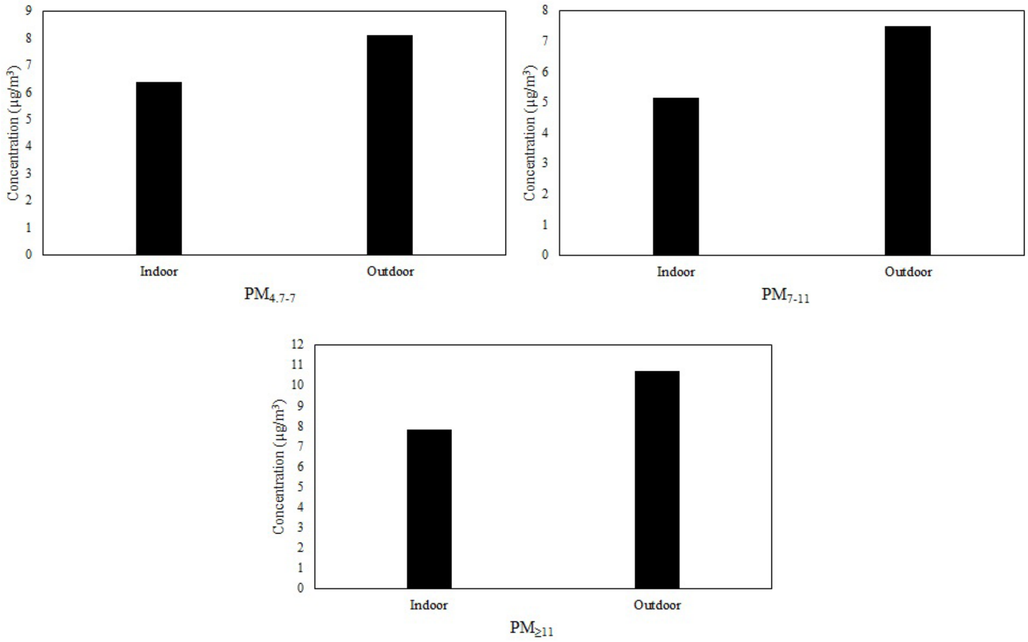

Fig. 2. The concentration of aerosols in indoor and outdoor environments in winter

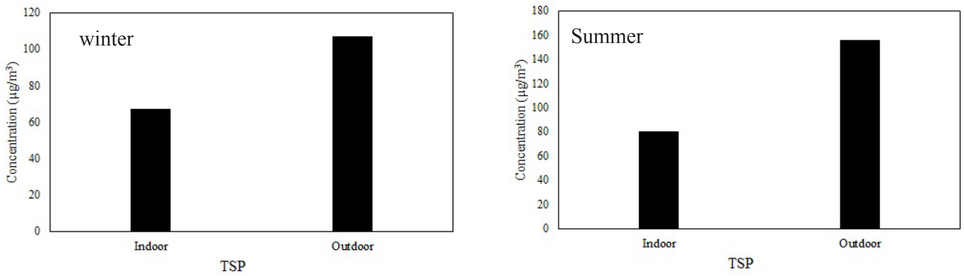

Fig. 3. The concentration of TSP in indoor and outdoor environments in summer and winter

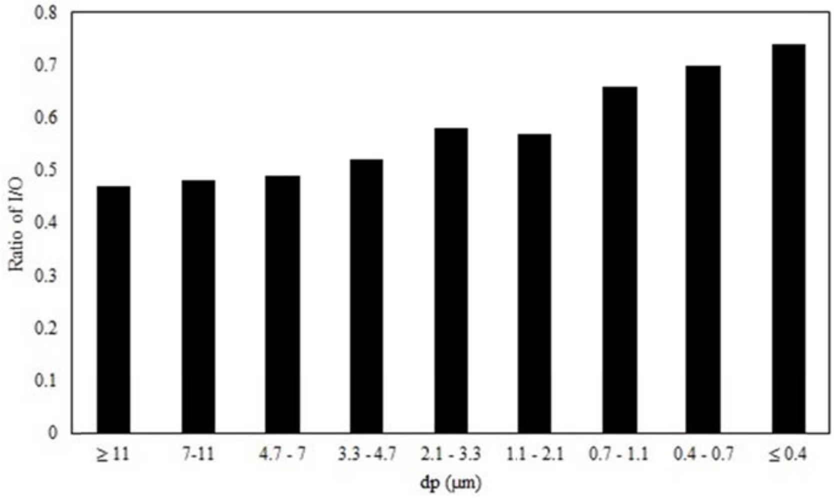

Fig. 4. Mean of I/O ratio for particles in summer with different aerodynamic diameters

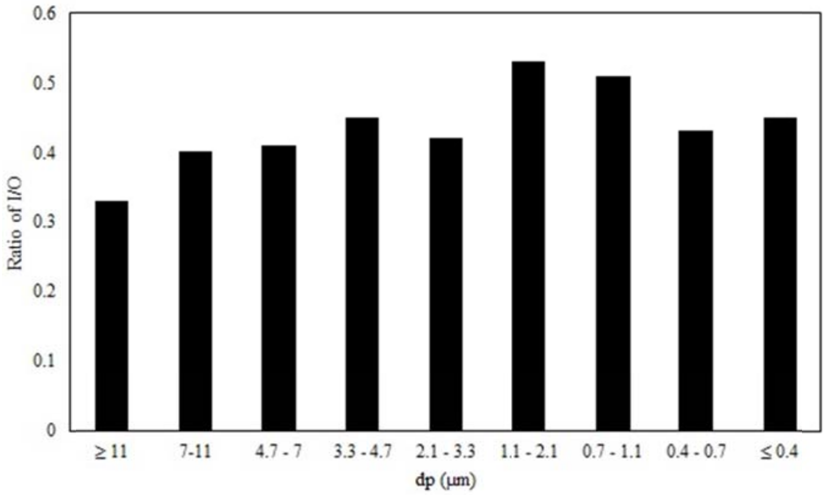

Fig. 5. Mean of I/O ratio for particles in winter with different aerodynamic diameters

The annual mean of I/O ratio for summer and winter with different the aerodynamic diameters is indicated in Figs 4. and 5. According to these results, the lowest value is for particles with a diameter greater than 11 µm. the highest value of this ratio is dedicated to $PM_{\leq 0.4}$ and with the increase of the aerodynamic diameter of the particles, the I/O decreases as well. Of course, the trend has been increasing in particles with a diameter of $PM_{2.1\text{-}3.3}$ and the trend is falling again. Also, the changing trend of I/O ratio for those particles that have different aerodynamic diameters has been reviewed during a year. The results of this review show that I/O ratio is less than 0.8 in most particles.

The lowest and highest indoor concentration of $PM_{\leq 0.4}$ was 2.12 and 10.4 µg/m^3, which recorded in winter and summer, respectively. Also, the highest and lowest outdoor concentration was 17.3 and 2.6 µg/m^3, which recorded in summer and winter, respectively. The results indicated that lower and higher of I/O ratio was in winter and summer with values 0.24 and 0.61, respectively. The results indicated that the correlation coefficient for various aerodynamic diameters is different from 0.66 to 0.35 for outdoor concentration; with the increase of diameter differences, the value of the correlation coefficient decreases. This coefficient for indoor concentration is varied from 0.61 to 0.35 which decreases with the increase of aerodynamic diameter. The lowest I/O ratio with value 0.24 in winter and the highest value with 0.65 in summer calculated for $PM_{0.4\text{-}0.7}$ particle. The highest and lowest concentration $PM_{0.4\text{-}0.7}$ for indoor and outdoor were 8.21, 3.02 and 16.77, 3.62 µg/m^3, respectively. Based on these results, the highest and lowest in indoor concentrations of $PM_{0.7\text{-}1.1}$ were 12.11 and 3.2 µg/m^3, respectively, and for outdoor concentration were 18.64 and 3.53 µg/m^3, in summer and winter, respectively. The results indicated that lowest ratio of I/O in winter (with amount 0.37), and higher value in summer (with amount 0.58). The lowest and highest I/O ratio of $PM_{1.1\text{-}2.1}$ was in winter and summer with the amount of 0.21 and 0.63, respectively. Also, the lowest concentration of $PM_{1.1\text{-}2.1}$ in indoor and outdoor were 2.51 µg/m^3 and 5.62 µg/m^3, respectively.

The results showed that I/O ratio of $PM_{2.1-3.3}$ in winter and summer with 0.23 and 0.64 was the lowest and highest, respectively. Based on these results, the highest and lowest indoor concentration of $PM_{2.1-3.3}$ for summer were 6.35.34 and 2.44 µg/m^3 respectively, and for outdoor concentration, winter and summer were 17.73 and 5.64 µg/m^3, respectively. Based on these results, the lowest and highest ratio of I/O ratio of $PM_{3.3-4.7}$ was in winter and summer with amounts of 0.26 and 0.73, respectively. Also, the highest and lowest indoor concentration of $PM_{3.3-4.7}$ particles calculated in 16.32 and 5.22 µg/m^3, respectively. The results indicated that the lowest and highest I/O ratio of $PM_{4.7-7}$ in winter and summer with the amount of 0.27 and 0.68, respectively. Also, the lowest and highest indoor concentration of $PM_{4.7-7}$ in winter and summer with values 4.46 and 26.42 µg/m^3, respectively. The lowest and highest indoor concentration of PM_{7-11} was in summer (6.52 µg/m^3) and winter (30.11 µg/m^3), respectively. Also, the highest and lowest of I/O ratio was 0.53 and 0.24 in autumn and summer, respectively. The results showed that lower and higher ratio of I/O $PM_{\geq 11}$ was 0.24 in winter and 0.58 in summer, respectively. Based on results, the highest and lowest indoor concentration was in summer and winter with 38.25 and 4.52 µg/m^3, respectively. Also, the lowest and highest outdoor concentration was in summer and winter with 17.45 and 44.63 µg/m^3, respectively. The results indicated that lower and higher of I/O ratio TSP was 0.32 and 0.61 in winter and summer, respectively. Also, the lowest and highest indoor concentration of TSP was in winter (60.25 µg/m^3) and summer (104.63 µg/m^3), respectively.

One of the most important indicators for determining effects of outdoor pollutants on indoor pollutants is I/O ratio determination [7, 8]. Some of these studies are: in the Athens area, in seven primary schools [47]; in three secondary schools in Lublin, Poland during the winter and summer [31]; in three naturally and six mechanically ventilated micro-environments of a mix-use commercial building in Delhi, India [26]; in the air in two teaching rooms in two Polish cities, Gliwice Warsaw [48]; in a building located in the urban area of Bologna, Italy [24]; in fourteen office US [49]; in the different compartment of the Brazilian Antarctic station and in two copy centers in Aveiro, Portugal similar studies have been done on the size distribution of indoor and outdoor particles [50, 23]. In this study, the calculated values for this ratio are agreed with some of the previously studied. The results of this research, the ratio of I/O is resulted to be less than 1, which agrees with studies: The study conducted in Queensland in primary school [39] and assess the relationships between particles number and mass concentration outdoor at a central site, right outside and inside the study home in four European cities: Birmingham, Amsterdam, Helsinki, and Athens [9]. The results of this study indicated that the highest value of I/O ratio was for $PM_{\leq 0.4}$ with the increase of the aerodynamic diameter of the particles, the value of I/O ratio decreases. The results of this study were consistent with the reported results in Xian Jiaotong University, that this results indicated the difference between indoor and outdoor temperatures can cause higher penetrability of the smaller particles ($PM_{\leq 0.4}$) in comparison with the bigger particles ($PM_{\geq 11}$) [34]. The reason for the higher penetrability of the small particles is the Brown diffusion effect. This effect causes a disturbance for particle deposition in the input pores and makes it possible for the smaller particles to penetrate through them [34]. The highest correlation coefficient is for $PM_{\leq 0.4}$ particle which is indicative of higher affectability of smaller particles (in comparison with bigger particles) of indoor environments. There were no significant relationship between the variables of type of use (residential, commercial, or official), heating and cooling devices, type of doors and windows (aluminum, metal, wood, or PVC), life of building, relative outdoor humidity, wind speed, and indoor and outdoor temperatures with I/O ratio for different particles ($P>0.05$). On the other hand, there was a significant relationship between season (spring, summer, autumn, and winter), ventilation type (natural or artificial), outdoor and indoor temperature with I/O ratio for different particles ($P<0.05$). In this study, indoor and outdoor concentration and I/O ratio of $PM_{\geq 11}$, $PM_{7\text{-}11}$, $PM_{4.7\text{-}7}$, $PM_{3.3\text{-}4.7}$, $PM_{2.1\text{-}3.3}$, $PM_{1.1\text{-}2.1}$, $PM_{0.7\text{-}1.1}$, $PM_{0.4\text{-}0.7}$, $PM_{\leq 0.4}$ and TSP particles evaluated for each season. The results indicated that the ratio of I/O for different particles is higher in warmer and moderate seasons in comparison with winter and autumn seasons. This ratio for $PM_{\leq 0.4}$ reaches its highest value in spring. The lowest value was recorded to TSP and $PM_{\geq 11}$, with 0.11 and 0.1 values, respectively in winter. Also, the higher value was recorded to the concentration of particles matter in summer and spring. The results indicated that with the increase of particle size, the ratio of I/O decreases in all the seasons. One of the most important parameters which can increase the value I/O ratio is natural ventilation [19, 51, 52]. Field studies and the results of this study indicated that the selected buildings had the highest amount of natural ventilation in warm and mild seasons. In cold seasons, none of these buildings used natural ventilation was indicated that seasonal fluctuations and type of ventilation affect the ratio of I/O [53].

Conclusion

Indoor air pollutions are either generated indoors or transported from the outdoor. Indoor particle concentration is a combination of outdoor particle infiltration and particle generation by internal sources. A number of human activities, such as conducting and parking vehicles, using cosmetic, cigarette smoking, toiletries, cooking and cleaning, candles and heating systems have been found to contribute to an increase in the concentrations of indoor particles. The change rate of an indoor pollutant concentration is therefore governed by sources and sinks. According to the results, the pollutant resources of indoor environments can be considered to be outdoor pollutants; therefore, most probably, amounts of outdoor particles penetrate into the indoor environment. Among all the effective factors, ventilation type and outdoor temperature have the most important role. So that with an increase in the outdoor temperature and using a natural ventilation method, I/O ratio will increase as well. There were no significant relationship between the variables of type of use (as residential, commercial, or official), heating and cooling devices, type of doors and windows (such as aluminum, metal, wood, or PVC), life of building, relative outdoor humidity, wind speed, and indoor and outdoor temperatures with I/O ratio for different particles . The results of this study indicated that the highest value of I/O ratio is for the $PM_{\leq 0.4}$ and with an increase in the aerodynamic diameter of the particles, this ratio decreases. I/O ratios in spring and summer have the highest values, and they have the lowest values in cold seasons; the reason can be the lack of natural ventilators in cold seasons.

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Competing interests

The authors declare no competing interests.

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Ethical considerations

Ethical issues (Including plagiarism, Informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely observed by the authors.

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