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Research article

Assessing the risks associated with indoor and outdoor air quality in relation to the geographic placement of nursing home

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A R T I C L E I N F O

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A B S T R A C T

Indoor air quality significantly impacts the well-being and health of elderly residents in nursing homes. This study was conducted to explore the connection between indoor and outdoor PM (Particulate Matter) concentrations in nursing homes and their association with the facilities' location and construction characteristics. The findings revealed that indoor $PM_{2.5}$ and PM_{10} concentrations ranged from 0.2 to 124 μg/m^3 and 2–188.4 μg/m^3, respectively, which were approximately 12.67 and 1.25 times higher than their outdoor counterparts. A strong correlation ($P < 0.05$) was identified between indoor PM levels and various factors, including proximity to parks, passenger terminals, and gas stations, as well as building attributes such as single-glazed windows, ceramic floor coverings, and the use of radiators. The risk assessment indicated that carcinogenic risk factors were well within acceptable limits for all nursing homes. However, it's important to note that certain PM components, particularly polycyclic aromatic hydrocarbons (PAH), may have long-term adverse effects on the health of nursing home residents. Even though indoor PM levels met the standards established by the U.S. Environmental Protection Agency (USEPA) for particulate matter risk assessments, the study emphasized that even low levels of indoor air pollutants can affect the health and well-being of older adults, particularly considering the increased vulnerability associated with aging. Consequently, the study underscores the importance of nursing home location selection and the regular monitoring of particulate matter concentrations. These measures are essential for enhancing air quality within nursing homes, ultimately contributing to the improved well-being and health of their residents.

1. Introduction

According to reports by Loomis et al., in 2013 and 2014, the International Agency for Research on Cancer (IARC) has categorized outdoor air pollution and its particulate matter (PM) components as carcinogenic (category 1) to humans [1,2]. Moreover, Han et al. (2016), Mehta et al. (2016), Power et al. (2011), Weuve et al. (2012) and Siregar et al. (2022) have shown that PM exposure is associated with a number of diseases, such as acute airway inflammation, pneumonia, chronic obstructive pulmonary disease, asthma, autonomic dysfunction, renal and cognitive impairment, as well as cardiovascular and respiratory mortality [3–7]. Guidelines for particulate matter ($PM_{2.5}$ and PM_{10}) concentrations in indoor air are provided by the World Health Organization (WHO). According to

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these recommendations, the 24-h average of $PM_{2.5}$ concentration should not be more than 25 μg/m3, and the annual average should not be higher than 10 μg/m3. Similarly, for PM_{10}, a 24-h average limit of 50 μg/m3 should be observed, and the annual average value should not surpass 20 μg/m3. These recommendations are meant to safeguard the general public's health and lower the chance of respiratory and cardiovascular conditions brought on by indoor air pollution exposure. As noted in the works of Majd et al. (2019) and Reddy et al. (2021), there are a number of factors that affect the indoor air quality of nursing homes, including ventilation rates, construction materials (e.g., flooring type), heating systems, window specifications (single or double glazing), and the presence of nearby facilities like parks, gas stations, passenger terminals, and ongoing construction activities [8,9].

Particularly, PM exposure—that is, particulate matter with a diameter of 2.5 μm or less—is found to be relatively lower in nursing homes. As the world's population ages, it is important to recognize that Iran's elderly population will experience a 25 % increase (DESA, 2015). This demographic group, the majority of whom are over 65 [10], is especially susceptible to the negative effects of air pollution because of their chronic health conditions and compromised immune systems. As a result, even extended exposure to low levels of indoor air pollutants can have a substantial negative impact on their health, well-being, and general quality of life, as explained by Segalin (2017) [11].

According to numerous studies, the interior air pollution levels at nursing homes are frequently higher than those outside. Reddy et al. (2021) pointed out that, regrettably, interior air quality (IAQ) in nursing homes is not regularly measured, in contrast to outside air quality [9]. Thus far, the main attention has been on gaseous pollutants and the air pollution index (API). It is essential to comprehend the dynamics of indoor and outdoor particle matter and their interactions in order to solve these challenges. Thus, it is highly desirable to create nursing homes that reduce indoor PM production and release in terms of location and building materials.

The importance of improving indoor air quality in nursing homes, where the health and well-being of the elderly are at risk, cannot be overstated in light of the world's aging population. In contrast to outdoor environments, indoor air quality in nursing homes is not subject to legislative regulation and is rarely observed. This is due to the lack of national IAQ standards and low awareness of inadequate IAQ risks in these settings (United States Environmental Protection Agency, n.d.). As a result, professional and technological resources are inadequately equipped to monitor and report IAQ data in nursing homes, nor to carry out the necessary corrective actions as recommended.

This study represents a ground-breaking effort to compare indoor and outdoor particle matter (PM_{10} and $PM_{2.5}$) exposure in nursing homes and assess the associated health risks. Through extensive assessments carried out at eighteen assisted living facilities, the study aims to accomplish the following goals: [1] Calculate the concentrations of $PM_{2.5}$ and PM_{10} in these nursing facilities' interior and outdoor settings. [2] Describe the connection between the amounts of particulate matter indoors and outdoors. [3] Assess how outside influences affect indoor PM concentrations. [4] Evaluate the dangers of exposure to PM in Mashhad.

2. Methods and materials

2.1. Study area

The study was carried out at nursing homes located in different metropolitan regions of Mashhad, which is Iran's second-largest city and has a cold, semi-arid climate. Mashhad, which has a population of over 3,208,000, is home to 18 nursing homes that care for 632 senior citizens in total, according to a report by Mansouritorghabeh et al. from 2022 [12]. The geographic distribution of these assisted living facilities around Mashhad is shown in Fig. 1. Within 500 m of these nursing facilities, the survey results showed that there were nine establishments near parks or green areas, five establishments near gas stations, one establishment near passenger terminals, and six establishments close to active construction.

2.2. Sampling

The sampling dates were determined according to the schedule recommended by the Environmental Protection Agency (EPA). In total, 812 samples were collected, comprising 740 indoor air samples and 72 outdoor air samples. The measurement equipment used in this study included a TES-5200 Mass Particle Counter, which was employed to assess indoor and outdoor particulate matter (PM_{10} and

Fig. 1. Test area map, Location of Nursing Homes and sampling point.

$PM_{2.5}$ concentrations), temperature, and relative humidity. Additionally, the study involved the chemical characterization of PM. The particulate matter sampling procedures were executed at a distance of 4.5–6 m from the entrance of the nursing home, at an elevation of 1.5 m above the floor, and at a flow rate of 2.83 L per minute (SKC company). Each nursing home underwent two rounds of sampling, with a 3-day gap between the two sampling sessions. After digestion, an ICP device was used to identify heavy metals from the filters. A revised version of a questionnaire, adapted from previous research studies, was employed in this investigation. Additionally, certain questions were drawn from the National Environmental Quality Standards (NEQS) of the United States National Institute for Occupational Safety and Health (NIOSH). The questionnaire encompassed two main sections: the first focused on demographic and social aspects, while the second provided information related to the nursing homes under scrutiny. The specific questionnaire sections and their content are detailed in Table 1.

The reference dose (RfD) refers to an estimated level of human daily intake without adverse health effects during a lifetime (mg/kg.day). The RfD was adopted from the Integrated Risk Information System (IRIS) database published by the US EPA.

2.3. Risk assessment

Health risk assessment for PM in indoor and outdoor air was calculated by following steps. At first daily exposure dose for inhalation, digestive, and dermal absorption was calculated according to Equations (1), (2), and (3) in the indoor and outdoor air of nursing homes.

$$D_{ing} = \left(C \times R_{ing} \times EF \times ED \times CF\right) / (BW \times AT) \tag{1}$$

$$D_{inh} = (C \times R_{inh} \times EF \times ED) / (BW \times AT \times PEF) \tag{2}$$

$$D_{dermal} = (C \times SA \times SL \times ABS \times EF \times ED \times CF) / (BW \times AT) \tag{3}$$

where C is the concentration of air pollutants (μg/m^3) which was calculated from an average of pollutant concentrations, Ring is the inhalation rate of the group (m^3/hour), ET is the exposure time (hours/day), and EF is the exposure frequency (days/year). ED is the exposure duration (years), BW is the body weight (kg), and AT is the average time (days The reference dose (RfD) refers to an estimated level of human daily intake without adverse health effects during a lifetime (mg/kg.day) [13]. The RfD was adopted from the Integrated Risk Information System (IRIS) database published by the US EPA [14].

The reference doses (RfD) for PM_{10} and $PM_{2.5}$ are 8.5×10^{-4} and 1.1×10^{-2} mg/kg day respectively [15].

$$RfD = RfC \times IRBW \tag{4}$$

Then the hazard quotient (HQ) was used for health risk assessment from exposure to indoor/outdoor PM (Equation (5)).

$$HQ = \left(D_{ing} + D_{inh} + D_{dermal}\right) / RfD \tag{5}$$

HQ is the ratio of potential exposure to pollutants and its level without adverse health effects. The level of hazard is classified by the HQ value as follows: HQ values less than 0.1 show no hazard exists; HQ values in the range of 0.1–1.0 show a low hazard risk; HQ values in the range of 1.1–10 show a moderate hazard risk, and finally, HQ values over 10 show a high hazard risk [13,16].

In the end, the total non-carcinogenic risk was calculated by the hazard index (HI) by Equation (6) [13]. This represents the overall

Table 1
Characteristics of the nursing homes.

Parameter	Descriptive Statistics
Total number of elderlies	632
Sex	Male:232 Female:400
Window Type	Single-glazed:87.2% Double-glazed:12.8%
Window Status	Open:8.4% Close:91.6%
Fan	Having fan:86% Lack of fan:14%
Fan Status	On:16.4% Off:83.6%
Heating Device	Heater:52.9% Radiator:42.2% Floor heating system:4.9%
Wall Covering	Color:78.4% Stone:3% Wallpaper:18.6%
Floor Covering	Stone:90.4% Parquet:9.6%
Number of nursing homes within 500 meters of the park or green places	9
Number of nursing homes within 500 meters of the petrol station	5
Number of nursing within 500 meters of passenger terminal	1
Number of nursing homes within 500 meters of construction works	3
Number of nursing homes within 500 meters of streets with heavy traffic	6

potential for non-cancer risk from exposure to every pollutant.

$$HI = HQ_1 + HQ_2 + \cdots + HQ_n \tag{6}$$

Additionally, the carcinogenic risk was calculated by the R index by Equation (7). The SF is the cancer slope factor. This factor is 2 $\times 10^{-6}$ mg/kg day for PM_{10}, but the SF value for $PM_{2.5}$ is not specified [17].

$$R = \left(D_{ing} + D_{inh} + D_{dermal}\right) \times SF \tag{7}$$

3. Result and discussions

3.1. PM concentrations

Fig. 2 illustrates the average concentrations of PM_{10} and $PM_{2.5}$ (in μg/m^3). Indoor $PM_{2.5}$ and PM_{10} concentrations within these facilities exhibited a range from 0.2 to 124 μg/m^3 and 2–188.4 μg/m^3, respectively. In comparison, outdoor $PM_{2.5}$ and PM_{10} concentrations ranged from 0.7 to 9.1 μg/m3 and 7.8–144.9 μg/m^3, respectively. The average temperatures inside and outside the nursing homes were 25.78 °C and 17.68 °C, respectively, while the average relative humidity indoors and outdoors stood at 18.22 % and 11.96 %, respectively.

Studies that have been conducted to assess indoor $PM_{2.5}$ concentrations in senior centers have found that in certain audited facilities, the levels surpass the current WHO limit value of 15 μg m^{-3}.The results highlight that 22 % of the nursing homes exceeded the guidelines set by the World Health Organization (WHO) for maximum indoor $PM_{2.5}$ concentrations. Additionally, 50 % and 39 % of the nursing homes recorded maximum indoor and outdoor PM_{10} concentrations that surpassed WHO guidelines, respectively.

Table 2 provides an insight into the Indoor-to-Outdoor (I/O) ratio of PM_{10} and $PM_{2.5}$ for all 18 nursing homes. The I/O ratio is a widely used metric as it establishes a direct link between indoor and outdoor PM mass concentrations, a concept well-documented by Wan et al., in 2015 [18]. Specifically, the I/O for PM_{10} is 0.89, while $PM_{2.5}$ exhibits a higher I/O ratio of 2.73, indicating that there is a greater generation of $PM_{2.5}$ indoors than outdoors, in alignment with the findings of Jones et al., in 2000 [19]. This underscores that particulate matter penetration is a primary contributor to indoor PM, particularly in the case of $PM_{2.5}$, as observed by Hassanvand et al., in 2014 [20]. Additionally, it was discovered that the average $PM_{2.5}/PM_{10}$ ratio indoors and outdoors in the nursing homes was 0.18 and 0.1, respectively. This result implies that the elderly residents are more exposed to coarser particles. Particles larger than 10 μm have a relatively smaller indoor-to-outdoor ratio compared to particles larger than 2.5 μm, indicating the absence of filtration in nursing homes.

In several of the assessed facilities, levels of PM2.5 over the current WHO limit value (15 μg·m−3) were reported by some of the studies that are now available for assessing the indoor concentrations of PM2.5 in aging centers [21–25]. Nevertheless, some studies have discovered PM2.5 levels in elderly places that meet the current WHO recommendation, demonstrating that these settings can produce levels that are healthy [26–28]. Living rooms and drawing rooms have been identified as having notably higher PM2.5 concentrations among the various areas tested inside elderly center buildings [21,22]. Indeed, peak concentrations in drawing rooms were reported by Mendes et al. [21]. These findings were explained by the faster resuspension of particles brought on by the room's occupancy as well as possible emissions from the drawing activities that take place there. Furthermore, the same authors supported the finding of higher concentrations of fine particles indoors than outdoors by identifying ventilation, building pathologies, construction features (such as flooring and insulation), and the presence of a building adapted for use as an elderly care center as potential contributors to PM2.5. However, due to the observation of indoor-to-outdoor (I/O) concentration ratios below the unit, additional investigations have shown that the ambient air is the primary contributor to the PM2.5 concentrations reported indoors [27,28]. According to reports [27,28], there are statistically significant associations between the levels measured inside senior centers and the levels observed outside in the same surroundings.

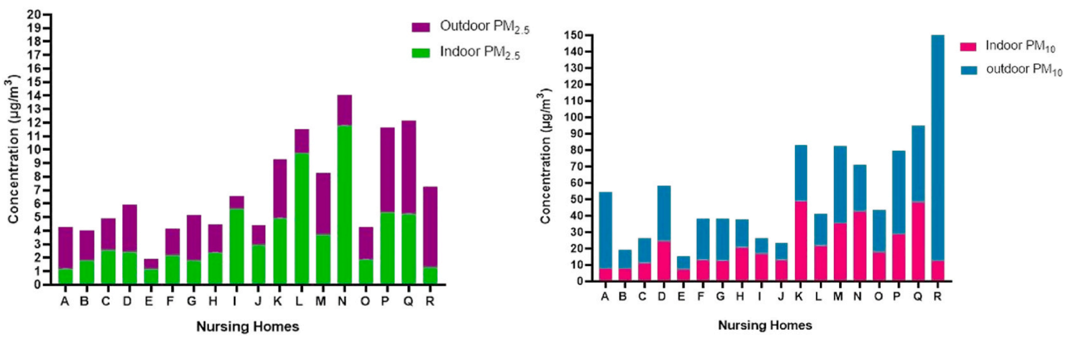

Fig. 2. Average $PM_{2.5}$ and PM_{10} concentration (μg/m^3).

Table 2
Indoor/outdoor ratio for PM_{10} and $PM_{2.5}$ at nursing home.

Nursing Home	Indoor/Outdoor $PM_{2.5}$ ratio			Indoor/Outdoor PM_{10} ratio		
	Minimum	Maximum	Average	Minimum	Maximum	Average
A	0.24	0.5	0.32 ± 0.11	0.12	0.26	0.15 ± 0.06
B	0.67	1.36	0.89 ± 0.24	0.63	1.12	0.73 ± 0.14
C	0.85	2.46	1.79 ± 0.61	0.61	1.23	0.78 ± 0.36
D	0.56	0.81	0.7 ± 0.15	0.51	0.9	0.7 ± 0.28
E	0.94	2.94	1.82 ± 0.42	0.65	1.31	0.95 ± 0.42
F	0.87	1.33	1.09 ± 0.31	0.42	0.79	0.65 ± 0.17
G	0.47	0.56	0.51 ± 0.13	0.38	0.58	0.46 ± 0.22
H	1.02	1.39	1.15 ± 0.49	1.05	1.57	1.31 ± 0.38
I	1.5	20.7	8.93 ± 3.2	1.01	4.32	2.29 ± 0.62
G	1.69	2.86	2.2 ± 0.53	1.01	2.15	1.45 ± 0.59
K	0.94	1.46	1.18 ± 0.81	0.96	2.63	1.53 ± 0.44
L	5.49	24.57	15.9 ± 7.3	1.11	3.4	2.3 ± 0.1.2
M	0.73	13.76	2.4 ± 0.028	0.62	1.28	0.82 ± 0.38
N	5.13	20.36	10.4 ± 3.8	1.37	3.67	2.2 ± 0.71
O	0.79	3.21	1.6 ± 0.51	0.67	1.08	0.8 ± 0.65
P	0.63	1.39	0.88 ± 0.27	0.4	0.86	0.63 ± 0.23
Q	0.84	1.64	1.13 ± 0.33	0.84	1.38	0.088 ± 0.029
R	0.13	0.37	0.22 ± 0.31	0.06	0.12	0.087 ± 0.041

3.2. PM chemical characterization

The PAHs with low molecular weight, containing 2–3 rings (Acy, Ace, Flo, Phe, Nap, and Ant), are abundant in petrogenic sources, primarily derived from petroleum. They were grouped together separately. Conversely, molecules with 4 rings (BaA, Flt, Chry, and Pyr), as well as those with 5–6 rings (BbF, BkF, Bap, DahA, InP, and BghiP), were categorized in another group. These PAHs are typically associated with pyrogenic sources, such as the combustion of coal, wood, vehicle fuel, and waste tire [29]. PM chemical compounds were identified in nursing homes. These compounds include water-soluble ions, metals, quasi-metals, and PAH. The sources and types of these compounds are shown in Table 4.

4 rings >5–6 rings> 2–3 rings

$SO_4^{2-} > NO^{3-} > Cl^{-} > Ca^{2+} > Na^{+} > NH^{4+} > K^{+} > Mg^{2+}$

Zn > Al > Fe > Si > Ti > Pb > Cu > Ba > Mn > Li > Ni > Cr > V > Mo > Sr > Cd > Co > Sn > As > Se

The comparable mean and median Σ16 PAHs levels between Novi Sad and Subotica suggest that these values are typical of homes in major Serbian cities. Nonetheless, there were notable differences in the Σ7cancPAHs values between these cities (Table SI4). This can be explained by the diverse profiles of the chemicals that have been found, which can be attributed to the influence of various emission sources. It's important to note that the Subotica and Bečej samples had low overall RSDs for Σ16 PAHs and Σ7cancPAHs (a measure of results variability, expressed as a percentage of standard deviation relative to the average value).

According to Table 5, the levels of indoor dust samples taken from Serbian houses were lower than those in Amman, Jordan; Guangzhou, China; Hunan Province, China; Warsaw, Poland; Palermo, Italy; Ottawa, Canada; and Barcelona, Spain. The study's comparatively low contents may be explained by the high percentage of natural gas usage for both individual and district heating (Table 5), as well as a lower level of industrial activity and fewer cars on the road compared to other large cities globally utilized as a point of comparison [30]. Furthermore, the Czech study relied on numerous dust samples taken in a single room. It must be underlined that the variety of sampling techniques, sample extraction and analysis methods, and sample quantity make it challenging to compare results from various studies [31]. For instance, research carried out in the Czech Republic, Greece, and Portugal involved up to 12 examined samples of PAH content, but investigations conducted in Portugal involved 28 samples (Table 1). More importantly, a variety of indoor and outdoor factors influence the difference in PAH concentration in indoor dust samples from various cities. Among them are building materials (such as flooring adhesives), building age and height, interior materials, percentage of carpet on the floor, house surroundings (such as nearby roads, intersections, greenery, and types of pavement), geographic location and climate conditions that further influence cultural customs, home design, and heating and cooling systems, as well as local sources of PAH emissions, density of population, fuel type consumed in cities [32] [31,33–35].

Longer heating times resulted in greater concentrations of heavy metals (HMs), whereas households using gas, electricity, or central heating displayed lower pollution levels. According to research conducted in Germany, coal heating contributed more to the buildup of lead in household dust than gas heating did [36]. A Canadian study found that compared to household dust from gas- or oil-heated homes, dust from electrically heated homes typically had greater concentrations of Pb and Hg [37]. We came to the conclusion that heating activity had a significant impact on the amounts of heavy metals (HM) in household dust in our investigation based on the explanation above. Three main factors were the kind of dwelling, family size, and ventilation time. Three main factors were the type of dwelling, the amount of people in the room, and the ventilation time. According to Zhao et al. [38], ventilation behavior represents the introduction of outside airborne particles into an interior space. Contrary to earlier findings, our data indicate that households with

Table 3
The HQ, HI, and R indices of the non-carcinogenic and carcinogenic risks for indoor and outdoor PM.

Nursing Home				HQ_{ing}	HQ_{inh}	HQ_{dermal}	HI	R
1	A	$PM_{2.5}$	Indoor	1.51×10^{-6}	2.21×10^{-7}	5.99×10^{-6}	7.72×10^{-6}	–
			Outdoor	4.56×10^{-6}	6.70×10^{-7}	1.82×10^{-5}	2.34×10^{-5}	–
		PM_{10}	Indoor	8.29×10^{-7}	1.22×10^{-7}	2.9×10^{-7}	1.24×10^{-6}	2.73 × 10-14
			Outdoor	5.3×10^{-6}	7.79×10^{-7}	1.85×10^{-6}	7.94×10^{-6}	1.75 × 10-13
2	B	$PM_{2.5}$	Indoor	2.95×10^{-6}	4.35×10^{-7}	1.18×10^{-5}	1.52×10^{-5}	–
			Outdoor	3.31×10^{-6}	4.87×10^{-7}	1.32×10^{-5}	1.69×10^{-5}	–
		PM_{10}	Indoor	9.45×10^{-7}	1.39×10^{-7}	3.76×10^{-6}	4.85×10^{-6}	1.07×10^{-13}
			Outdoor	1.29×10^{-6}	1.9×10^{-7}	5.15×10^{-6}	6.63×10^{-6}	1.46×10^{-13}
3	C	$PM_{2.5}$	Indoor	6.33×10^{-6}	9.30×10^{-7}	2.53×10^{-5}	3.26×10^{-5}	–
			Outdoor	3.53×10^{-6}	5.19×10^{-7}	1.41×10^{-5}	1.81×10^{-5}	–
		PM_{10}	Indoor	1.32×10^{-6}	1.94×10^{-7}	5.25×10^{-6}	6.76×10^{-6}	1.49×10^{-13}
			Outdoor	1.69×10^{-6}	2.49×10^{-6}	6.75×10^{-6}	1.09×10^{-5}	2.4×10^{-13}
4	D	$PM_{2.5}$	Indoor	3.62×10^{-6}	5.32×10^{-7}	1.45×10^{-5}	1.86×10^{-5}	–
			Outdoor	5.15×10^{-6}	7.57×10^{-7}	2.06×10^{-5}	2.65×10^{-5}	–
		PM_{10}	Indoor	2.71×10^{-6}	3.98×10^{-7}	1.08×10^{-5}	1.39×10^{-5}	3.06×10^{-13}
			Outdoor	3.85×10^{-6}	1.54×10^{-5}	5.66×10^{-7}	1.98×10^{-5}	4.36×10^{-13}
5	E	$PM_{2.5}$	Indoor	2.13×10^{-6}	3.14×10^{-7}	8.51×10^{-6}	1.10×10^{-5}	–
			Outdoor	1.18×10^{-6}	1.73×10^{-7}	4.69×10^{-6}	7.6×10^{-6}	–
		PM_{10}	Indoor	9.13×10^{-7}	1.35×10^{-7}	3.64×10^{-6}	4.69×10^{-6}	1.032×10^{-13}
			Outdoor	9.64×10^{-7}	1.41×10^{-7}	3.83×10^{-6}	4.94×10^{-6}	1.09×10^{-13}
6	F	$PM_{2.5}$	Indoor	3.13×10^{-6}	4.61×10^{-7}	1.25×10^{-5}	1.65×10^{-5}	–
			Outdoor	2.87×10^{-6}	4.21×10^{-7}	1.14×10^{-5}	1.47×10^{-5}	–
		PM_{10}	Indoor	1.85×10^{-6}	2.71×10^{-7}	7.35×10^{-6}	9.45×10^{-6}	2.08×10^{-13}
			Outdoor	2.83×10^{-6}	4.16×10^{-7}	1.13×10^{-5}	1.45×10^{-5}	3.2×10^{-13}
7	G	$PM_{2.5}$	Indoor	2.59×10^{-6}	3.81×10^{-7}	1.03×10^{-5}	1.33×10^{-5}	–
			Outdoor	5×10^{-6}	7.35×10^{-7}	2×10^{-5}	2.58×10^{-5}	–
		PM_{10}	Indoor	1.35×10^{-6}	1.99×10^{-7}	5.41×10^{-6}	6.96×10^{-6}	1.53×10^{-13}
			Outdoor	2.9×10^{-6}	4.27×10^{-7}	1.15×10^{-5}	1.49×10^{-5}	3.28×10^{-13}
8	H	$PM_{2.5}$	Indoor	3.48×10^{-6}	5.13×10^{-7}	1.39×10^{-5}	1.79×10^{-5}	–
			Outdoor	3.01×10^{-6}	4.44×10^{-7}	1.2×10^{-5}	1.54×10^{-5}	–
		PM_{10}	Indoor	2.55×10^{-6}	3.75×10^{-7}	1.02×10^{-5}	1.31×10^{-5}	2.88×10^{-13}
			Outdoor	1.95×10^{-6}	2.85×10^{-7}	5.94×10^{-6}	8.16×10^{-6}	1.80×10^{-13}
9	I	$PM_{2.5}$	Indoor	1.32×10^{-5}	1.93×10^{-6}	5.24×10^{-5}	6.74×10^{-5}	–
			Outdoor	1.47×10^{-6}	2.16×10^{-7}	5.87×10^{-6}	7.55×10^{-6}	–
		PM_{10}	Indoor	2.49×10^{-6}	3.66×10^{-7}	9.91×10^{-6}	1.27×10^{-5}	2.8×10^{-13}
			Outdoor	1.08×10^{-6}	1.6×10^{-7}	4.33×10^{-6}	5.57×10^{-6}	1.23×10^{-13}
10	G	$PM_{2.5}$	Indoor	4.71×10^{-6}	6.92×10^{-7}	1.88×10^{-5}	2.42×10^{-5}	–
			Outdoor	2.13×10^{-6}	3.14×10^{-7}	8.51×10^{-6}	1.10×10^{-5}	–
		PM_{10}	Indoor	1.68×10^{-6}	2.47×10^{-7}	6.72×10^{-6}	8.65×10^{-6}	1.90×10^{-13}
			Outdoor	1.16×10^{-6}	1.71×10^{-7}	4.63×10^{-6}	5.96×10^{-6}	1.31×10^{-13}
11	K	$PM_{2.5}$	Indoor	7.6×10^{-6}	1.12×10^{-6}	3.04×10^{-5}	3.91×10^{-5}	–
			Outdoor	6.4×10^{-6}	9.4×10^{-7}	2.55×10^{-5}	3.28×10^{-5}	–
		PM_{10}	Indoor	5.99×10^{-6}	8.81×10^{-7}	2.39×10^{-5}	3.08×10^{-5}	6.78×10^{-13}
			Outdoor	3.9×10^{-6}	5.74×10^{-7}	2.23×10^{-4}	2.27×10^{-4}	5×10^{-12}
12	L	$PM_{2.5}$	Indoor	4.09×10^{-5}	6.02×10^{-6}	1.64×10^{-4}	2.11×10^{-4}	–
			Outdoor	2.58×10^{-6}	3.79×10^{-7}	1.03×10^{-5}	1.32×10^{-5}	–
		PM_{10}	Indoor	5.06×10^{-6}	7.45×10^{-7}	2.02×10^{-5}	2.6×10^{-5}	5.72×10^{-13}
			Outdoor	2.2×10^{-6}	3.24×10^{-7}	8.77×10^{-6}	1.43×10^{-5}	3.14×10^{-13}
13	M	$PM_{2.5}$	Indoor	1.67×10^{-5}	2.46×10^{-6}	6.68×10^{-5}	8.6×10^{-5}	–
			Outdoor	6.76×10^{-6}	9.95×10^{-7}	2.69×10^{-5}	3.47×10^{-5}	–
		PM_{10}	Indoor	4.41×10^{-6}	6.49×10^{-7}	1.76×10^{-5}	2.27×10^{-5}	5×10^{-13}
			Outdoor	5.37×10^{-6}	7.9×10^{-7}	2.15×10^{-5}	2.76×10^{-5}	6.08×10^{-13}
14	N	$PM_{2.5}$	Indoor	3.45×10^{-5}	5.07×10^{-6}	1.38×10^{-4}	1.78×10^{-4}	–
			Outdoor	3.31×10^{-6}	4.87×10^{-7}	1.32×10^{-5}	1.69×10^{-5}	–
		PM_{10}	Indoor	7.19×10^{-6}	1.05×10^{-6}	2.87×10^{-5}	3.7×10^{-5}	8.14×10^{-13}
			Outdoor	3.26×10^{-6}	4.8×10^{-7}	1.3×10^{-5}	1.67×10^{-5}	3.68×10^{-13}
15	O	$PM_{2.5}$	Indoor	5.68×10^{-6}	8.34×10^{-7}	2.27×10^{-5}	2.92×10^{-5}	–
			Outdoor	3.53×10^{-6}	5.19×10^{-7}	1.41×10^{-5}	1.81×10^{-5}	–
		PM_{10}	Indoor	2.38×10^{-6}	3.5×10^{-7}	9.45×10^{-6}	1.22×10^{-5}	2.68×10^{-13}
			Outdoor	2.95×10^{-6}	4.34×10^{-7}	1.17×10^{-5}	1.51×10^{-5}	3.32×10^{-13}
16	P	$PM_{2.5}$	Indoor	8.16×10^{-6}	1.2×10^{-6}	3.26×10^{-5}	4.2×10^{-5}	–
			Outdoor	9.27×10^{-6}	1.36×10^{-6}	3.69×10^{-5}	4.75×10^{-5}	–
		PM_{10}	Indoor	3.66×10^{-6}	5.39×10^{-7}	1.46×10^{-5}	1.88×10^{-5}	4.14×10^{-13}
			Outdoor	5.81×10^{-6}	8.54×10^{-7}	2.32×10^{-5}	2.98×10^{-5}	6.56×10^{-13}
17	Q	$PM_{2.5}$	Indoor	8.15×10^{-6}	1.2×10^{-6}	3.25×10^{-5}	4.19×10^{-5}	–
			Outdoor	7.2×10^{-6}	1.06×10^{-6}	2.87×10^{-5}	3.69×10^{-5}	–
		PM_{10}	Indoor	5.62×10^{-6}	8.26×10^{-7}	2.25×10^{-5}	2.89×10^{-5}	6.36×10^{-13}
			Outdoor	5.67×10^{-6}	8.35×10^{-7}	2.26×10^{-5}	2.92×10^{-5}	6.42×10^{-13}

(*continued on next page*)

Table 3 (*continued*)

Nursing Home				HQ_{ing}	HQ_{inh}	HQ_{dermal}	HI	R
18	R	$PM_{2.5}$	Indoor	1.98×10^{-6}	2.89×10^{-7}	7.86×10^{-6}	1.01×10^{-5}	–
			Outdoor	8.82×10^{-6}	1.29×10^{-6}	3.52×10^{-5}	4.53×10^{-5}	–
		PM_{10}	Indoor	1.43×10^{-6}	2.09×10^{-7}	5.67×10^{-6}	7.31×10^{-6}	1.61×10^{-13}
			Outdoor	1.61×10^{-5}	2.36×10^{-6}	6.42×10^{-5}	8.26×10^{-5}	1.82×10^{-12}

Table 4
PM chemical characterization in nursing homes.

Chemical characterization	Source	Type
Water-soluble ions	Crustal	Mg^{2+}, Ca^{2+}, Na^{+}
	Combustional	NO_3^-, NH_4^+
	Combustional & crustal	K^+, SO_4^{2-}, Cl^-
Metal & quasi-metal	Crustal elements	Al, Si, Fe, Ti
	Vehicular emissions	Ba, Mo, Cu, Mn, Zn, As, Cd
	Industrial	V, Ni, Cr, Pb
	Others	Li, Se, Sn, Sr, Co
PAH	6 rings	Benzo [g,h,i]perylene, Indeno [1,2,3,c,d]pyrene
	5 rings	Benzo [b]fluoranthene, Benzo [k]fluoranthene, Benzo [a]pyrene, Dibenzo [a,h]anthracene
	4 rings	Fluoranthene, Pyrene, Benzo [a]anthracene, Chrysene
	3 rings	Acenaphthene, Acenaphthylenes, Fluorene, Phenanthrene, Anthracene
	2 rings	Naphthalene

more members typically had lower levels of dust pollution [38]. It is also known that the concentrations of As, Ni, Cu, Zn, and Hg in household dust are influenced by nearby factories in terms of ventilation behavior [39].

3.3. *Location of nursing home*

To assess the relationship between indoor and outdoor mass concentrations of PM_{10} and $PM_{2.5}$, we conducted a correlation analysis using Spearman's coefficient. Our findings revealed a significant correlation between indoor and outdoor PM concentrations ($P < 0.05$), indicating the inflow of particles from the external environment into the buildings.

Among the nursing homes, "L" and "P" stood out with the highest average indoor and outdoor $PM_{2.5}$ concentrations, registering at 27.85 μg/m3 indoors and 6.3 μg/m^3 outdoors, respectively. "L" is situated in proximity to parks and green areas, whereas "P" is located near areas with heavy traffic, a petrol station, and construction activities.

On the other hand, "N" and "R" nursing homes exhibited the highest average indoor and outdoor PM_{10} concentrations, measuring 63.3 μg/m^3 indoors and 141.6 μg/m3 outdoors for "N," while "R" had the highest outdoor PM_{10} concentration. "N" is situated near parks and construction activities, while "R" is close to petrol stations, parks, and passenger terminals.

An interesting observation was the significant relationship between the concentration of PM and the proximity of nursing homes to parks and green spaces ($P < 0.05$). Our sampling conducted during the winter season, when tree leaves and vegetation in parks decrease, illustrated that airborne particles enter the nursing homes located near parks. However, in seasons when foliage and vegetation are more abundant, trees can intercept approximately 7 % of PM_{10} emissions.

3.4. *Building characteristics of nursing homes*

Using the questionnaires that were prepared, which are briefly referenced in Table 1 and attached in the appendix, the building Characteristics of the elderly homes were collected. Significant relationships between $PM_{2.5}$ and PM_{10} concentrations in nursing homes and various building characteristics were observed ($P < 0.05$). Our findings indicated that nursing homes equipped with radiators tend to exhibit higher PM concentrations, particularly $PM_{2.5}$. Furthermore, nursing homes with single-glazed windows that were cracked showed higher particulate concentrations compared to those with other window types. Therefore, the incorporation of double-glazing in the design of nursing homes can contribute to reducing particle levels and enhancing indoor air quality.

In addition, a significant correlation was noted between PM_{10} concentration in nursing homes and the status of windows (open or closed) and the type of flooring cover ($P < 0.05$). The analysis suggests that the influx of particles into nursing homes is notably high when windows are open. Furthermore, approximately 70 % of the nursing homes featured ceramic floor coverings, and these places exhibited the highest PM_{10} concentrations. Some studies have shown that ordinary indoor activities such as walking over carpeted or hard floor areas can result in increased particulate concentrations in the indoor environment (Cheng et al., 2010). Therefore, the type of flooring and the window status have a substantial impact on indoor particulate matter levels, emphasizing the importance of proper window sealing and careful selection of flooring materials in nursing home design to improve air quality.

Table 5
Range, mean total concentrations of PAHs (∑PAHs) and Benzo[*a*]pyrene (BaP) analyzed in indoor dust collected from different parts of the world.

Country	City/region	Sample type	Number of samples	Number of PAH analyzed	Concentration range (μg. kg^{-1})	∑PAHs (μg. kg^{-1})	Mean BaP (μg. kg^{-1})	Reference
Serbia	Novi Sad	Indoor dust	32	16	140–8265	1866	33	Jelena Živančev et al. (2022)
	Subotica		5		1258–2480	1797	38	
	Zrenjanin		4		420–6393	2780	91	
	Bečej		6		717–1186	990	19	
	Vojvodina Province		47		140–8265	1825	36	
Jordan	Amman	Floor dust	10	13	714–5153	2859.3	149	Maragkidou et al. (2017)
United Kingdom	Northern part	Indoor dust	12	18	438–10500		616	Sánchez-Piñero et al. (2020)
Kuwait	90 cities	Indoor house dust	180	16		1112	48	Al-Harbi et al. (2020)
China	Guangzhou	House dust	21	16		284285	338	Luo et al. (2020)
	Beijing	Indoor dust	67	15	388–8140			Cao et al. (2019)
	Hunan Province	Indoor dust	15	15	5007–24236	14049[a]		Kang et al. (2015)
Saudi Arabia	Jeddah	Household floor dust	20	13	55–16275	3715	79	Ali (2019)
Greece	SW and NW Greece	Household dust	11	16	20.6–1394	415.3	7.1	Christopoulou et al. (2012)
Poland	Warsaw	House dust	48	16		35030	700	Tatur et al. (2009)
Italy	Palermo	Indoor dust	45	16	36–34453	5111	112	Mannino and Orecchio (2008)
Canada	Ottawa	Settled house dust	51	13	1500–325000	29300	2910	Maertens et al. (2008)
Czech Republic	Brno	Floor dust	12	13		39.1		Melymuk et al. (2016)
Portugal	Porto	Settled Floor dust	28	11	10–8010	260		Arnold et al. (2018)
Australia	Brisbane and Canberra	Floor dust	28	13		1400	54	Wang et al. (2019)
Spain	Barcelona	Settled dust	11	15		10525[a]	26[a]	Velázquez-Gómez et al. (2019)

[a] Median value.

3.5. Health risk assessment

The assessment of non-carcinogenic and carcinogenic risks associated with indoor and outdoor PM exposure was conducted using the HQ, HI, and R indices, as presented in Table 3. The risk assessment results for PM revealed that, in most nursing homes, dermal exposure accounted for the majority of potential risks. However, the average HI index (representing non-carcinogenic risk) across all nursing homes remained below the standard set by the U.S. Environmental Protection Agency (USEPA), with HI $\leq$ 1.

Furthermore, the assessment indicated that carcinogenic risk factors were within acceptable limits for all nursing homes, with 10-4$\leq$CR $\leq$ 10-6. This means that the risk of cancer due to PM exposure was considered low in all of these facilities [17].

Nonetheless, it's important to acknowledge that, given their chemical nature, airborne particles can have long-term adverse effects on the health of nursing home residents, even when immediate risks appear to be within acceptable limits. Monitoring and managing indoor and outdoor air quality in these settings remains essential for the well-being of the elderly population. Based on surveyed exposure factors with a one-to-one relationship, a health risk assessment was carried out to estimate the carcinogenic and non-carcinogenic hazards posed to the 632 participants.The following was the ranking of HMs' HI values: As $\gg$ Pb $>$ Hg $>$ Ni $>$ Cu $>$ Zn. The lifetime cancer risks were evaluated using the US EPA's current Ni, As, and Pb cancer. The carcinogenic hazards associated with heavy metals (HMs) were found to be lower than the US EPA's reference value of 10−4, indicating an acceptable level of carcinogenic risk (US EPA, 2001a, US EPA, 2001b).

4. Conclusion

This is the first case study that we are aware of about PAH levels, heavy metals, and PM ($PM_{2.5}$ and PM_{10}) in the indoor of elderly housing facilities. The findings suggest that a combination of factors related to building characteristics, such as window type, window status, heating system type, and floor covering, as well as outdoor sources of PM, including vehicular emissions, parks, passenger terminals, petrol stations, and construction activities, significantly contribute to indoor PM concentrations. Research evaluating indoor $PM_{2.5}$ concentrations in senior centers has revealed that levels in some audited facilities are higher than the current WHO limit value of 15 μg m^{-3}.The findings show that 22 % of the assisted living facilities went above WHO recommended upper limit for indoor $PM_{2.5}$ concentrations. Furthermore, the maximum indoor and outdoor PM_{10} concentrations were found to be higher than WHO limits in 50 % and 39 % of the nursing facilities, respectively.

Additionally, the risk assessment of particulate matter indicated acceptable levels of both carcinogenic and non-carcinogenic risks. However, it's crucial to note that PM chemical compounds, particularly polycyclic aromatic hydrocarbons (PAH), can have adverse effects on the health of nursing home residents when exposed over the long term. One of the limitations of this study was the restriction on sampling from the nursing homes.

These findings underscore the importance of implementing regular monitoring of indoor air quality in nursing homes, developing targeted regulations, and implementing control measures that address particle emission sources when selecting nursing home locations. These proactive measures will lead to enhanced indoor air quality within nursing homes, ultimately improving the health, well-being, and overall quality of life for their residents.

CRediT authorship contribution statement

Mojgan Jafari Shahri: Writing – original draft, Methodology. **Maryam Sarkhosh:** Supervision, Project administration, Methodology. **Hossein Alidadi:** Supervision. **Ali Asghar Najafpoor:** Methodology. **Vahid Ghavami:** Data curation. **Sima Baridkazemi:** Writing – review & editing.

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.

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Appendix A. Supplementary data

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