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Original Research

The Variability of Indoor Air Pollutants in the Office and Their Impact on the Workers' Health

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Abstract

This study examines the dynamics of indoor air quality in an office environment within a metropolis, with a specific focus on particulate matter (PM), formaldehyde, and total volatile organic compounds (TVOCs). The levels of PM concentrations stay constant at a value of 13.9±2.9 μg/m^3 for PM2.5 throughout working hours, with a significant impact on human activities. The formaldehyde concentration inside increases thrice during 8 hours, from 9±5 μg/m^3 to 27±14 μg/m^3, primarily from furniture and electronics. The total volatile organic compounds (TVOCs) levels significantly increase from 0.050±0.044 μg/m^3 at 8.00 to 0.14±0.11 μg/m^3 at 15.00, which can be attributed to indoor contaminants such as plastics and consumer items. PM concentrations exhibit seasonal fluctuations, with higher levels observed during colder months (37±5 μg/m^3 for PM2.5 in December and 8±1 μg/m^3 for PM2.5 in August in the office, mainly due to outdoor contribution. Analysis of settled dust indicates a varied composition, suggesting the presence of both building materials and human activity. Employees exhibit symptoms consistent with Sick Building Syndrome, with a higher prevalence among females. The results emphasize the significance of dealing with variations in indoor air quality and identifying the causes that affect the health of occupants and the well-being of the workplace.

Keywords: indoor pollution, volatile organic compounds, Sick Building Syndrome, particulate matter, formaldehyde

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Introduction

Globally, an increasing percentage of the modern workforce carries out their activities within the limitations of office spaces [1], yet the well-being and health status of the people working in enclosed spaces have become a significant concern due to the impact of indoor air quality (IAQ) on their overall condition [2, 3]. In 2001, a National Human Activity Pattern Survey (NHAPS) was performed in North America [4] and revealed that individuals spend over 87% of their time indoors, enclosed in industrial or office buildings, educational institutions [5], at home, or in department stores [6], and about 6% of their time in different vehicles [4, 7], making exposure to indoor contaminants almost inevitable [7]. Therefore, when pollutants are present within buildings, indoor settings accumulate them, increasing human inhalation exposure or dose by 100-1,000 times compared to pollutants existing in outdoor air [3]. Hence, it is imperative to maintain a high standard of IAQ in enclosed areas to prevent any adverse effects on human health [2].

Another study performed in 2022 [8] reports that Americans and Koreans spend over 95% and 97% of their time indoors, leading to numerous health problems due to poor indoor air quality [8]. Office workers are exposed daily to physical, biological, and chemical contaminants that significantly impact their comfort, health, sick days, and overall performance [9]. IAQ often surpasses outdoor air quality in terms of pollution levels [8]. Various chemical and physical reactions influence this effect within buildings, including combustion sources, household products, building materials, and, indirectly, outdoor pollutants [10, 11].

In many developing countries, due to the limited availability of modern energy sources, a significant contributor to indoor air pollution arises from the burning of solid fuels (coal, biomass) used for both indoor heating (fireplaces and stoves) and the preparation of everyday food (cooking appliances) [12], indoor smoking, burning candles, and incense [13, 14]. When these materials undergo combustion, they can release a host of harmful byproducts directly into the indoor environment. Among these byproducts, the most concerning are carbon monoxide, particulate matter (PM), and nitrogen dioxide [15]. The management and maintenance of these sources are critical to safeguarding indoor air quality and the health of occupants. However, solid fuel consumption has increased in developed nations due to rising electricity and natural gas costs and several environmental regulations promoting biomass as a renewable fuel source [16]. It is essential to mention that burning solid fuels like wood and coal in household appliances presently constitutes around 38% of primary PM2.5 emissions [17].

Another important source of indoor pollutants that indirectly introduce chemicals to indoor air is represented by everyday household and office products: cleaning supplies (carpet, floor, and bathroom cleaners, furniture polishes, and waxes) [18], air fresheners and deodorizers [19], and several electronic devices like computers and printers (ozone and PM) [8, 9], and poorly maintained air conditioning (amplifying indoor chemical reactions) [11].

According to Mølhave et al., dust comprises solid particles with a relatively inert core on whose surface various organic or inorganic compounds can be adsorbed from the outdoor and indoor environments [20]. The settled dust and particulate matter outdoors can contain minerals, metals, metalloids, sea salts, ammonium nitrate and sulfate, organic compounds, and elemental carbon [21, 22]. Varrica et al. have demonstrated that the abundance of outdoor dust's various organic and inorganic components is temporally and spatially variable [23]. The indoor dust serves as a passive sampler for a diverse range of gases [24] and organic volatile compounds [25] emanating from human activities as well as emissions from building and furnishing materials. Inorganic salts (i.e., CO_3^{2-}, NH_4^+, SO_4^{2-}, NO_3^-, etc.) [26, 27], solid particles such as silicates, phyllosilicates, feldspars, and clay minerals [28, 29], or bio-organic particles (i.e., desquamated skin cells, molds, etc.) [30] were identified in the structure and composition of indoor settled dust. According to Butte and Heinzow, indoor dust emerges as an ideal screening material, offering insights into historical emissions and effectively indicating indoor contamination [31]. Additionally, as analyses of indoor dust provide an approximation of indoor pollution contamination, they present valuable information regarding human exposure to indoor pollutants [24, 32-35]. The term "sick building syndrome" (SBS) refers to a higher-than-normal prevalence of symptoms concerning the respiratory tract, the skin, the eyes, and the head [36], in workers from office buildings, due to prolonged exposure to indoor air pollutants. Some studies reported this syndrome in 1 in 5 office workers [37], with nasal symptoms, skin-related symptoms, and throat symptoms being most frequently reported [38].

The primary objective of this study was to assess the year-long concentration of indoor pollutants within an official building and to analyze the composition of accumulated dust using FTIR. Our secondary goal was to investigate the prevalence of symptoms typical of Sick Building Syndrome (SBS) among the office workers in the building.

Experimental

Samples were collected intermittently from March 2022 to March 2023 within three distinct rooms-office, corridor, and bathroom – of office space and from the external ambient air. The building is situated in Resita town, Western Romania, with geographical coordinates of latitude 45°19'15" N and longitude 21°52'02" E (refer to Fig. 1 for a visual representation). Sampling within each room occurred at a uniform height of 1 meter from

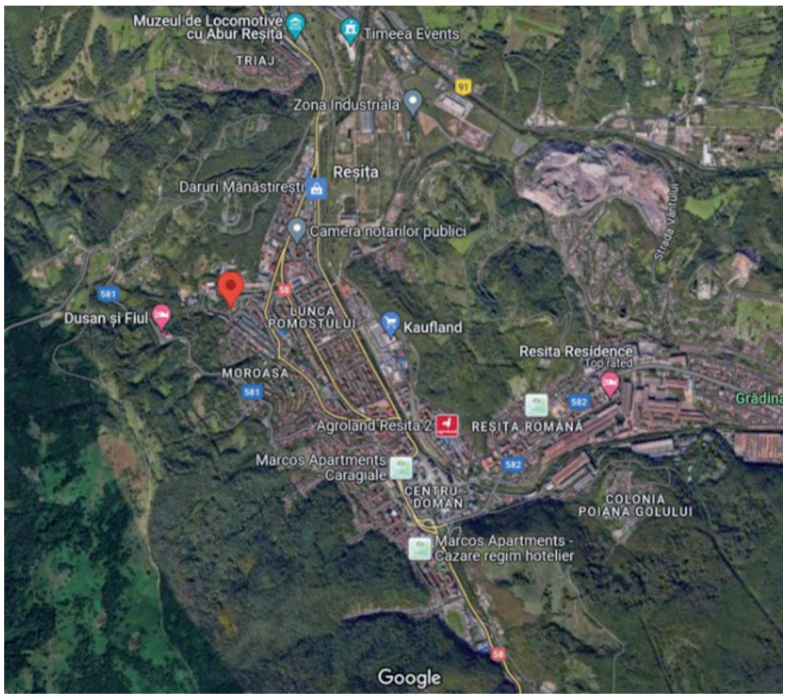

Fig. 1. Satellite photos of the sampling zone. The position of the sampling site is marked with a red pin.

the floor, ideally positioned at the center of the room. External measurements were taken in the parking lot, approximately 2 meters from the entrance door. The sampling protocol involved a standardized duration of 30 minutes, with readings conducted post-stabilization. Monthly assessments were conducted consistently on the same day (Wednesday) and at the same hour (noon), totaling four measurements per month. The parameters assessed included total volatile organic compounds, PM1, PM2.5, PM10, and formaldehyde. Analysis was performed using a Dienmern DM 106 professional air analyzer (Shenzhen Dienmern Testing Technology Co., Ltd., Guangdong, China) and Honeywell MultiRAE (Sunnyvale, CA, USA). The detection limit for all determinations was established at 1 µg/m³.

The dust samples were collected in open Petri dishes with a diameter of 25 cm. The sampling was conducted between March 2022 and March 2023 through the natural settling of dust from the external and internal environments of the office, bathroom, and corridor. The dust sample from the outdoor environment was collected at approx. 2.5m from the ground and the Petri dish was placed on the windowsill of the office in an area protected from air currents and the direct action of precipitation. The samples from the indoor environment were collected at a height of approx. 2.5 m from the floor and no major cleaning actions were taken in the collection areas during the sampling period. The daily activities of the people who had access to the dust sample collection areas proceeded normally. Still, the airing/ventilation was reduced to the minimum possible, especially in the office. The mass of settled dust samples collected for one year indoors was ~0.5 g, while ~1.35 g was collected outdoors. All collected samples had a non-fibrous consistency.

FTIR spectra of settled dust samples were obtained using a Bruker Vertex 70 spectrophotometer (Bremen, Germany) equipped with an ATR accessory (Pike Miracle with ZnSe crystal). The interaction of infrared radiation with the investigated samples was recorded in the 4000-600 cm^{-1} wavelength range at a resolution of 4 cm^{-1} using a number of 63 scans per spectrum. FTIR spectra were recorded in triplicate for each sample, and finally, the average spectrum was plotted. Before each scan, the ZnSe crystal was cleaned (with isopropanol), and a background spectrum was recorded with the same number of scans and at the same resolution. OPUS software (version 6.5) was used to record and process the spectra (including vectorial normalization and baseline correction). The settled dust samples were subjected to FTIR-ATR scans taken from both the external environment and the three internal locations without processing.

To evaluate the presence of SBS symptoms in employees from the office, we applied a standardized questionnaire developed based on previous studies on SBS [39]. The list of symptoms included eye symptoms (dry, itching, or watering eyes), ear, nose, and throat (ENT) symptoms (stuffed or runny nose, dry throat, pain in the throat), difficulty breathing, headache, chest pain, skin problems (dryness, rash, itching), fatigue, and flu-like symptoms. Symptoms were recorded at least twice in the last year. Workers could also report any other symptoms they considered related to the work environment. The questionnaire also included questions about the medical history to identify possible confounding factors: allergies, acute infections of

the respiratory tract in the past week, and known medical history of eye, ENT, respiratory, or cardiac diseases. Parametric data were presented as mean±standard deviation (SD), while data with a nonparametric distribution were reported using the median and percentile values of the IQ range (25th, 75th). For symptom analysis, we used descriptive statistics.

Results and Discussion

PM1, PM2.5, and PM10 concentrations do not vary significantly over the working hours (Fig. 2). The concentration of particulate matter did not considerably decrease in the office compared with the outside air. The same trend was seen for all particulate matter sizes. The ratio between PM2.5 and PM10 for the outside air was 0.83±0.08 μg/m³. Such a high ratio of fine particles indicates that the air pollution is more from anthropogenic sources [40, 41]. Prior research discovered that the mean ratios of PM2.5 to PM10 in Wuhan were 0.62 [42], while in Europe, where urbanization is more prevalent, the ratios of PM2.5 to PM10 range from 0.39 to 0.74 [43]. Anyhow, in our case, since the building is in the middle of the city, the sources of particulate matter are mostly from transport. The values of PM10 did not exceed the E.U. Air Quality Directive, which set a maximum limit of 40 μg/m³ for the yearly average concentration of the fine particulate matter PM10 (E.U. Directive 2008/50/E.C.).

The formaldehyde concentration remains constant outside of the building at a 13 μg/m³ level. In contrast, it increased almost three times inside the building over 8 hours (Fig. 3).

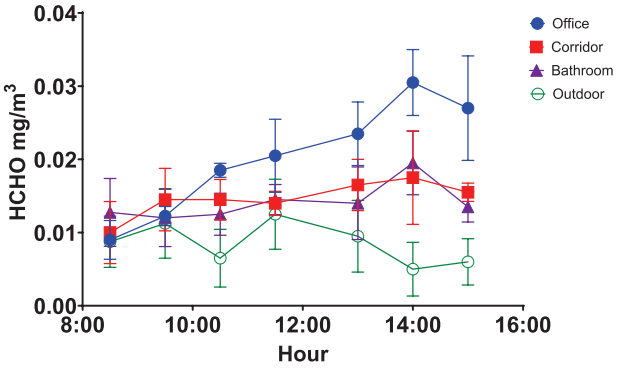

Fig. 3. The variation of formaldehyde concentrations over working hours.

From 2011 to 2015, the median indoor formaldehyde concentrations in newly renovated offices were 94 μg/m³ across China [44]. Significant differences exist between concentrations inside the office (0.021 μg/m³) and outside (0.012 μg/m³) after 3.5 hours (p<0.05). The same trend has been found for air in corridors and bathrooms, which could be explained by formaldehyde emission from the surface area of materials (wood products, carpet, and insulation) [45, 46]. Interestingly, at the end of the program, the formaldehyde concentration became significantly higher than in the corridor due to the emission from different furniture and electronic devices presented in the office [47].

The total volatile organic compound concentration (TVOC) increased indoors while the concentration remained constant outdoors (Fig. 4). A level of around 50 μg/m³ of volatile organic compounds outside

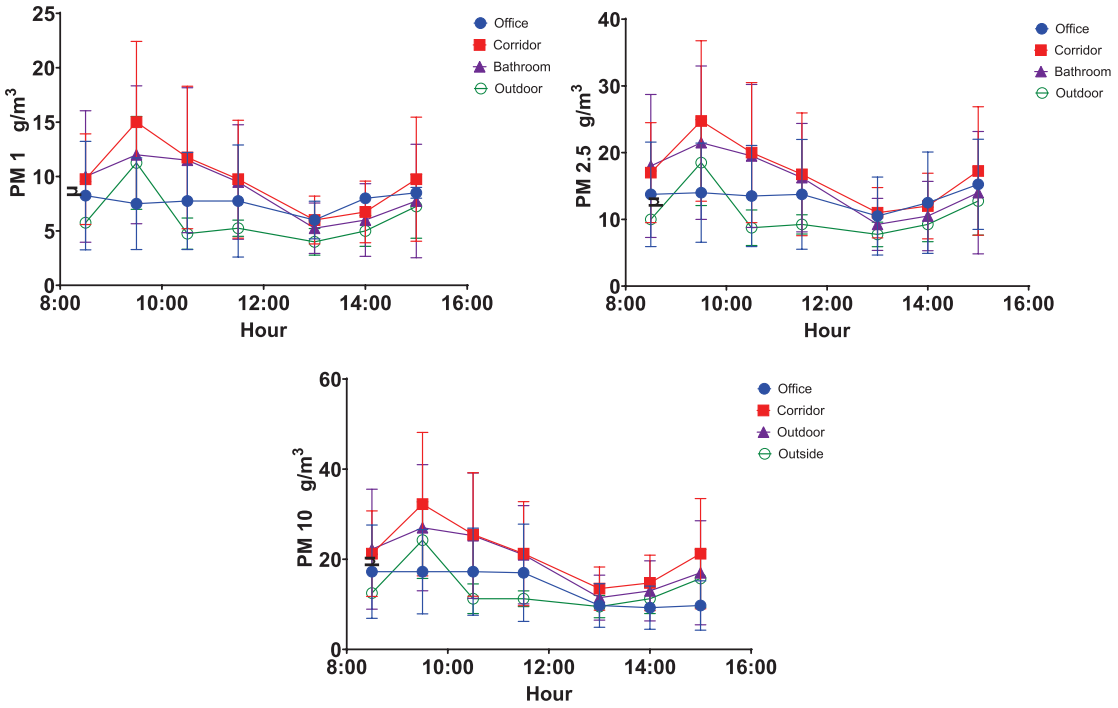

Fig. 2. The variation of PM1, PM2.5 and PM10 concentrations over working hours.

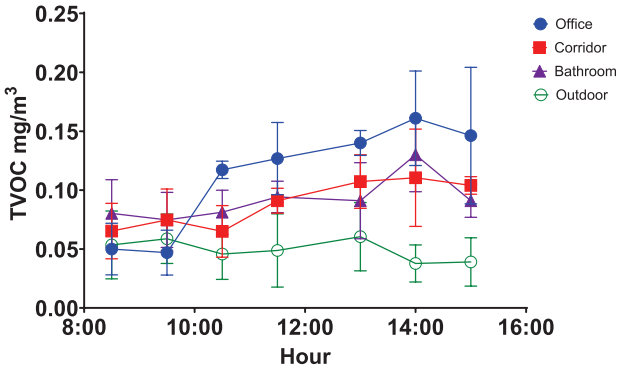

Fig. 4. The variation of total volatile organic compound concentrations (TVOC) over working hours.

is average for a city with medium traffic. For example, in Seul, the TVOC exceeded 75 μg/m^3 [48], while in a heavy industrial city (Handan, Hebei Province, China), the observed mixing ratio of total VOCs was 30.32±15.76 ppbv [49]. The sources of TVOC could be traffic and industrial emissions, but the domestic emissions of TVOCs cannot be neglected.

After the first hour of work, the concentration of TVOC increases steeply in the office, while the trend is not so evident in the corridor and bathroom. Such a trend has been found not only in the offices but also in the regular houses [50, 51]. The sources for TVOC in the office could be attributed to plastics, paint, and mainly consumer products such as perfumes and body spray. Even more, some studies have demonstrated that the human body emits volatile organic compounds at a level of 4.6 (0.5 mg/hour/person [48, 49]). The influence of TVOC concentration from outside is low, as the ratio between outside and inside was 0.58.

The concentrations of particulate matter over one year are presented in Fig. 5.

The variation of the PM1, PM2.5, and PM10 concentrations is significant over the year, with a maximum of 45 μg/m^3, 75 μg/m^3, and 96 μg/m^3, respectively. Analysis of seasonal patterns indicates that PM1.0, PM2.5, and PM10 exhibit notably elevated concentrations throughout the colder months, reaching their lowest levels in the summer. This pattern's primary causes are decreased mixing-layer heights, restricted oxidation capacity, and reduced residential heating emissions. The same trend has been found in the Urumqi urban area [52], Beijing, Suning, and Islamabad [53], Eastern Poland [54], and Cairo [55]. The average indoor air concentrations of PM2.5, PM1, and PM10 were 9.6±10.1 μg/m^3, 16.6±16.5 μg/m^3, and 20.9±21.4 μg/m^3, respectively. The findings suggest that the average daily levels of PM10 and PM2.5 concentrations inside were within the recommended limits of the World Health Organization (WHO). Anyhow, there are three months with high PM concentrations: March, May, and December. The higher concentrations in the office exceed 90 μg/m^3, the same range as the 25 naturally ventilated urban residences in Alexandria, Egypt [56]. The lower concentration in corridors and bathrooms could be explained by the higher ventilation in those rooms than in the office. The sources of PMs in the offices could be an accumulation of dust and dirt on surfaces, furniture,

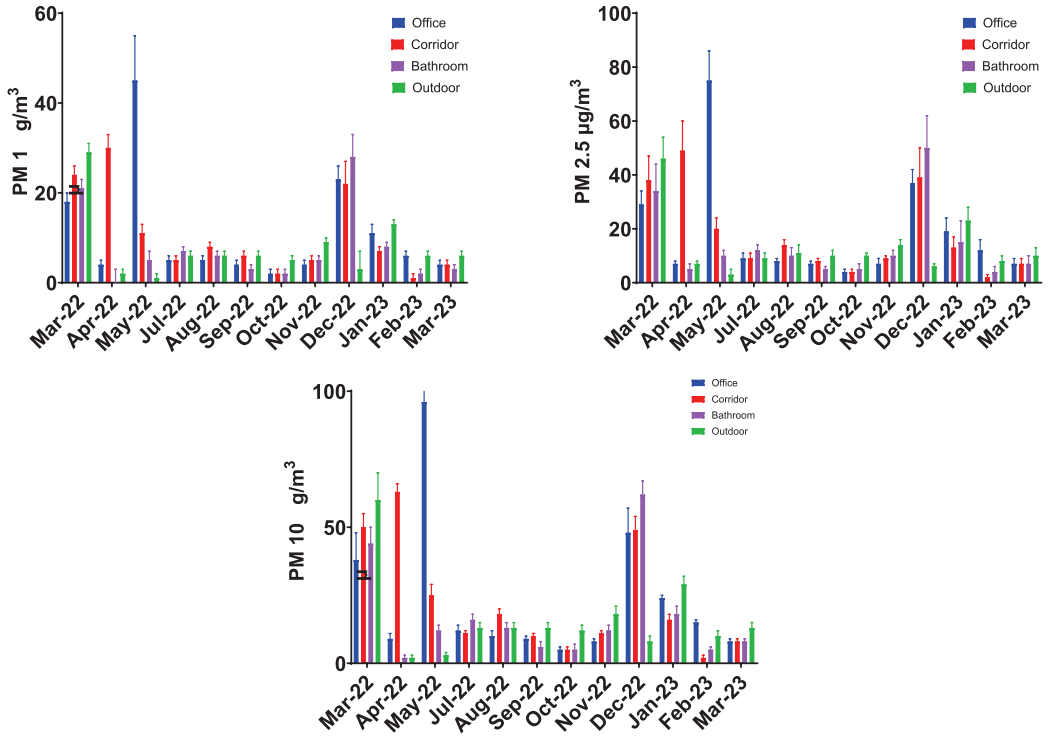

Fig. 5. The variation of PM1, PM2.5 and PM10 concentrations over one year time.

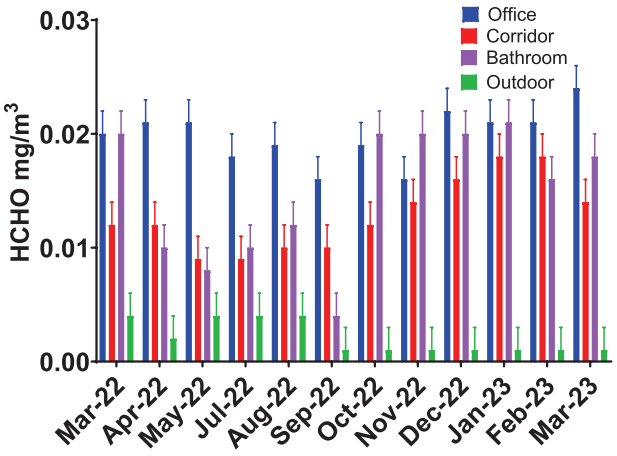

Fig. 6. The variation of formaldehyde concentrations over one year time.

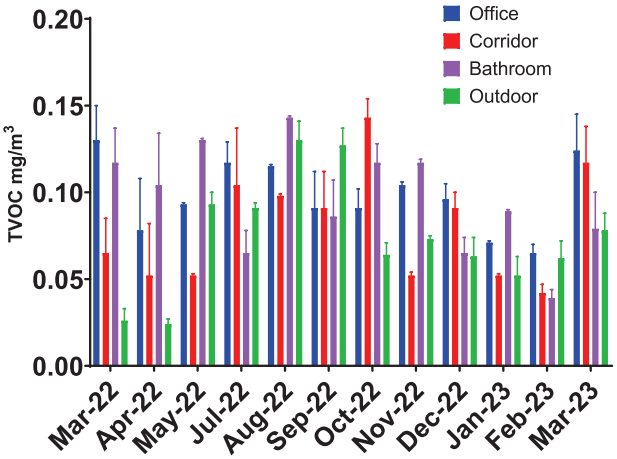

Fig. 7. The variation of total volatile organic compound concentrations over one year time.

and office equipment. Carpets and upholstered furniture can trap dust and particles, which can be released into the air when disturbed. Another important source could be airborne particles from outside, such as pollen, pollution, or nearby construction, which can infiltrate the office and contribute to indoor PM.

The formaldehyde concentration in the indoor air is relatively constant throughout the year (Fig. 6).

Outside of the shop, the formaldehyde concentration was minimal at a level of 2 μg/m³. The data is in accordance with a review paper showing that the outdoor formaldehyde concentration measured in many regions (mainly in Europe and the USA) was in the range of 1 to 9 μg/m³ (below 9 μg/m³, the chronic inhalation REL set by the OEHHA in California, USA) [57].

In the office, the formaldehyde concentration is significantly higher than in the corridor and bathroom (p<0.05, two-way ANOVA, multiple comparisons). Still, no significant differences have been found between the formaldehyde concentration in the bathroom and corridor (p = 0.188). The medium value of 19.8±2.4 μg/m³ is lower than that found in 422 air-conditioned offices in Hong Kong, where the formaldehyde levels were assessed at 32±2.7 μg/m³ [58]. The formaldehyde concentration in the office did not vary dramatically across the year, but the concentration was lower in September and higher in March 2023 than in the other months. Interestingly, during the summer, the formaldehyde concentrations in the corridor and bathroom exhibited a noteworthy decrease, measuring 9.7 μg/m³ for the corridor and 8.7 μg/m³ for the bathroom.

In contrast, they revealed significantly higher levels in the winter months, with concentrations peaking at 15.3 μg/m³ for the corridor and 17.6 μg/m³ for the bathroom. The consistent findings extend to environmental monitoring in English homes, revealing a notable trend of formaldehyde concentrations decreasing by half from winter to summer [59]. The variation in trends between the office and other rooms may be attributed to disparities in ventilation systems. Additionally, the presence of diverse electronic equipment in the office could serve as a significant source of formaldehyde. Furthermore, the comparatively shorter duration of time spent by individuals in the corridor and bathroom, as opposed to the office, could contribute to these distinctions.

The total concentration of volatile organic compounds in indoor and outdoor air is presented in Fig. 7.

The ambient concentrations of volatile organic compounds (VOCs) exhibited a discernible seasonal variation, with notably elevated levels during the summer compared to the winter. Our data indicate that the mean concentration from May to September reached 110±21 μg/m³. In contrast, a distinct reduction was observed during the October-April interval, with a mean concentration of 55±20 μg/m³. This observed disparity in VOC concentrations between seasons underscores the influence of meteorological and environmental factors on atmospheric composition, thereby necessitating a comprehensive understanding of the underlying mechanisms governing such seasonal variations. The same variation in TVOC concentration has been found in a remote Mediterranean station on the northern tip of Corsica (Ersa, France) over 25 months, from June 2012 to June 2014 [60]. The indoor concentrations of volatile organic compounds (VOCs) surpassed their outdoor counterparts, manifesting a pronounced variability across both spatial locations and temporal intervals, as indicated by the outcomes of a two-way analysis of variance (ANOVA) with statistical significance (p<0.05). This observed indoor-outdoor disjunction in VOC concentrations underscores the intricacies associated with indoor air quality dynamics, wherein a myriad of factors, such as occupant activities, building materials, and ventilation systems, contribute to the observed variation [61]. The identification of the organic functions and the inorganic groups present in the settled dust samples collected both inside and outside the environment was carried out by Attenuated

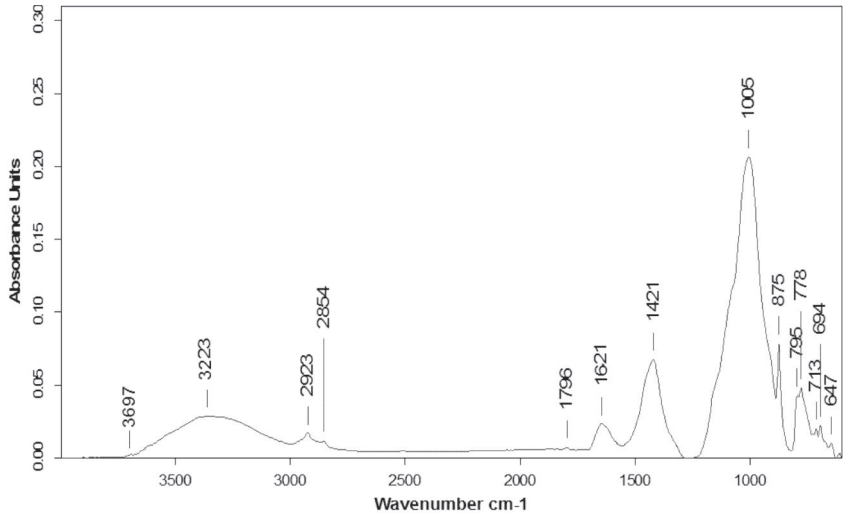

Fig. 8. FTIR-ATR spectrum of the outdoor dust sample.

Total Reflectance – Fourier Transform Infrared Spectrometry (ATR-FTIR). This analytical technique provides essential details on the type and nature of the samples' functional groups (organic/inorganic and aliphatic/aromatic). Various authors have frequently used it to characterize the chemical composition of both $PM_{2.5}$/PM_{10} and settled dust based on the positions of the vibrational bands recorded in the FTIR spectra [23, 25, 27, 28, 62, 63].

Fig. 8 shows the FTIR-ATR spectrum obtained for the settled dust sample collected in the outdoor environment, and Fig. 8 shows the recorded spectra for the samples collected from the indoor environment in the three locations: (a) office; b) bathroom; c) corridor).

Based on the wavelength values, Table 1 shows the vibrational bands' assignment in the FTIR-ATR spectra for all analyzed samples.

The FTIR-ATR spectrum of the settled dust sample taken from the outdoor environment is dominated by the vibrational bands of phyllosilicates, clay minerals, and quartz located at 3697 cm^{-1}, 1621 cm^{-1}, 1005 cm^{-1}, 795 cm^{-1}, 778 cm^{-1}, 694 cm^{-1} and 647 cm^{-1} [21] Also, the presence of calcite-type carbonates can be identified. According to literature data, FTIR vibrational spectra of carbonates exhibit different types of vibrations, including symmetric stretching (ν1), usually inactive in the IR, asymmetric stretching (ν2), out-of-plane bending (ν3), and in-plane bending (ν4) [64-66]. In pure calcite ($CaCO_3$), the (ν2), (ν3), and (ν4) bands are recorded at ~1427 cm^{-1}, 876 cm^{-1}, and 725 cm^{-1}, but in the presence of other mineral compounds, the positions of these bands can change, as frequently observed in published studies [35, 65, 67]. In the case of the analyzed outdoor sample of settled dust, the specific vibrational bands of calcite were recorded at 1796 cm^{-1} (ν1+ ν4 combination mode) [68], 1421 cm^{-1}, 875 cm^{-1}, and 713 cm^{-1}.

The presence of silicates, aluminosilicates, and carbonates in the chemical composition of settled dust taken from the atmosphere was observed and reported in the literature by several authors. It was attributed especially to soil erosion, Saharan dust events, and protective coating building materials [23, 27, 35, 62-64, 69]. The organic compounds of the aliphatic hydrocarbon type were clearly identified in the outdoor investigated sample by the bands located in the FTIR spectrum at 2923 cm^{-1} and 2854 cm^{-1} [70]. Studies have shown that the hydrocarbons in dust particles come mainly from fuel combustion processes [23, 32, 34, 62]. The presence of ammonium salts (i.e., NH_4NO_3) cannot be excluded from the chemical composition of the outdoor sample, but over the (NH_4^+) vibrational band located at ~1414 cm^{-1}, the asymmetric stretching vibration frequencies of (CO_3^{2-}) overlap.

Compared to the outdoor sample, the FTIR-ATR spectra (Fig. 9) of the settled dust samples collected from the office, bathroom, and corridor are more complex and contain, in addition to the bands identified in Fig. 6, a series of new bands specific to some inorganic, organic, or bio-organic compounds generated by indoor sources (i.e., wall construction materials, wall covering materials, insulation materials, carpets, electronic devices, furniture, human activities, the human body, hygiene and personal care products, etc.). Thus, the presence of gypsum ($CaSO_4 \cdot 2H_2O$) originating from the interior plaster walls was observed in all three indoor samples (~3535 cm^{-1}, ~3399 cm^{-1}, ~1113 cm^{-1}, and ~670 cm^{-1} [71-74]), along with calcite, quartz, phyllosilicates, and clay minerals (minerals from both the wall finishing materials and the outdoor atmosphere due to ventilation). In the office, where the ventilation was reduced to a minimum during the collection of the settled dust sample, the intensity of the specific calcite band located at ~874 cm^{-1} was highest, proving this compound's origin from indoor sources. Due to (Si-O) asymmetrical stretching, the band was recorded at 1036-1031 cm^{-1}, showing a shift to a higher wavelength than in the outdoor dust sample. According to Senthil Kumar and Rajkumar [69], this behavior can

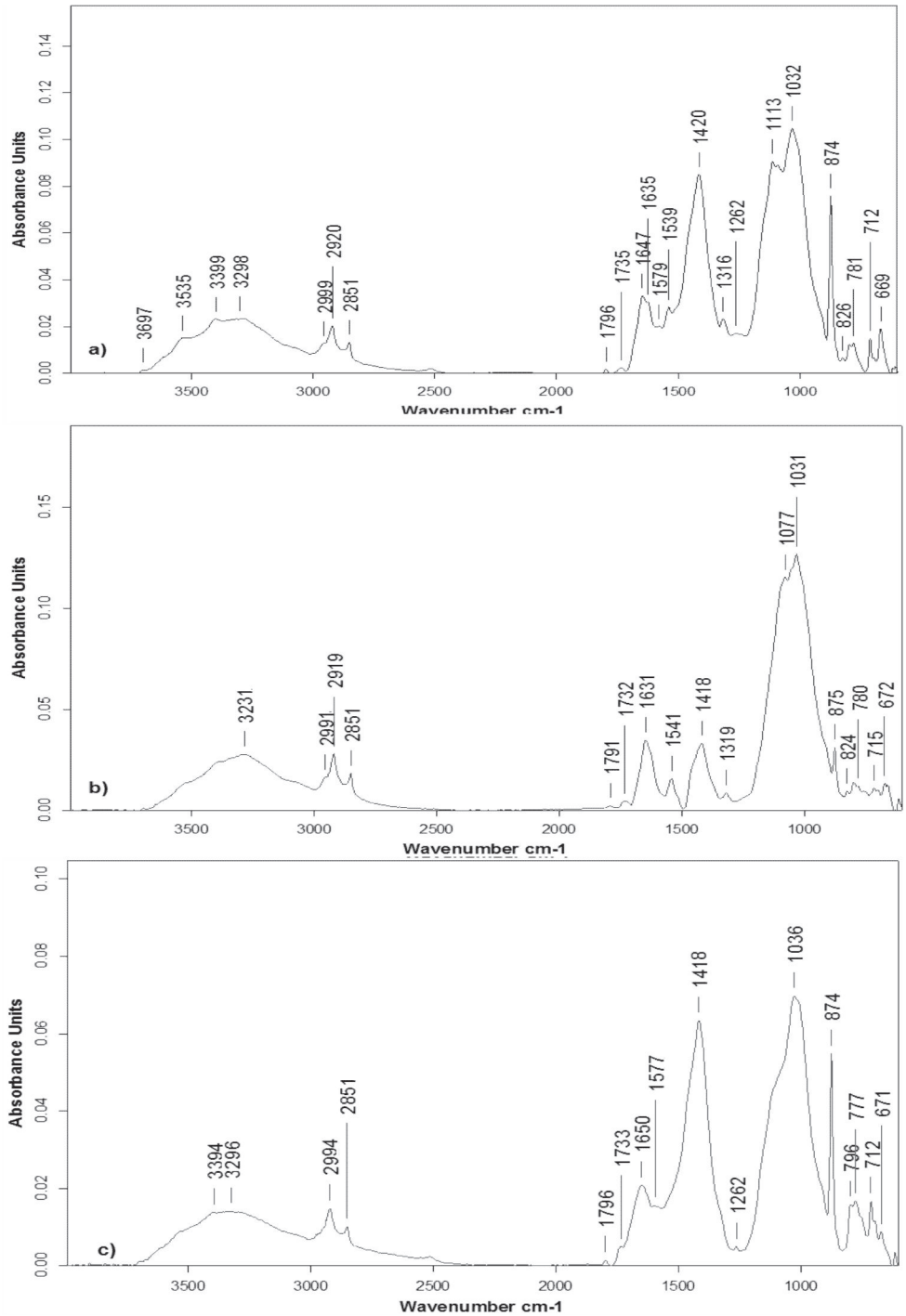

Fig. 9. FTIR-ATR spectra of the indoor environment dust samples: (a) office; b) bathroom; c) corridor.

be attributed to K-feldspar and plagioclase compounds, which seem to be dominant silicates in the settled dust from the interior spaces and are generated from the used construction materials [26, 28, 31]. In the FTIR-ATR spectrum of the sample collected from the indoor bathroom environment, a band located at 1077 cm^{-1} was recorded due to the stretching vibration of the group (Si-O-Si) from polysiloxanes (silicon) used as insulating materials [75]. The presence of the NH_4NO_3 compound (~826 cm^{-1}) was observed only in the office and bathroom dust samples. Various authors have frequently reported inorganic nitrates in dust samples due to acid deposits and indoor contamination [23, 26, 27, 31, 62].

Regarding the organic compounds present in all indoor dust samples, the presence of the ~1733 cm^{-1} band due to the carbonyl group from the aliphatic aldehydes can be noted. The aliphatic aldehydes (formaldehyde) were identified as indoor air pollutants (as previously demonstrated in Fig. 2 and Fig. 5) along with a series of saturated and unsaturated VOCs whose stretching bands were recorded at ~2991/2999 cm^{-1}, ~2920 cm^{-1} and 2851 cm^{-1}. In the office and corridor dust samples,

Table 1. The infrared absorption frequencies (cm^{-1}) of the settled dust samples collected from outdoor and indoor environments.

Outdoor	Office	Bathroom	Corridor	Tentative assignments
3697	3697	3697	3694	(O-H) stretching from inter-layer clay minerals (i.e., smectite and kaolinite)
-	3535 sh 3399 sh	3534 sh 3399 sh	3536 sh 3394 sh	(O-H) stretching characteristic of $CaSO_4 \cdot 2(H_2O)$ (gypsum)
3223	3298	3231	3296	(O-H) stretching in alcohols/phenols, absorbed H_2O; N-H stretching from amide (Amide A band)
-	2999	2991	-	=C-H stretching from unsaturated hydrocarbons (Csp^2)
2923 2854	2920 2851	2919 2851	2921 2851	-C-H symmetrical and asymmetrical stretching from CH_2 and CH_3 groups from saturated hydrocarbons
1796	1796	1791	1796	(C=O) stretching from calcite
-	1735	1732	1733	(C=O) stretching from the carbonyl group in aliphatic aldehydes and ketones
-	1647	-	1650	(C=O) stretching from carbonyl bonds in the peptide backbone (1st amide band)
-	1635	1631	-	(C=C) bond vibration in aliphatic/aromatic compounds
1621	-	-	-	(O-H) bending of absorbed H_2O, phyllosilicates (i.e., illite, muscovite, palygorskite), and clay minerals (i.e., smectite and kaolinite)
-	1579	-	1577	(N-H) bending and (C-N) stretching vibrations of the amide group (2nd amide band) in protein structures
-	1539	1541	-	(NO_2^-) asymmetric stretching vibrations in nitrated-polyaromatic hydrocarbons (n-PAHs)
1421	1420	1418	1418	(C-O) asymmetrical stretching from carbonates (i.e.calcite); (NH_4^+) vibration from ammonium salts
-	1316	1319	-	(NO_2^-) symmetric stretching vibrations in nitrated-polyaromatic hydrocarbons (n-PAHs)
-	1262	-	1262	(C-N) stretching and (N-H) bending in protein structures (3th amide band)
-	1113	1112 sh	1114 sh	sulfate group $(SO_4)^{2-}$ stretching vibration from $CaSO_4 \cdot 2(H_2O)$ (gypsum)
-	-	1077	-	(Si-O-Si) stretching from polysiloxanes
-	1032	1031	1036	(Si-O) asymmetrical stretching of K-feldspar and plagioclase feldspar
1005	-	-	-	(Si-O) asymmetrical stretching of phyllosilicates and clay minerals
875	874	875	874	(C-O) out-of-plane bending of $(CO_3)^{2-}$ from carbonates (i.e.calcite)
-	826	824	-	(NO_3^-) vibration from inorganic salts
795	797	796	796	(Si-O) symmetrical stretching mainly from quartz
778	781	780	777	(Si-O-Si) symmetrical stretching from quartz
713	712	715	712	(C-O) in-plane bending of $(CO_3)^{2-}$ from carbonates
694	-	-	-	(Si-O) symmetrical bending in quartz
-	669	672	671	sulfate group $(SO_4)^{2-}$ stretching vibration from gypsum
647	648	648	646	(Si-O-Si) bending of silicates, phyllosilicates, and feldspar

the presence of proteins was clearly identified based on the specific bands located at ~3298 cm^{-1} (Amide A band), ~1650 cm^{-1} (1st amide band), ~1577 cm^{-1} (2nd amide band), and 1262 cm^{-1} (3rd amide band) [76, 77]. According to Gustafsson et al., the presence of protein structures in indoor dust particles is generated either by the human body (i.e., desquamated skin cells, dandruff) or by biological contaminants such as fungi (*Penicillium*, *Aspergillus, Cladosporium*, etc.) and molds [30]. The aromatic structures and nitrate-polyaromatic hydrocarbons (n-PAH) were identified in the FTIR-ATR spectrum of the dust samples collected in the office and bathroom based on the (C=C) vibration located at ~1630 cm^{-1} and on the symmetrical and asymmetrical stretching vibrations of the (NO_2^-) group located at ~1319 cm^{-1} and 1540 cm^{-1} [22]. The presence of n-PAH in dust composition and other compounds with aromatic rings was also reported by Shankar et al., who identified anthropogenic sources as responsible for these emissions [22]. Patel et al. determined that PAH-type pollutants

are toxic, mutagenic, carcinogenic, teratogenic, and immunotoxicogenic for various life forms [78].

Nineteen employees responded to our questionnaire, 11 (57.9%) females. The mean age of the group was 53.8±6.7 years old (between 42 and 67 years). Only one subject reported known allergies, and one was diagnosed with other associated diseases. No participant had an upper or lower airway infection in the previous week. The subject with a known allergy reported five symptoms, like the patient with a known medical condition. Eighteen (89.5%) subjects had at least one symptom, 47.4% had 2 to 3, and 5 (21.1%) subjects had four or more symptoms. The median number of symptoms per patient was 2 (IQ range=1.5-4, range: 0-10) (Fig. 10).

Regarding SBS symptoms among the subjects included in this study, our study showed that most of our subjects experienced at least one SBS symptom, possibly related to the work environment. Fatigue, ENT, head, and eye-related symptoms were the most frequent, while none of the subjects reported skin-related problems. Eye problems were observed in 31% of the participants, similar to other studies [79].

Formaldehyde and VOCs in high concentrations can cause the so-called sensory irritation symptoms, with irritation of the eyes, nose, and throat [80]. Headache and fatigue are also presumed to be caused by VOCs. Indoors, individual VOCs are less likely to be present at concentrations sufficient to cause sensory irritation symptoms. Nevertheless, indoor air contains a mixture of many VOCs. Some studies focused on this idea and showed that not individual VOCs but higher concentrations of some groups of VOCs, like VOCs attributed to cleaning products, water-based paints [81], or photocopiers, are responsible for symptoms. Our subjects worked in city hall offices; therefore, they were exposed to VOCs derived from photocopiers, printers, and paints. The measured TVOC and formaldehyde had similar concentrations inside the office and outside of the building only during the first two working hours but doubled and even tripled afterward. High concentrations of TVOCs were also reported in new buildings. A study from Japan showed that SBS symptoms were related to increased TVOC concentrations, long working hours (>50 hours per week) in females, and smoking in males [82]. In our study, TVOC concentrations were low compared to the study of Takigawa T et al. [82], even at the end of the day (150 µg/m^3). However, our subjects experienced several SBS symptoms. Smoking might have been a confounding factor, but we did not collect data about smoking habits in our study group. Regarding the working hours, in our country, the program is 40 hours a week. Indoor VOCs and formaldehyde have also been related to allergies, asthma, and respiratory symptoms like coughing or dyspnea [83, 84]. Small particulate matter can cause respiratory symptoms or aggravate respiratory conditions. In our study, PMs were stable throughout the day, and formaldehyde increased in parallel with TVOC. Only one subject in our research reported difficulty breathing, but she also mentioned chest pain. We can hypothesize that an unknown cardiac problem might have determined these symptoms. Formaldehyde is an eye irritant at high concentrations, around 0.3-0.5 mg/m^3 [85]. Most studies involved subjects directly exposed to formaldehyde at work, such as pathologists or funeral service workers. Workers exposed to high formaldehyde concentrations had an odds ratio of 2.18 for cough and 2.91 for dyspnea [86]. Our study measured significantly lower concentrations of formaldehyde than those known to cause eye irritation (the most sensitive organ). However, one in 3 patients reported eye symptoms. More likely, the TVOCs and other indoor pollutants we did not measure contributed to this finding.

Female subjects reported more symptoms (n = 3.1) compared to male subjects (n = 1.8), but the difference was not statistically significant (p = 0.2, Mann-Whitney).

More than half of the subjects reported fatigue (63.1%). Stuffed nose, headache, and runny nose were reported in 42%, 36.8%, and 31.5% of the subjects. Ten subjects (52.6%) had at least one ENT-related symptom, while 6 (31.5%) reported eye symptoms (Fig. 11). In our

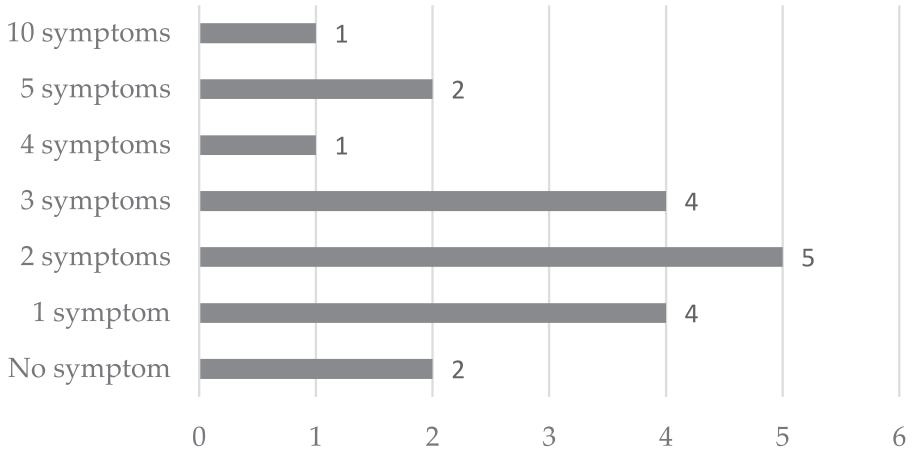

Fig. 10. The total number of symptoms per patient in the study group (n = 19).

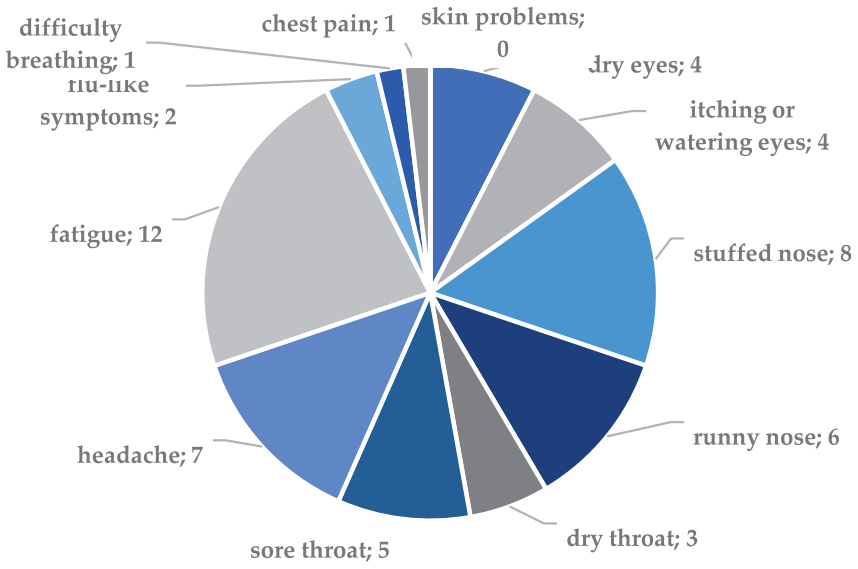

Fig. 11. The count of reported symptoms per category.

study, 42.1% of subjects had three or more symptoms. The number of symptoms influences work absenteeism [87], but we do not have data on the number of sick leave per subject. Both males and females reported SBS symptoms. The females in our research tended to report more symptoms compared to males, although the difference did not reach statistical significance. Other studies also noted that women reported more symptoms compared to men and that people reporting symptoms were younger compared to those not reporting symptoms [36].

While our study spans one year, encompassing seasonal fluctuations, it is essential to acknowledge that there may be limits on how well this period reflects long-term trends. Long-term climate change and atypical weather patterns can impact the quality of indoor air, which may not be fully reflected by studying it for only one year. One further constraint is that the research is centered solely on a solitary office structure located in Resita, Western Romania. Although this study offers detailed indoor air quality (IAQ) analysis at the mentioned location, its findings may not apply to different geographical areas, climates, or building structures. However, the study acknowledges the impact of outside contaminants on interior air quality. However, it lacks a comprehensive assessment of outside air quality or a simulation of the interactions between interior and outdoor settings. The study examines the origins and consequences of inadequate indoor air quality. However, it may not thoroughly investigate the efficacy of measures or treatments that might enhance IAQ and decrease health hazards.

This study could be a breakthrough for some future studies as measurements across different geographic locations and in various types of buildings (e.g., residential, industrial, educational) to understand how regional climates, building designs, and usage patterns affect indoor air quality and health outcomes, and to implement long-term studies to monitor changes in indoor air quality over several years and their impact on health, considering factors like building aging, renovation activities, and changes in occupant behavior. This could provide insights into the long-term effects of exposure to indoor pollutants. Concerning occupational health and policy, additional research could concentrate on the specific occupational health consequences associated with indoor air quality in office buildings and other work environments. This research could also assess the efficacy of current policies and regulations about indoor air quality while identifying areas where new policies could be formulated.

Conclusions

This study provides clear evidence that office environments, as examples of enclosed workspaces, are exposed to various indoor air pollutants, such as particulate matter (PM), volatile organic compounds (VOCs), and formaldehyde. Specifically, we observed that the levels of volatile organic compounds increased from an average of 0.050±0.044 μg/m^3 at 8:00 AM to 0.14±0.11 μg/m^3 by 3:00 PM. Similarly, formaldehyde concentrations rose significantly over an 8-hour period, from an average of 9±5 μg/m^3 to 27±14 μg/m^3. These pollutants come from a mix of sources, including building materials, office machinery, and everyday activities, making it challenging to maintain good indoor air quality (IAQ). Our research also highlights that the amount of pollutants inside can change with the seasons, with higher levels of particulate matter found during the colder months. More importantly, we found a strong link between being exposed to higher levels of these indoor pollutants and experiencing symptoms related to Sick

Building Syndrome (SBS). The office workers in the building we studied reported various health issues, such as irritation of the eyes, breathing difficulties, and even problems with concentration and memory, emphasizing the urgent need for action to improve indoor air quality and prevent these health problems. In simpler terms, our study shows that offices can have air pollution from different sources, which can get worse at certain times of the day or year, leading to health issues for the people working there. This underlines how important it is to take steps to clean the air in these spaces to keep everyone healthy.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. MANDIN C., TRANTALLIDI M., CATTANEO A., CANHA N., MIHUCZ V.G., SZIGETI T., MABILIA R., PERRECA E., SPINAZZÈ A., FOSSATI S., DE KLUIZENAAR Y., CORNELISSEN E., SAKELLARIS I., SARAGA D., HÄNNINEN O., DE OLIVEIRA FERNANDES E., VENTURA G., WOLKOFF P., CARRER P., BARTZIS J. Assessment of indoor air quality in office buildings across Europe – The OFFICAIR study. Science of The Total Environment, **579**, 169, **2017**.
2. NIU R.P., CHEN X., LIU H. Analysis of the impact of a fresh air system on the indoor environment in office buildings. Sustainable Cities and Society, **83**, 103934, **2022**.
3. INSTITUTE OF MEDICINE Climate Change, the Indoor Environment, and Health. National Academies Press, Washington, DC, **2011**.
4. KLEPEIS N.E., NELSON W.C., OTT W.R., ROBINSON J.P., TSANG A.M., SWITZER P., BEHAR J.V., HERN S.C., ENGELMANN W.H. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. Journal of Exposure Science & Environmental Epidemiology, **11** (3), 231, **2001**.
5. KORSAVI S.S., MONTAZAMI A., MUMOVIC D. Indoor air quality (IAQ) in naturally-ventilated primary schools in the UK: Occupant-related factors. Building and Environment, **180**, 106992, **2020**.
6. TEPENEU A., LUPITU A., SURDEA-BLAGA T., MOISA C., CHAMBRE D., COPOLOVICI D.M., COPOLOVICI L. Variability of Air Pollutants in the Indoor Air of a General Store. Applied Sciences, **13** (23), 12572, **2023**.
7. MANNAN M., AL-GHAMDI S.G. Indoor Air Quality in Buildings: A Comprehensive Review on the Factors Influencing Air Pollution in Residential and Commercial Structure. International Journal of Environmental Research and Public Health, **18** (6), **2021**.
8. SEO S.-H., JUNG K.-S., PARK M.-K., KWON H.-O., CHOI S.-D. Indoor air pollution of polycyclic aromatic hydrocarbons emitted by computers. Building and Environment, **218**, 109107, **2022**.
9. CARRER P., WOLKOFF P. Assessment of Indoor Air Quality Problems in Office-Like Environments: Role of Occupational Health Services. International Journal of Environmental Research and Public Health, **15** (4), **2018**.
10. SARAGA D.E., QUEROL X., DUARTE R.M.B.O., AQUILINA N.J., CANHA N., ALVAREZ E.G., JOVASEVIC-STOJANOVIC M., BEKÖ G., BYČENKIENĖ S., KOVACEVIC R., PLAUŠKAITĖ K., CARSLAW N. Source apportionment for indoor air pollution: Current challenges and future directions. Science of The Total Environment, **900**, 165744, **2023**.
11. WESCHLER C.J., CARSLAW N. Indoor Chemistry. Environmental Science & Technology, **52** (5), 2419, **2018**.
12. GUERCIO V., POJUM I.C., LEONARDI G.S., SHRUBSOLE C., GOWERS A.M., DIMITROULOPOULOU S., EXLEY K.S. Exposure to indoor and outdoor air pollution from solid fuel combustion and respiratory outcomes in children in developed countries: a systematic review and meta-analysis. Science of The Total Environment, **755**, 142187, **2021**.
13. WEBER L.P., AL-DISSI A., MARIT J.S., GERMAN T.N., TERLETSKI S.D. Role of carbon monoxide in impaired endothelial function mediated by acute second-hand tobacco, incense, and candle smoke exposures. Environmental Toxicology and Pharmacology, **31** (3), 453, **2011**.
14. WU Z., LYU H., GUO Y., MAN Q., NIU H., LI J., JING X., REN G., MA X. Polycyclic aromatic hydrocarbons and polybrominated diphenyl ethers inside university campus: Indoor dust-bound pollution characteristics and health risks to university student. Building and Environment, **221**, 109312, **2022**.
15. DEL CARMEN GONZÁLEZ-CABALLERO M., DE ALBA-GONZALEZ M., TARAZONA J.V. Pollution, indoor air. Elsevier, **2023**.
16. CHAFE Z., BRAUER M., HÉROUX M.-E., KLIMONT Z., LANKI T., SALONEN R. O., SMITH K.R. Residential heating with wood and coal: health impacts and policy options in Europe and North America, **2015**.
17. DEFRA Clean air strategy. Defra UK, **2019**.
18. CASAS L., DUMAS O., LE MOUAL N. Chapter 6 – Indoor air and respiratory health: Volatile organic compounds and cleaning products. Academic Press, **2023**.
19. NAZAROFF W.W., WESCHLER C.J. Cleaning products and air fresheners: exposure to primary and secondary air pollutants. Atmospheric Environment, **38** (18), 2841, **2004**.
20. MØLHAVE L., SCHNEIDER T., KJÆRGAARD S.K., LARSEN L., NORN S., JØRGENSEN O. House dust in seven Danish offices. Atmospheric Environment, **34**, 4767, **2000**.
21. LUTHRA A., RAVI A., LI S., NYSTROM S., THOMPSON Z., COE J. Dust Library of Plasmonically Enhanced Infrared Spectra of Individual Respirable Particles. Applied Spectroscopy, **70**, **2016**.
22. SHANKAR S., GADI R., SHARMA S.K., MANDAL T. Identification of Carbonaceous Species and FTIR Profiling of PM2.5 Aerosols for Source Estimation in Old Delhi Region of India. MAPAN, **37**, 1, **2022**.
23. VARRICA D., TAMBURO E., VULTAGGIO M., DI CARLO I. ATR–FTIR Spectral Analysis and Soluble Components of PM10 And PM2.5 Particulate Matter over the Urban Area of Palermo (Italy) during Normal Days

and Saharan Events. International Journal of Environmental Research and Public Health, **16**, **2019**.
24. SADRIZADEH S., YAO R., YUAN F., AWBI H., BAHNFLETH W., BI Y., CAO G., CROITORU C., DE DEAR R., HAGHIGHAT F., KUMAR P., MALAYERI M., NASIRI F., RUUD M., SADEGHIAN P., WARGOCKI P., XIONG J., YU W., LI B. Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment. Journal of Building Engineering, **57**, 104908, **2022**.
25. REFF A., TURPIN B., PORCJA R., GIOVENNETTI R., CUI W., WEISEL C., ZHANG J., KWON J., ALIMOKHTARI S., MORANDI M., STOCK T., MABERTI S., COLOME S., WINER A., SHENDELL D., JONES J., FARRAR C. Functional group characterization of indoor, outdoor, and personal PM 2.5: Results from RIOPA. Indoor Air, **15**, 53, **2005**.
26. DUBOCQ F., KÄRRMAN A., GUSTAVSSON J., WANG T. Comprehensive chemical characterization of indoor dust by target, suspect screening and nontarget analysis using LC-HRMS and GC-HRMS. Environmental Pollution, **276**, 116701, **2021**.
27. RADULESCU C., STIHI C., IORDACHE S., DUNEA D., DULAMA I. Characterization of urban atmospheric PM2.5 by ATR-FTIR, ICP-MS and SEM-EDS techniques. Revista de Chimie -Bucharest, **68**, **2017**.
28. KUMAR S., JAIN M.K. Characterization and morphometric study of household settled dust: A case study in Dhanbad, the coal capital of India. Applied Geochemistry, **144**, 105398, **2022**.
29. ANAKE W.U., NNAMANI E.A. Physico-chemical characterization of indoor settled dust in Children's microenvironments in Ikeja and Ota, Nigeria. Heliyon, **9** (6), e16419, **2023**.
30. GUSTAFSSON Å., KRAIS A., GORZSÁS A., LUNDH T., GERDE P. Isolation and characterization of a respirable particle fraction from residential house-dust. Environmental Research, **161**, 284, **2017**.
31. BUTTE W., HEINZOW B. Pollutants in house dust as indicators of indoor contamination. Reviews of Environmental Contamination and Toxicology, **175**, 1, **2002**.
32. GUPTA P., SATSANGI M., SATSANGI G.P., JANGID A., LIU Y., PANI S.K., KUMAR R. Exposure to respirable and fine dust particle over North-Central India: chemical characterization, source interpretation, and health risk analysis. Environmental Geochemistry and Health, **42** (7), 2081, **2020**.
33. LI Y., PADOAN E., AJMONE-MARSAN F. Soil particle size fraction and potentially toxic elements bioaccessibility: A review. Ecotoxicology and Environmental Safety, **209**, 111806, **2021**.
34. MANISALIDIS I., STAVROPOULOU E., STAVROPOULOS A., BEZIRTZOGLOU E. Environmental and Health Impacts of Air Pollution: A Review. Frontiers in Public Health, **8**, **2020**.
35. ARTESANI A., DI TURO F., ZUCCHELLI M., TRAVIGLIA A. Recent Advances in Protective Coatings for Cultural Heritage–An Overview. Coatings, **10** (3), **2020**.
36. MARMOT A.F., ELEY J., STAFFORD M., STANSFELD S.A., WARWICK E., MARMOT M.G. Building health: an epidemiological study of „sick building syndrome" in the Whitehall II study. Occupational and Environmental Medicine, **63** (4), 283, **2006**.
37. LU C.Y., TSAI M.C., MUO C.H., KUO Y.H., SUNG F.C., WU C.C. Personal, Psychosocial and Environmental Factors Related to Sick Building Syndrome in Official Employees of Taiwan. International Journal of Environmental Research and Public Health, **15** (1), **2017**.
38. SURAWATTANASAKUL V., SIRIKUL W., SAPBAMRER R., WANGSAN K., PANUMASVIVAT J., ASSAVANOPAKUN P., MUANGKAEW S. Respiratory Symptoms and Skin Sick Building Syndrome among Office Workers at University Hospital, Chiang Mai, Thailand: Associations with Indoor Air Quality, AIRMED Project. International Journal of Environmental Research and Public Health, **19** (17), **2022**.
39. RAW G.J., ROYS M.S., WHITEHEAD C., TONG D. Questionnaire design for sick building syndrome: An empirical comparison of options. Environment International, **22** (1), 61, **1996**.
40. FAN H., ZHAO C., YANG Y. A comprehensive analysis of the spatio-temporal variation of urban air pollution in China during 2014-2018. Atmospheric Environment, **220**, 117066, **2020**.
41. ZHAO C., WANG Y., SHI X., ZHANG D., WANG C., JIANG J.H., ZHANG Q., FAN H. Estimating the contribution of local primary emissions to particulate pollution using high-density station observations. Journal of Geophysical Research: Atmospheres, **124** (3), 1648, **2019**.
42. XU X., HUANG G., LIU L., GUAN Y., ZHAI M., LI Y. Revealing dynamic impacts of socioeconomic factors on air pollution changes in Guangdong Province, China. Science of the Total Environment, **699**, 134178, **2020**.
43. EEFTENS M., TSAI M.-Y., AMPE C., ANWANDER B., BEELEN R., BELLANDER T., CESARONI G., CIRACH M., CYRYS J., DE HOOGH K., DE NAZELLE A., DE VOCHT F., DECLERCQ C., DĖDELĖ A., ERIKSEN K., GALASSI C., GRAŽULEVIČIENĖ R., GRIVAS G., HEINRICH J., HOFFMANN B., IAKOVIDES M., INEICHEN A., KATSOUYANNI K., KOREK M., KRÄMER U., KUHLBUSCH T., LANKI T., MADSEN C., MELIEFSTE K., MÖLTER A., MOSLER G., NIEUWENHUIJSEN M., OLDENWENING M., PENNANEN A., PROBST-HENSCH N., QUASS U., RAASCHOU-NIELSEN O., RANZI A., STEPHANOU E., SUGIRI D., UDVARDY O., VASKÖVI É., WEINMAYR G., BRUNEKREEF B., HOEK G. Spatial variation of PM2.5, PM10, PM2.5 absorbance and PMcoarse concentrations between and within 20 European study areas and the relationship with NO_2 – Results of the ESCAPE project. Atmospheric Environment, **62**, 303, **2012**.
44. FANG L., LIU N., LIU W., MO J., ZHAO Z., KAN H., DENG F., HUANG C., ZHAO B., ZENG X., SUN Y., QIAN H., SUN C., GUO J., ZHENG X., ZHANG Y. Indoor formaldehyde levels in residences, schools, and offices in China in the past 30 years: A systematic review. Indoor Air, **32** (10), e13141, **2022**.
45. SALTHAMMER T. Formaldehyde sources, formaldehyde concentrations and air exchange rates in European housings. Building and Environment, **150**, 219, **2019**.
46. SALTHAMMER T., MENTESE S., MARUTZKY R. Formaldehyde in the Indoor Environment. Chemical Reviews, **110** (4), 2536, **2010**.
47. NAOHIDE S., ATSUSHI M., TOSHIYUKI K., KOICHI T., MASASHI G., YUKIO Y. Distribution of indoor concentrations and emission sources of formaldehyde in Japanese residences. IntechOpen, Rijeka, **2011**.
48. KIM S.-J., LEE S.-J., LEE H.-Y., SON J.-M., LIM H.-B., KIM H.-W., SHIN H.-J., LEE J.Y., CHOI S.-D.

Characteristics of volatile organic compounds in the metropolitan city of Seoul, South Korea: Diurnal variation, source identification, secondary formation of organic aerosol, and health risk. Science of the Total Environment, **838**, 156344, **2022**.
49. YAO S., WANG Q., ZHANG J., ZHANG R., GAO Y., ZHANG H., LI J., ZHOU Z. Ambient volatile organic compounds in a heavy industrial city: Concentration, ozone formation potential, sources, and health risk assessment. Atmospheric Pollution Research, **12** (5), 101053, **2021**.
50. NORRIS C.L., EDWARDS R., GHOROI C., SCHAUER J.J., BLACK M., BERGIN M.H. A pilot study to quantify volatile organic compounds and their sources inside and outside homes in urban India in summer and winter during normal daily activities. Environments – MDPI, **9** (7), **2022**.
51. SRIVASTAVA A., DEVOTTA S. Indoor Air Quality of Public Places in Mumbai, India in Terms of Volatile Organic Compounds. Environmental Monitoring and Assessment, **133** (1), 127, **2007**.
52. MENG X., WU Y., PAN Z., WANG H., YIN G., ZHAO H. Seasonal Characteristics and Particle-size Distributions of Particulate Air Pollutants in Urumqi. International Journal of Environmental Research and Public Health, **16** (3), **2019**.
53. LV D., CHEN Y., ZHU T., LI T., SHEN F., LI X., MEHMOOD T. The pollution characteristics of PM10 and PM2.5 during summer and winter in Beijing, Suning and Islamabad. Atmospheric Pollution Research, **10** (4), 1159, **2019**.
54. CICHOWICZ R., WIELGOSIŃSKI G., FETTER W. Dispersion of atmospheric air pollution in summer and winter season. Environmental Monitoring and Assessment, **189** (12), 605, **2017**.
55. BOMAN J., SHALTOUT A.A., ABOZIED A.M., HASSAN S.K. On the elemental composition of PM2.5 in central Cairo, Egypt. X-Ray Spectrometry, **42** (4), 276, **2013**.
56. ABDEL-SALAM M.M.M. Seasonal variation in indoor concentrations of air pollutants in residential buildings. Journal of the Air & Waste Management Association, **71** (6), 761, **2021**.
57. LIU C., MIAO X., LI J. Outdoor formaldehyde matters and substantially impacts indoor formaldehyde concentrations. Building and Environment, **158**, 145, **2019**.
58. HUI P.S., MUI K.W., WONG L.T. Influence of indoor air quality (IAQ) objectives on air-conditioned offices in Hong Kong. Environmental Monitoring and Assessment, **144** (1-3), 315, **2008**.
59. STAMP S., BURMAN E., SHRUBSOLE C., CHATZIDIAKOU L., MUMOVIC D., DAVIES M. Seasonal variations and the influence of ventilation rates on IAQ: A case study of five low-energy London apartments. Indoor and Built Environment, **31** (3), 607, **2021**.
60. DEBEVEC C., SAUVAGE S., GROS V., SALAMEH T., SCIARE J., DULAC F., LOCOGE N. Seasonal variation and origins of volatile organic compounds observed during 2 years at a western Mediterranean remote background site (Ersa, Cape Corsica). Atmospheric Chemistry and Physics, **21** (3), 1449, **2021**.
61. PACIÊNCIA I., MADUREIRA J., RUFO J., MOREIRA A., FERNANDES E.D.O. A systematic review of evidence and implications of spatial and seasonal variations of volatile organic compounds (VOC) in indoor human environments. Journal of Toxicology and Environmental Health, Part B, **19** (2), 47, **2016**.
62. EL-ZAHHAR A.A., IDRIS A.M., FAWY K.F., ARSHAD M. SEM, SEM-EDX, μ-ATR-FTIR and XRD for urban street dust characterisation. International Journal of Environmental Analytical Chemistry, **101** (7), 988, **2021**.
63. SAHU V., ELUMALAI S.P., SINGH N., SINGH P. Characterization of indoor settled dust and investigation of indoor air quality in different micro-environments. International Journal of Environmental Health Research, **28**, **2018**.
64. MORRICONE A., MACCHIA A., CAMPANELLA L., DAVID M., DE TOGNI S., TURCI M., MARAS A., MEUCCI C., RONCA S. Archeometrical Analysis for the Characterization of Mortars from Ostia Antica. Procedia Chemistry, **8**, 231, **2013**.
65. REIG F., GIMENO-ADELANTADO J.V., MORENO M. FTIR Quantitative Analysis of Calcium Carbonate (Calcite) and Silica (Quartz) Mixtures Using the Constant Ratio Method. Application to Geological Samples. Talanta, **58**, 811, **2002**.
66. SATHYA P., VELRAJ G., MEYVEL S. Fourier transform infrared spectroscopic study of ancient brick samples from Salavankuppam Region, Tamilnadu, India. Advances in Applied Science Research, **3** (2), 776, **2012**.
67. ZHAO C., ZHANG Y., WANG C.-C., HOU M., LI A. Recent progress in instrumental techniques for architectural heritage materials. Heritage Science, **7** (1), 36, **2019**.
68. BRUNI S., LONGONI M., DE FILIPPI F., CALORE N., BAGNASCO GIANNI G. External Reflection FTIR Spectroscopy Applied to Archaeological Pottery: A Non-Invasive Investigation about Provenance and Firing Temperature. Minerals, **13** (9), **2023**.
69. SENTHIL KUMAR R., RAJKUMAR P. Characterization of minerals in air dust particles in the state of Tamilnadu, India through FTIR, XRD and SEM analyses. Infrared Physics & Technology, **67**, 30, **2014**.
70. NANDIYANTO A.B.D., OKTIANI R., RAGADHITA R. How to Read and Interpret FTIR Spectroscope of Organic Material. Indonesian Journal of Science and Technology, **4** (1), 22, **2019**.
71. BOGDAN A., CHAMBRE D., COPOLOVICI D.M., BUNGAU T., BUNGAU C.C., COPOLOVICI L. Heritage Building Preservation in the Process of Sustainable Urban Development: The Case of Brasov Medieval City, Romania. Sustainability, **14** (12), 6959, **2022**.
72. CARVALHO F., SOUSA P., LEAL N., SIMÃO J., KAVOULAKI E., LIMA M.M., DA SILVA T.P., ÁGUAS H., PADELETTI G., VEIGA J.P. Mortars from the Palace of Knossos in Crete, Greece: A Multi-Analytical Approach. Minerals, **12** (1), 30, **2022**.
73. COMITE V., POZO-ANTONIO J.S., CARDELL C., RIVAS T., RANDAZZO L., RUSSA M.F.L., FERMO P. Environmental impact assessment on the Monza cathedral (Italy): a multi-analytical approach. International Journal of Conservation Science, **11** (1), **2020**.
74. SOLONGO S., FRANKEN C., TENGIS S., ULAMBAYAR E., TUMUR-OCHIR B. Multi-method (XRF, FTIR, TGA) analysis of ancient bricks from Karabalgasun : A preliminary study. Proceedings of the Mongolian Academy of Sciences, **60**, 1, **2020**.
75. ABD HALIM Z.A., AHMAD N., YAJID M.A.M., HAMDAN H. Thermal insulation performance of silicone rubber / silica aerogel composite. Materials Chemistry and Physics, **276**, 125359, **2022**.
76. LORENZ-FONFRIA V.A. Infrared Difference Spectroscopy of Proteins: From Bands to Bonds. Chemical Reviews, **120** (7), 3466, **2020**.

77. SCHWAIGHOFER A., LENDL B. Infrared Spectroscopy for Structure Analysis of Protein Inclusion Bodies. Springer US, New York, NY, **2023**.
78. PATEL A.B., SHAIKH S., JAIN K.R., DESAI C., MADAMWAR D. Polycyclic Aromatic Hydrocarbons: Sources, Toxicity, and Remediation Approaches. Frontiers in Microbiology, **11**, 562813, **2020**.
79. BACKMAN H., HAGHIGHAT F. Indoor-air quality and ocular discomfort. Journal of the American Optometric Association, **70** (5), 309, **1999**.
80. ANDERSSON K., BAKKE J.V., BJØRSETH O., BORNEHAG C.G., CLAUSEN G., HONGSLO J.K., KJELLMAN M., KJÆRGAARD S., LEVY F., MØLHAVE L., SKERFVING S., SUNDELL J. TVOC and Health in Non-industrial Indoor Environments. Indoor Air, **7** (2), 78, **1997**.
81. BRINKE J.T., SELVIN S., HODGSON A.T., FISK W.J., MENDELL M.J., KOSHLAND C.P., DAISEY J.M. Development of New Volatile Organic Compound (VOC) Exposure Metrics and their Relationship to "Sick Building Syndrome" Symptoms. Indoor Air, **8** (3), 140, **1998**.
82. TAKIGAWA T., HORIKE T., OHASHI Y., KATAOKA H., WANG D.-H., KIRA S. Were volatile organic compounds the inducing factors for subjective symptoms of employees working in newly constructed hospitals? Environmental Toxicology, **19** (4), 280, **2004**.
83. MARION H., MARZIA S., GIOVANNI V., ISABELLA A.-M. Respiratory health and indoor air pollutants based on quantitative exposure assessments. European Respiratory Journal, **40** (4), 1033, **2012**.
84. MCGWIN G., LIENERT J., KENNEDY J.I. Formaldehyde exposure and asthma in children: a systematic review. Environmental Health Perspectives, **118** (3), 313, **2010**.
85. WOLKOFF P., NIELSEN G.D. Non-cancer effects of formaldehyde and relevance for setting an indoor air guideline. Environment International, **36** (7), 788, **2010**.
86. MATHUR N., RASTOGI S.K. Respiratory effects due to occupational exposure to formaldehyde: Systematic review with meta-analysis. Indian Journal of Occupational and Environmental Medicine, **11** (1), 26, **2007**.
87. NIEMELÄ R., SEPPÄNEN O., KORHONEN P., REIJULA K. Prevalence of building-related symptoms as an indicator of health and productivity. American Journal of Industrial Medicine, **49** (10), 819, **2006**.