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Research Article

Correlation between the Prevalence of Sick-Building Syndrome and Safe Indoor Air Quality Concept in Private Residential Housing in Jordan

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Indoor air quality (IAQ) and related health problems have witnessed remarkable attention recently. The prevalence of sick-building syndrome (SBS) is considered the most common health issue. This study conducted in the Al-Dahrieh neighborhood in Jordan showed for the first time how indoor air quality (IAQ) factors affect the prevalence of sick-building syndrome among occupants in residential buildings. The study investigated the concentration levels of air pollutants and comfort parameters. Architectural and urban design configurations were collected through site observation. In addition, daily activities for occupants were gathered through an online questionnaire. All statistical and descriptive analyses of the data collected for this study were carried out by Spearman's rho correlation test (SPSS) and Excel 2016. It was done using two-tailed (2-tailed) tests and a 1% statistical significance level ($p < 0.01$); interestingly, all expected parameters checked using SPSS are acceptable according to the significant factor of $p < 0.05$. The research explored low air quality in the selected case studies and suggested simple mitigation strategies to reduce pollutants concentration in the buildings, such as natural ventilation and control of pollution from internal sources. Moreover, architects may take these findings to enhance neighborhood and building design to achieve the goal of constructing healthier buildings.

1. Introduction

Indoor air quality (IAQ) and related health problems are critical challenges in the whole world as people spend most of their time indoors [1]. Sick-building syndrome (SBS) is an illness that occurs among occupants linked to time spent in buildings [2]. Elderly people and children are considered more susceptible to sick-building syndrome than others [3]. The main reason behind the infection is the significant exposure to numerous indoor air pollutants from different indoor and outdoor sources [4]. Symptoms in the occupants range from minor to more serious illnesses [5]. Most recent research has focused on poor indoor air quality diseases, considerably affecting users' health, comfort, and productivity [6]. Therefore, several organizations have identified many health diseases that result from poor indoor air quality, such as building-related illnesses (BRIs), and sick-building syndromes (SBSs) that affect the population inside the buildings [7]. The United States Environmental Protection Agency (US EPA), for instance, defines building-related illness (BRI) as a disease caused by exposure to indoor environmental factors within a building and direct toxic effects from contaminants [8].

A study done by [9] in Egypt on the effect of socioeconomic factors on SBS by measuring indoor and outdoor levels of pollutants for 60 households located in two urban residential areas in Alexandria's study of air exchange rates (AERs) measured the living rooms of all the selected residences showing that socioeconomic factors have a strong relationship with IAQ and cause sick building syndrome.

Furthermore, a study done by the authors in [6] about the impact of different air contaminants on human beings showed that a high concentration of pollutants leads to health issues such as eczema, respiratory diseases croup, and wheezing. In addition, low ventilation rates inside the buildings lead to the accumulation of pollutants inside the building which increases the presence of SBS [10].

2. Definition of Sick-Building Syndrome

Sick-building syndrome (SBS) is a term that was written in 1983 by the World Health Organization (WHO) after researchers discovered that 10–30% of newly constructed office buildings in the West had IAQ issues (ibid). The term of SBS has been used by the Environmental Protection Agency (EPA) as tight-building syndrome which is referred to symptoms that are often linked to the time spent in a specific building and may improve or disappear completely when the individual is away from it [11]. It is used to describe a collection of symptoms that building occupants experience, such as headaches, fatigue, and respiratory problems, without a clear cause [12].

2.1. Symptoms of Sick-Building Syndrome. Health risk issues of SBS affect users' productivity, comfort, and physical health [13], and it is usually nonspecific and can be caused by many factors, making it difficult to diagnose. According to Sarkhosh, these effects are divided into six main groups, namely, physical, chemical, biological, psychological, personal, and other [14]. Through various studies, it has been shown that the symptoms of sick-building syndrome include infection of all organs of the body and range from short-term symptoms, such as eye irritation and runny nose, to long-term diseases affecting the respiratory and cardiovascular systems that lead to increased hospital admissions, for example, lung cancer, chronic obstructive pulmonary diseases, and asthma, which can often lead to increased death rates [13].

2.2. Causes of Sick-Building Syndrome. Sick-building syndrome is a complex phenomenon that is caused by a variety of factors, including poor indoor air quality, inadequate ventilation, exposure to environmental toxins, unfavorable room temperature, and air humidity; the exact causes of SBS can be difficult to identify and may vary from building to building [11]. Many researchers have determined that the most important factor of poor IAQ is the presence of indoor air pollutants such as volatile organic compounds (VOCs), carbon monoxide (CO), particulate matter (PM), formaldehyde (HCHO), and biological contaminants, and these containments are usually in much greater quantities and concentrations in indoor air than in outdoor air and might cause different types of illnesses [4]. All types of buildings are exposed to the accumulation of pollutants inside them, such as hospitals, workplaces, and schools [15]. However, residential buildings in urban areas suffer more from the accumulation of pollutants than other types of buildings [16]. The air quality index (AQI) is used to detect the concentrations of pollutants inside buildings. It is a unified system that determines pollution levels at the internal and external levels and gives occupants an indication of health issues related to high pollution levels, identifying pollution problems and making adjustments accordingly. Nonetheless, the AQI includes values ranging from 0 to 500 so that people can easily read and analyze, where a value of zero represents the purest air while 500 is the zenith of polluted air [17]. The spread of COVID-19, for instance, shows that high exposure to PM_{10} above the WHO guidelines leads to the severity of COVID-19 mortality and can be predicted through long-term exposure to PM_{10}, as it was found that increased exposure is the most important factor, as the higher the concentration of PM_{10}, the more severe the cases of COVID-19 [18].

Moreover, previous scientific studies have proven the effect of occupants' activity factors on increasing indoor air pollution and its danger to users' health. A study conducted in Toronto, Canada, measured (PM2.5) the main pollutant produced by smoking and showed that smoking apartments had concentrations that were two to three times higher than nonsmoking apartments [17]. In addition, cooking emissions are the most important indoor sources of pollution including two types of pollutants, namely, ultrafine particles (UFPs) and fine particles (PM2.5); according to the scientific literature, the phrase cooking fumes (CFs) or cooking oil fumes (COFs) refer to particulate matter (PM_{10} and PM2.5) and chemical compound pollutants which consist of inorganic and organic emissions [19]. On the other hand, total volatile organic compound (TVOC) emissions released from cleaning products also significantly impact occupants' health [20].

However, indoor plants can cause phytoremediation to a wide variety of indoor contaminants and offer an efficient, cost-effective, self-regulating, and sustainable solution for improving IAQ and thereby human well-being and productivity in closed and confined spaces [16]. A study done by Hassan shows that meteorological factors, temperature, and humidity strongly affect pollutant transport and enhance outdoor and indoor air quality through natural ventilation applications [21].

Furthermore, the essential factors of increasing the concentration of pollutants inside buildings might result from poor urban and architectural design [4]. Through research on urban design and the effect of the prevalence of SBS, it was found that urban design significantly impacts the high concentration of pollutants inside homes [22].

In a study conducted by Chan, it was found that urban design factors may cause symptoms of the sick-building syndrome and affect the indoor air quality inside buildings through a set of factors represented by neighborhood building density, building setbacks, facade orientation, cleanliness of surrounding areas, building height, neighborhood open green space, and location of the building [23].

However, referring to many specialized scientific references, it was found that many factors significantly affect IAQ inside the dwelling at the occupancy stage, such as building quality and the ventilation type [19]. Space configuration also affects IAQ, and there are different types and amounts of organic chemical compounds in specific spaces inside homes [24].

A limited number of studies have been conducted in Jordanian cities on indoor air quality. Therefore, more studies are still necessary to discover the impact of different factors on IAQ in residential buildings. This paper aims to determine the correlation between the parameters of IAQ with the spread of sick-building syndrome symptoms among occupants. The study assumes that there is a correlation among the following factors, architectural design, urban design, and occupants' activities with sick-building syndrome. Site observation and measuring pollutants (TVOC, HCOH, PM_{10}, PM2.5, and CO_2) inside houses by using specialized electronic tools to detect their concentrations besides online questionnaires were used. Previous studies that were analyzed focused on the factors that lead to increased indoor pollution and health issues like SBS, in addition to the most important indoor pollutants in other countries.

3. Methodology

3.1. Study Design. The study was conducted during winter from the first of February to the end of March 2022 in the second-largest city in Jordan, Al-Zarqa, located at latitude 32 degrees, 4 minutes north (north of the equator), and longitude 36 degrees, 5 minutes east (east of Greenwich) . In this research, the indoor and outdoor airborne pollutants were TVOC, HCHO, PM2.5, PM10, and CO_2, as well as comfort parameters, temperature, and humidity [2], measured concurrently inside the dwellings. Sixty flats were selected to study the correlation between the pollutants concentration and factors of IAQ in an overcrowded urban area with high population density and a poor living environment where only apartment owners were accepted to be part of the study. The study neighborhood is known as Al-Dahrieh. The neighborhood is located between Al-Zarqa and 15 km northeast of Amman and it covers an area of about 60 square kilometers *o* on a vital main street, Yajouz Street, located at 32.0260° latitude and 36.0646° longitude, as shown in Figures 1 and 2. Most of the selected dwellings are private flats occupied in different stories of residential buildings. There were different reasons for choosing Al-Dahrieh neighborhood for this study; the area suffers from serious problems related to IAQ [25]. Through site visits, it was observed that there is a failure to comply with building setbacks and proximity of buildings and, on the other hand, the narrow and long alleys and lack of good design of the spaces nearby the buildings.

4. Population Density

Population density is defined as the number of people in a specific area. It is calculated by dividing the number of people by the area, measuring the number of people per square meter [26]. High population density refers to an area with more than 1,000 people per square meter; however, low density population means ten or less people per square meter [27].

Several factors contribute to the increase in population densities in Al-Dahrieh, including frequent migrations to the region and its strategic location. These factors have led to a rise in population density, prompting the local residents to expand their homes without adhering to legal setbacks in order to meet the needs of the growing population. This, in turn, has resulted in poor housing and living conditions. These conditions were observed through a questionnaire study that identified the factors contributing to the emergence of symptoms of sick-building syndrome among residents.

The population of Al-Dahrieh is approximately 650 thousand people, and its organizational area covers an estimated 40 square kilometers. It is one of the densely populated cities in Jordan, with an estimated population density of about 15 thousand people per square kilometer.

4.1. Measurements of Air Pollutants and Comfort Parameters. Indoor pollutants were measured in the living room only, whereas it was impossible to reach the rest of the rooms to preserve the residents' privacy. The measurements were done by using suitable devices located at 1.5 height above the floor level. Outdoor pollutants were also measured in balconies at the same height 1.5 m from the base level. The pollutants TVOC, HCHO, PM2.5, PM10, CO_2, and meteorological parameters (temperature and humidity) were measured through buildings. All residential buildings in the current study were selected approximately near the main traffic road. Measurements of indoor and outdoor pollutants in addition to interviews with residents were conducted on the selected residential buildings in the Al-Dahrieh neighborhood to collect data related to time spent inside the home, the number of occupants, SBS symptoms (fatigue, headache, and runny nose) or any chronic diseases; in addition, the occupants were asked to do their daily activities during the period of taking measurements such as cooking, cleaning, and smoking. Furthermore, general data related to buildings, for example, building age, furniture status, maintenance, building materials (floor, walls, doors, windows, and ceiling), area of the living room and related windows, and the type of ventilation (one side or two side) were asked to fill the manual survey. The daily mean indoor airborne pollutants levels (TVOC, HCHO, PM_{10}, PM2.5, and CO_2) and meteorological factors (temperature and humidity) for all the selected flats in Al-Dahrieh are shown in Table 1.

Table 1 shows the mean, minimum, maximum, and median concentrations for the measured indoor air pollutants, temperature, and humidity. The highest concentration of air pollutants was PM2.5 inside the building. On the other hand, the lowest measured value was CO_2. Spatial variations of the pollutants (TVOC, HCHO, PM2.5, PM10, and CO_2) in targeted buildings are shown in Figures 3–7, respectively, in the line charts.

4.2. Spatial Variation of Air Pollutants

(1) TVOC

It was found by measuring the concentrations of indoor air pollutants in housing and comparing them with the standards related to indoor air quality parameters that

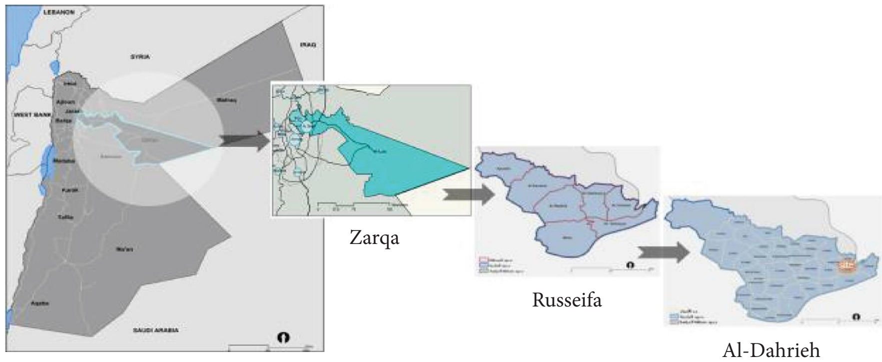

Figure 1: Neighborhood site location; source: Russeifa municipality, 2020.

Figure 2: Location of the study area: Al-Dahrieh neighborhood, Jordan, in the city of Al-Zarqa.

Table 1: Summary statistics for indoor airborne pollutants concentration, levels of target air pollutants, and comfort parameters measured in 20 homes located in Al-Dahrieh.

Parameters	Mean	Min	Max	Median
TVOC (mg/m^3)	26.69	0.9	120	18.6
HCHO (mg/m^3)	0.6	0.1	0.9	0.5
PM2.5 (mg/m^3)	86.55	10	283	82.5
PM10 (mg/m^3)	48.4	8	113	44
CO_2 (PPM)	531.4	300	760	532.5
Temperature (°C)	17.1	13	30	15.5
Humidity (%)	49.5	45	59	49

TVOC concentrations were higher than the acceptable level for a healthy environment (15 mg/m^3) [10]. Figure 3 shows the daily evolution of TVOC concentration; it was noticed by taking and recording the measurements on the buildings that contain smokers and poorly ventilated housing recorded higher TVOC rates than others. The period between 15 and 17 minutes witnessed a significant increase in TVOC concentrations due to the presence of smokers and a low ventilation rate.

(2) PM2.5

The acceptable concentration of PM2.5 according to standards is 12 mg/m^3 (ibid). The graph shows that the concentration of PM2.5 is significantly higher than the required level, as shown in Figure 4. One of the reasons for the increase in PM2.5 concentrations in the indoor air of houses is due to the repeated cooking process and the increase in smoking coinciding with poor ventilation; the presence of PM2.5 inside buildings is classified as one of the most important causes of sick-building syndrome.

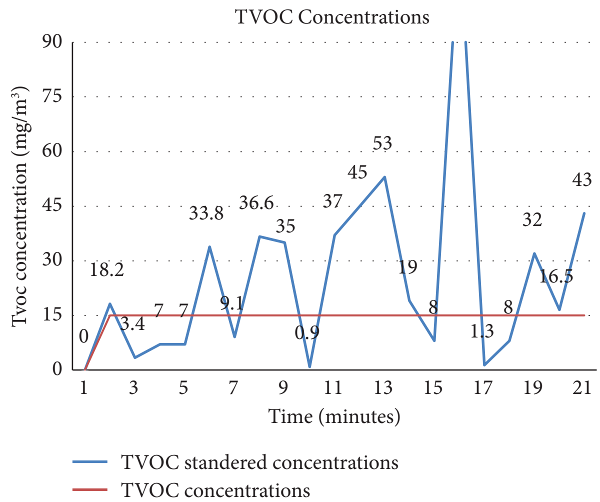

Figure 3: Daily evolution of TVOC concentrations (Authors, 2023).

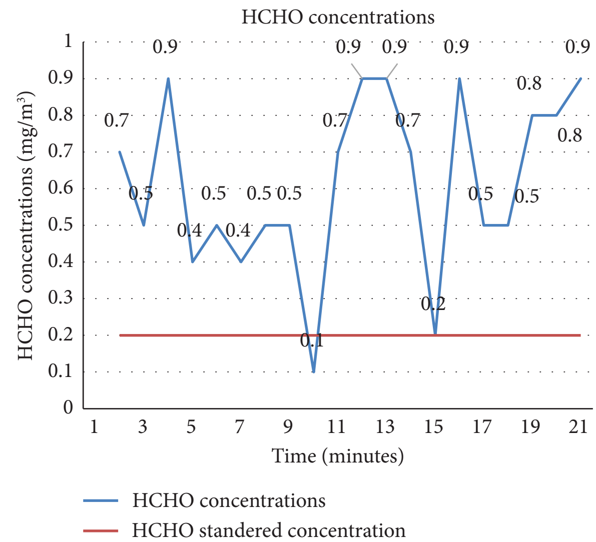

Figure 5: Daily evolution of HCHO concentrations (Authors, 2023).

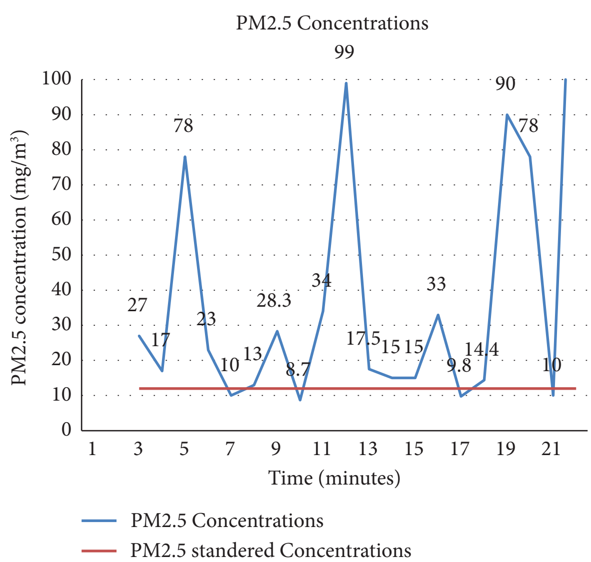

Figure 4: Daily evolution of PM2.5 concentrations (Authors, 2023).

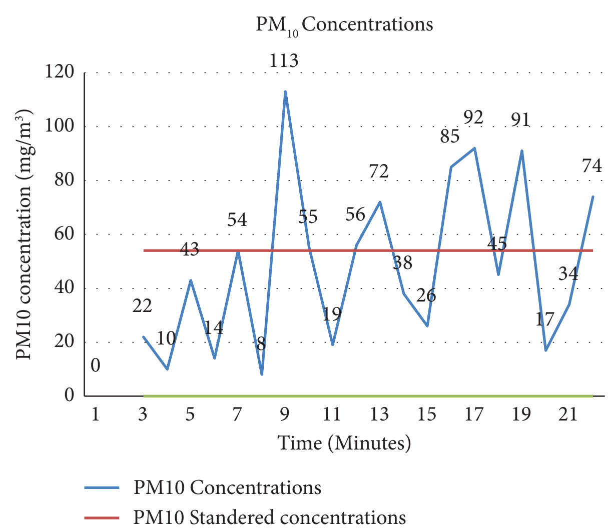

Figure 6: Daily evolution of PM_{10} concentrations (Authors, 2023).

(3) HCHO

As for the rest of the pollutant measurements, the concentration was all higher than the indoor air quality standards. Furthermore, most of the HCHO measurements were higher than the normal range for a healthy environment, i.e., 0.2 mg/m^3 (ibid), as shown in Figure 5.

(4) PM10

The bulk of the in situ measurements of PM10 concentration is within the permitted normal rates for healthy environments according to international codes, which are 54 mg/m^3 (ibid), as shown in Figure 6.

(5) CO_2

Many scientific researchers have adopted the concentration of CO_2 gas as a major component of indoor air quality, while in other sources, it has been considered an indoor air pollutant. When measuring its concentrations inside houses in the Al-Dhahirah neighborhood, it was found that most of the readings were within the permissible limits according to international standards, i.e., 650 mg/m^3 (ibid), as shown in Figure 7.

4.3. Online Questionnaire. An online questionnaire was distributed to 384 households in residential buildings to assess five levels of factors related to the assessment of the

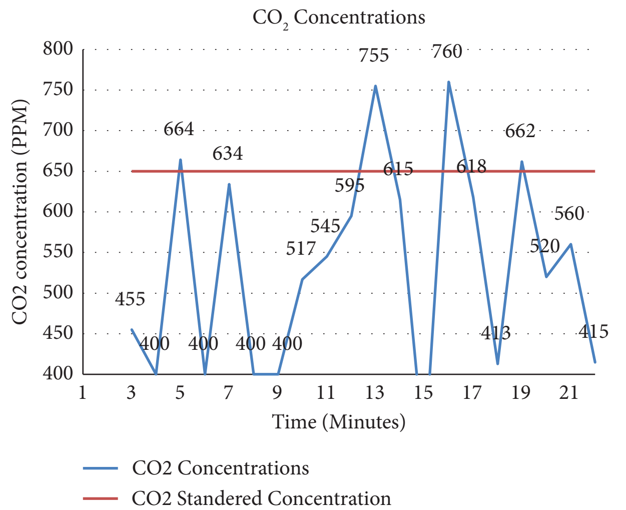

FIGURE 7: Daily evolution of CO_2 concentrations (Authors, 2023).

IAQ and SBS symptoms in the current study area. The survey was divided into five sections to determine the correlation between the prevalence of sick-building syndrome and IAQ in residential buildings as follows:

Section one: sociodemographic factors. Multiple choice questions include sociodemographic information of the respondents consisting of gender, age, etc.

Section two: this section contains 4 factors to measure the correlation between sick-building syndrome and IAQ in residential buildings.

Factor 1: occupant's activities. The first factor covers the occupant's activities (smoking, cooking, etc.) on IAQ and SBS

Factor 2: architectural design assessment. The second factor addresses the residential building design (spatial configuration of spaces, etc.).

Factor 3: neighborhood design assessment. The third factor concerns the residents' satisfaction with the urban design elements of the area, empty spaces, alleyways, and the proximity and adhesion of buildings.

Factor 4: health of the occupants. Assessment of short-term symptoms and long-term diseases associated with sick-building syndrome symptoms.

5. Discussion

5.1. SPSS Analysis. Data that were previously collected, whether by personal measurements or an online questionnaire distributed to the residents of the area, were analyzed and entered by using the SPSS program for finding the relationship between the spread of SBS and the expected factors that affect indoor air quality.

Since the questionnaire was distributed electronically, both genders were able to answer all questions and it was found that the percentage of females was greater than the percentage of males by 10% and the most common age group was between 31 and 40 years. Furthermore, approximately 0.51% of the residents spent most of their time inside their homes. The occupants depend on the natural ventilation system either by opening windows or fans to remove airborne pollutants that result from different sources; however, 26.5% of the population does not open their windows during and after the smoking process. The percentage of cooking frequency was 36% during the day.

All statistical and descriptive analyses of the data collected for this study were carried out by Spearman's rho correlation test (SPSS) and Excel 2016. Statistical data analysis was done using two-tailed (2-tailed) tests and a 1% statistical significance level ($p < 0.01$). Pearson correlation analysis was used to investigate the strength of linear relationships in the following main factors: neighborhood design, architectural design, and occupant's behavior, with SBS symptoms among residents in residential buildings.

All detailed results, which represent the expected relationships of the influence of subfactors of the following main factors on the prevalence of SBS in residential buildings, are an important base for future studies related to the subject of the research. The followings are the results of the analysis of the factors studied in this research:

(1) Urban design factors.

To study the correlation between neighborhood design subfactors (open green space, density of buildings and height of the buildings, and cleanliness of surroundings area) and occupant's health as shown in Table 2.

(2) Architectural design factors.

Residential building design factors are categorized into three main groups, and each group contains subfactors (space configuration, building quality, and ventilation) as shown in Tables 3 and 4.

(3) Occupant's activity factors.

Occupant's activity factors' subfactors are time spent at home, smoking, cooking, plantation, cleaning, and awareness as shown in Tables 5 and 6.

(4) Field study for objective measurements.

The results were reached by measuring the percentages of the pollutants concentration at the site of the Al-Dahrieh neighborhood and their relationship to health to obtain more accurate results regarding the goal of the research, which is to reach the correlation between indoor air quality factors and the spread of SBS in residential buildings as shown in Tables 7 and 8.

6. Result

There is a crucial need to study the impact of different factors on the indoor pollutants concentration and the prevalence of sick-building syndrome in order to enhance IAQ and occupants' health in residential buildings. Based on the study approach that was used to test the research hypotheses, the results showed the following.

All factors were selected as independent variables in Spearman's rho while occupants' health was chosen as

Table 2: Spearman's rho correlation between urban design factors and location of the buildings and occupant's health (Authors.2022).

Occupant's health factors (independent factor)	Urban design factor (dependent factors) Neighborhood design							Location of the building	
	IAQ satisfaction	Building setbacks	Design of space nearby the building	Cleanliness	Open spaces	The density of the building	Height of the building	Nearby pollution source construction site industrial or chemical plants	Main road
COVID-19	−0.129*	−0.304**	−0.279**	−0.262**	−0.307**	−0.303**	−0.212**	0.288**	0.193**
Long-term asthma	0.126*	−0.297**	−0.272**	−0.272**	−0.265**	−0.294**	−0.171**	0.193**	0.129*
Short-term allergy	−0.258**	−0.367**	−0.276**	−0.368**	−0.296**	−0.282**	−0.196**	0.202**	0.135**
SBS symptoms	−0.197**	−0.346**	−0.239**	−0.265**	−0.261**	−0.287**	−0.270**	0.184**	0.094

**correlation is significant at the 0.01 level (2-tailed). *correlation is significant at the 0.05 level (2-tailed).

Table 3: Spearman's rho correlation between architectural design factors (space configuration) and occupant's health (Authors, 2022).

Occupant's health factors (independent factor)	Architectural design factor (dependent factors) Space configuration					
	Location of dining hall	Kitchen design (open kitchen)	Basement (lack of optima ventilation)	House dust accumulation in the basement	Presence garages under buildings	Garage opening directly to the dwelling
COVID-19	0.602**	0.295**	0.271**	0.263**	0.051	0.199**
Long-term asthma	0.258**	0.154**	−0.046	0.138**	−0.061	0.129*
Short-term allergy	0.386**	0.111*	0.243**	0.219**	0.184**	0.137**
SBS symptoms	0.199**	0.068	0.132*	0.187**	0.080	0.132**

**correlation is significant at the 0.01 level (2-tailed). *correlation is significant at the 0.05 level (2-tailed).

TABLE 4: Spearman's rho correlations between architectural design (building quality and ventilation) and occupant's health (Authors, 2022).

Occupant's health factors	Architectural design factor						
	Building quality					Ventilation	
	Housing condition	Orientation and façade prototype	Finishing material	Maintenance	The age of the dwelling	Dwelling level	Ventilation type
COVID-19	0.260**	0.251**	0.321**	0.196**	0.006	−0.130*	0.224**
Long-term asthma	0.181**	0.043	0.163**	0.119*	−0.119*	−0.037	0.084
Short-term allergy	0..266**	0.112*	0.225**	0.230**	0.005	−0.010	0.102*
SBS symptoms	0.193**	0.151**	0.253**	0.127*	−0.140**	−0.008	0.104*

Table 5: Spearman's rho correlation between occupant's activity factors (time spent at home, smoking, and cooking) and occupant's health (Authors, 2022).

Occupant's health factors	Time: Time spent at home	Smoking: Negative smoking	Smoking: Ventilation rate through smoking	Cooking: Frequency of cooking	Cooking: Ventilation type during cooking	Cooking: Household cooking fuel type
COVID-19	0.535**	0.226**	0.157**	0.279**	0.221**	0.210**
Long-term asthma	0.300**	0.254**	0.074	0.148**	0.129*	0.134**
Short-term allergy	0.335**	0.211**	−0.027	0.191**	0.110*	0.248**
SBS symptoms	0.216**	0.090	0.135**	0.134**	0.142**	0.150**

**correlation is significant at the 0.01 level (2-tailed). *correlation is significant at the 0.05 level (2-tailed).

Table 6: Spearman's rho correlation between occupant's activity factors (plantation, cleaning, and awareness) and occupant's health (Authors, 2022).

Occupant's health factors	Plantation: Presence of plantation inside the home	Cleaning: Using cleaning products	Cleaning: Windows opening during cleaning	Cleaning: Used sterilization products	Awareness: Adequate information about pollution"	Awareness: Green products
COVID-19	0.234**	0.213**	0.034	0.305**	0.102*	0.089
Long-term asthma	0.119*	0.126*	0.116*	0.189**	0.055	−0.020
Short-term allergy	0.179**	0.100	0.071	0.192**	0.138**	0.038
SBS symptoms	0.068	0.096	0.172**	0.079	0.203**	0.082

**correlation is significant at the 0.01 level (2-tailed). *correlation is significant at the 0.05 level (2-tailed).

Table 7: Spearman's rho correlation between pollutants concentration and meteorological factors and occupant's health (Authors, 2022).

Occupant's health factors	Pollutant concentration factors: TVOC (mg/m^3)	HCHO (mg/m^3)	PM2.5	PM10	PM1.0	CO2 (PPM)	Metrological factors: Temperature	Humidity (%)
COVID-19	0.304	0.167	0.009	0.000	−0.139	0.044	0.112	−0.194
Long-term asthma	−0.200	−0.145	−0.090	−0.170	0.060	−0.030	0.242	0.000
Short-term allergy	0.347	0.144	0.347	0.231	0.000	−0.058	0.140	−0.471*
SBS symptoms	0.243	0.138	0.113	0.191	−0.113	0.070	−0.154	0.071

**correlation is significant at the 0.01 level (2-tailed). *correlation is significant at the 0.05 level (2-tailed).

Table 8: Spearman's rho correlation between building quality, ventilation, and occupant's activity (smoking) factors and occupant's health (Authors, 2022).

Occupant's health factors	Building quality: Age of the building	Building quality: New furniture	Building quality: Maintenance	Ventilation: No. of rooms	Ventilation: Floor level	Ventilation: Ventilation type	Occupant's behavior: Smoking
COVID-19	−0.087	0.302	0.503*	0.049	0.294	0.073	−0.229
Long-term asthma	−0.423	0.058	−0.406	−0.565**	0.393	−0.156	−0.132
Short-term allergy	−0.029	−0.034	0.202	−0.293	−0.276	−0.155	−0.076
SBS symptoms	0.035	−0.101	0.103*	−0.235	−0.147	−0.073	0.229

**correlation is significant at the 0.01 level (2-tailed). *correlation is significant at the 0.05 level (2-tailed).

a dependent variable. Based on the correlation test, all subfactors related to the first hypothesis according to the neighborhood design are significantly negatively correlated with the occupant's health, while the positive correlation is with the location of the building. A negative relationship means that a good design of the neighborhood environment leads to a decrease in the impact of airborne hazards on occupants' health.

Analytical results in Table 2 showed that the building setbacks are the most important factor compared to other factors related to the neighborhood design and the extent of its impact on the health of the population. It exhibits a moderate correlation, indicated by a correlation ratio of −0.367** with allergy symptoms and −0.346** with the prevalence of sick building syndrome, but it is the strongest among the other factors, and it is identical to what has been studied in previous studies. As for the factor of proximity to the main street, the results indicated that it was the weakest correlation among the mentioned factors, with a correlation ratio of $0.094 < 0.1$, and this means that it can be neglected. However, a weak to moderate negative correlation was found between cleanliness and occupants' health, but building height shows the lowest value among all the factors related to population health; this result is logical, given that all buildings in the area are no more than four stories high. However, a negative correlation between the density of the buildings and occupants' health is shown in Table 2. The results related to the effect of neighborhood design on residents' health are identical to what has been studied in previous studies that confirm that the" Indoor Environment" is mediated between the neighborhood environment and the occupant's health.

Results related to a spatial configuration (Table 3) and the health of users are represented by the strongest relationship of subfactor location of the dining hall with a correlation ratio between 0.199^{**} and 0.602^{**}, followed by the moderate relationship of kitchen design (open kitchen) and house dust accumulation in the basement; however, the weakest relationship was according to garage location, where most of the apartments in the area do not contain a garage.

A weak to moderate correlation was found between building quality and ventilation and occupant's health, as shown in Table 4. However, a weak to moderate correlation is shown between the finishing material and the occupant's health.

It is clear that strong, weak, and moderate correlations were shown between occupants' activities and occupant health according to Tables 4 and 5. A strong correlation was shown between the time the residents spend in buildings and the impact on their health.

Furthermore, plantation cleaning and awareness showed a moderate result correlation with occupants' health.

A positive and moderate correlation was shown between TVOC pollutants with COVID-19 allergy and SBS symptoms. The results of this confirm what was stated in the previous studies that TVOC is one of the most dangerous pollutants to the health of the population and it is one of the causes of the symptoms of sick-building syndrome. However, the correlation between temperature and humidity with occupants' health is very weak and can be neglected, as shown in Table 7.

7. Research Limitations

The presented results cannot be compared with similar studies in Jordan due to the scarcity of studies conducted on the same research topic. In addition, pollutants were measured in homes for a short period from the first of February to the end of March 2022 and only in the living room, where it was not possible to reach the rest of the rooms to preserve the privacy of the residents, and this gives the possibility of not taking sufficient comprehensive readings of the concentration of pollutants inside the home, as it was indicated in previous studies that the concentration of pollutants varies according to the distribution of internal spaces. On the other hand, the device companies that were used to measure pollutants in the air provide information about the reliability of the readings provided by these devices, but due to their low cost and ease of use, the readings were taken with them due to the difficulty of obtaining international accreditation from abroad. It is recommended to obtain greater accuracy of the results to use the methods mentioned in the previous study "the double exponential decay model." The main concept of this model is to purify the outside area through the filter.

8. Conclusion

In conclusion, the study in the Al-Dahrieh neighborhood has identified several critical findings related to indoor air quality and its impact on occupants' health. We have found that indoor air pollutants, including VOCs, PM2.5, and HCHO, exceed recommended levels, while PM10 and CO_2 remain within acceptable limits. Our research has revealed a positive and moderate correlation between TVOC pollutants and the prevalence of sick-building syndrome symptoms among residents.

Furthermore, we have identified key factors contributing to poor indoor air quality, including inadequate ventilation, occupants' behavior, and external sources such as proximity to chemical factories. This has led to the emergence of sick-building syndrome in the area.

Overall, our study highlights the urgent need for improved indoor air quality in residential buildings within the Al-Dahrieh neighborhood. We recommend the implementation of mitigation strategies, such as natural ventilation and pollution control measures, to reduce indoor pollutant concentrations. Architects and urban planners can also leverage these findings to design healthier buildings and neighborhoods.

9. Future Studies

This study draws the attention of researchers to develop an architectural and urban design to reduce the effects of indoor air pollution on residents' health and prevent the spread of SBS, where the residents spend most of their time indoors, through choosing a larger sample for study at the level of Jordan or the governorates due to the lack of study conducted about the research and discussing the factors that were not mentioned in the study to reach a more comprehensive idea of the factors that affect indoor air quality and consequently the spread of sick-building syndrome. Other researchers could include broader contradictions related to microclimate issues, maybe to answer contradictions with some other similar research studies conducted in different countries.

Data Availability

The data used to support the findings of this study have been deposited in a repository: https://github.com/ghaidafreihat/appendices.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] P. Babu and G. Suthar, "Indoor air quality and thermal comfort in green building: a study for measurement, problem and solution strategies," in *Indoor Environmental Quality: Select Proceedings of the 1st ACIEQ*, Springer Singapore, Singapore, 2020.
[2] N. S. J Alwi, M. H. Hassim, and N. A. Hamzah, "Indoor air quality and sick building syndrome among garment manufacturing workers in kota bharu," *Malaysian Journal of Medicine \& Health Sciences*, vol. 17, 2021.
[3] C. R. Jung, Y. Nishihama, S. F. Nakayama et al., "Indoor air quality of 5,000 households and its determinants. Part B: volatile organic compounds and inorganic gaseous pollutants in the Japan Environment and Children's study," *Environmental Research*, vol. 197, Article ID 111135, 2021.
[4] V. V. Tran, D. Park, Y. C. Lee, and P. health, "Indoor air pollution, related human diseases, and recent trends in the control and improvement of indoor air quality," *International Journal of Environmental Research and Public Health*, vol. 17, no. 8, p. 2927, 2020.
[5] M. R. Hosseini, R. Fouladi-Fard, R. J. I. Aali, and B. Environment, "COVID-19 pandemic and sick building syndrome," *Indoor and Built Environment*, vol. 29, no. 8, pp. 1181–1183, 2020.
[6] C. Sun, X. Huang, J. Zhang, R. Lu, C. Su, and C. Huang, "The new model for evaluating indoor air quality based on childhood allergic and respiratory diseases in Shanghai," *Building and Environment*, vol. 207, Article ID 108410, 2022.
[7] R. Mansor and L. Sheau-Ting, "A measurement model of occupant well-being for Malaysian office building," *Building and Environment*, vol. 207, Article ID 108561, 2022.
[8] N. Farrag, M. A. S. Abou El-Ela, and S. Ezzeldin, "Sick Sick building syndrome and office space design in Cairo, Egyptuilding syndrome and office space design in cairo, egypt," *Indoor and Built Environment*, vol. 31, no. 2, pp. 568–577, 2021.
[9] M. M. J. B. Abdel-Salam, *Environment, Relationship between Residential Indoor Air Quality and Socioeconomic Factors in Two Urban Areas in Alexandria, Egypt*, Elsevier, Amsterdam, Netherlands, Article ID 108425, 2022.
[10] F. D. A. Gonzalo, M. Griffin, J. Laskosky, P. Yost, and R. A. González-Lezcano, "Assessment of indoor air quality in residential buildings of new england through actual data," *Sustainability*, vol. 14, no. 2, p. 739, 2022.
[11] P. Trofimova, A. Cheshmehzangi, W. Deng, and C. Hancock, "Post-occupancy evaluation of indoor air quality and thermal performance in a zero carbon building," *Sustainability*, vol. 13, no. 2, p. 667, 2021.
[12] J. Hu, Y. He, X. Hao, N. Li, Y. Su, and H. Qu, "Optimal temperature ranges considering gender differences in thermal comfort, work performance, and sick building syndrome: a winter field study in university classrooms," *Energy and Buildings*, vol. 254, Article ID 111554, 2022.
[13] J. Lee, T. Wan Kim, C. Lee, and C. J. J. Koo, "Integrated approach to evaluating the effect of indoor CO 2 concentration on human cognitive performance and neural responses in office environment," *Journal of Management in Engineering*, vol. 38, no. 1, Article ID 04021085, 2022.
[14] M. Sarkhosh, A. A. Najafpoor, H. Alidadi et al., "Indoor Air Quality associations with sick building syndrome: an application of decision tree technology," *Building and Environment*, vol. 188, Article ID 107446, 2021.
[15] N. A. Megahed and E. M. Ghoneim, "Indoor Air Quality: Rethinking rules of building design strategies in post-pandemic architecture," *Environmental research*, vol. 193, Article ID 110471, 2021.
[16] B. Bhargava, S. Malhotra, A. Chandel, A. Rakwal, R. R. Kashwap, and S. Kumar, "Mitigation of indoor air pollutants using Areca palm potted plants in real-life settings," *Environmental Science and Pollution Research*, vol. 28, no. 7, pp. 8898–8906, 2021.
[17] A. Y. Mendell, A. Mahdavi, and J. A. J. S. C. Siegel, "Particulate matter concentrations in social housing," *Sustainable Cities and Society*, vol. 76, Article ID 103503, 2022.
[18] M. M. Marquès, E. Correig, D. Ibarretxe et al., "Long-term exposure to PM10 above WHO guidelines exacerbates COVID-19 severity and mortality," *Environment international*, vol. 158, Article ID 106930, 2022.
[19] M. Marć, M. Śmiełowska, J. Namieśnik, B. J. E. S. Zabiegała, and P. Research, "Indoor air quality of everyday use spaces dedicated to specific purposes—a review," *Environmental Science and Pollution Research*, vol. 25, no. 3, pp. 2065–2082, 2018.
[20] A. Steinemann, N. Nematollahi, B. Rismanchi, N. Goodman, and S. D. Kolev, "Pandemic products and volatile chemical emissions," *Air Quality, Atmosphere & Health*, vol. 14, no. 1, pp. 47–53, 2021.
[21] A. M. Hassan, A. A. Fatah El Mokadem, N. A. Megahed, and O. M. Abo Eleinen, "Improving outdoor air quality based on building morphology: numerical investigation," *Frontiers of Architectural Research*, vol. 9, no. 2, pp. 319–334, 2020.
[22] R. Bano and U. J. A. Q. Khayyam, "Industrial air pollution and self-reported respiratory and irritant health effects on adjacent residents: a case study of Islamabad Industrial Estate (IEI)," *Air Quality, Atmosphere & Health*, vol. 14, no. 10, pp. 1709–1722, 2021.
[23] I. Y. Chan and A. M. Liu, "Effects of neighborhood building density, height, greenspace, and cleanliness on indoor environment and health of building occupants," *Building and Environment*, vol. 145, pp. 213–222, 2018.
[24] Q. Liu, Y. J. Son, L. Li, N. Wood, A. M. Senerat, and J. Pantelic, "Healthy home interventions: Healthy home interventions: Distribution of PM2.5 emitted during cooking in residential settingsistribution of PM2. 5 emitted during cooking in residential settings," *Building and Environment*, vol. 207, Article ID 108448, 2022.
[25] Annual report, *Russeifa Municipality*, 2020.
[26] N. G. Nurullayevna and E. M. Nuralievich, "Geographical characteristics of factors affecting population density in the territory of Surkhandarya region," *Central Asian Journal of Arts and Design*, vol. 3, no. 6, pp. 14–20, 2022.
[27] D. M. Theobald, "Land-use dynamics beyond the American urban fringe," *Geographical Review*, vol. 91, no. 3, pp. 544–564, 2001.