Asian Journal of Water, Environment and Pollution, Vol. 20, No. 4 (2023), pp. 79-86.
DOI 10.3233/AJW230054

Assessment of Indoor Air Quality in Different Spaces of Residential and Commercial Buildings in Jeddah, Saudi Arabia

Maryam Bagaber and Shifana Fatima Kaafil*
Hekma School of Design and Architecture, Dar Al-Hekma University, Jeddah, Saudi Arabia
✉ skaafil@dah.edu.sa

Received February 23, 2023; revised and accepted May 5, 2023

Abstract: Indoor air pollution has a significant impact on human health, triggering and inducing a wide range of diseases that result in high morbidity and mortality. In this study, indoor air pollution in different spaces of residential and commercial buildings is assessed in terms of air quality index (AQI), particulate matter PM2.5, particulate matter PM10, carbon dioxide, formaldehyde (HCHO), the total volatile organic compound (TVOC), humidity, and temperature. Two residential apartment buildings are chosen for study, one is in a busy outdoor area and the other is situated in a calm outdoor area to see the effects of outdoor air quality on indoor spaces. It is found that the indoor air quality of bedrooms in residential spaces and cafés in commercial buildings is higher than the standards, and it is recommended to provide proper ventilation for better living of the occupants. Also, it is found that there is minimal effect of infiltration of outdoor air pollutants on indoor air quality and the reason is due to the provision of mechanical ventilation with air filters and effective building envelope.

Key words: Indoor air quality, residential, commercial, low-cost sensors.

Introduction

Pollution has a harmful impact on the environment or the organisms. It is considered the leading cause of major diseases, and it has been classified into five types, i.e., water pollution, sound pollution, radioactive pollution, air pollution, and sound pollution. Undoubtedly air pollution is the most devastating pollution type causing worldwide mortality (Ghorani-Azam et al., 2016). Research on the urban population has confirmed that people spend more than 90% of their daily lifespan in indoor environments (Hollbacher et al., 2017; Klepeis et al., 2001). So, it is highly essential to study the quality of indoor air. Indoor air pollution causes serious consequences on human health and the ecosystem. It is substantial to find practical solutions for this dilemma since pollution affects every corner of the globe. Environmental pollution is not a new issue, but it is still the world's most serious problem and one of the top causes of disease and mortality among humans. Both developed and developing countries share this burden, however, developed countries have done a better job of maintaining their environment due to increased awareness and tougher legislation. Although pollution has received worldwide attention, the impact is still felt due to its severe long-term implications (Manisalidis et al., 2020). Inhaling polluted indoor air can increase the risk of developing health problems. People with heart or lung diseases are particularly vulnerable to air pollution, including adults and children (Lowther et al., 2021). Also, it can harm people's nervous system, brain, kidneys, livers, and other organs over time. Some

*Corresponding Author

scientists believe that contaminants in the air cause birth abnormalities (Calderon-Garciduenas et al., 2002).

The main aim of this study is to investigate the indoor air quality index (AQI), particulate matter PM2.5, particulate matter PM10, carbon dioxide, formaldehyde, total volatile organic compound, humidity, and temperature in different spaces of residential and commercial buildings located in Jeddah, Saudi Arabia for 24 hours during the winter season (in the month of December and January). In addition to the above, two different residential buildings are selected to study the effect of outdoor infiltration on indoor air quality. One building is situated on the main street of a busy area and the other one is in the interior street of a quiet area to study how outdoor activities affect the indoor air quality.

Methodology

The indoor carbon dioxide levels of residential and commercial indoor spaces are recorded for 24 hours with the help of sensors used in the Siemens carbon dioxide measure instrument (Figure 1), which can measure up to 6000 ppm (parts per million). AQI, HCHO, TVOC, PM2.5, PM10, humidity, and temperature are measured using Air Quality Monitor Biaoling Accurate tester shown in Figure 2.

Figure 1: Instrument to measure carbon dioxide.

Figure 2: Air quality monitor biaoling accurate tester.

The CO_2 sensors used in Siemens carbon dioxide measuring instrument are initially calibrated. The device is used for continuous operation for at least 25 days with no power failures. During this time, the sensor calibrates itself several times. During this time that the room is ventilated, and the CO_2 concentration is lowered at least once to approx. 400 ppm. This is the case when the room is "flushed" with outside air and the room is not occupied.

For the Biaoling air quality, a monitor polymer lithium battery is used continuously for 10-12 hours after full charging, which will yield a good solution for testing in different environments for a long time. This instrument is designed by the DART Electrochemical Sensor technology with the combination of factory testing, calibration and ISO compliance will provide you with trustworthy measurements. The acceptable level of carbon dioxide for indoor spaces is 600-800 ppm as mentioned in the Encyclopedia of Building & Environmental Construction (2021). The Air Quality Index (AQI) provides real-time data on air pollution (air now, air quality index (AQI) Basics, 2021). If the AQI is between 0 and 50 then the air is clean and devoid of pollutants (IQ Air, Air quality in Saudi Arabia, 2021). According to National Pollutant Inventory (2019), PM2.5 is particulate matter with a diameter of 2.5 micrometers or less and the permissible limit is 15 micro grams per cubic meter for 24 hrs. PM2.5 is important to measure because of its impact on health and its capacity to penetrate deep inside the body (Wang et al., 2005). PM10 is particulate matter with a diameter of 10 micrometers or less and the permissible limit is 45 micro grams per cubic meter for 24 hrs (Heal et al., 2012). Formaldehyde is a colourless gas that is combustible and extremely reactive; its level should not exceed 0.125 milligram per cubic meter (WHO, 2010). The acceptable range of TVOC is 0.3 to 0.5 milligram per cubic meter (Environmental Protection Agency EPA, 2021; Molhave et al., 2004). Temperature and humidity are considered important elements of air quality by the EPA for comfort (NEPIS- National Service Center for Environmental Publications, 2017). The ratio of temperature and relative humidity is calculated and if it is greater than 3 requires action to adjust the temperature or the humidity of the building, to reduce the risk of mold growth (Wolkoff, 2018).

One of the residential buildings chosen for study is located in the interior street of the Al-Rehab district in Jeddah and there are no buildings opposite the chosen residential building and the street is very quiet most of the time. The result of this residential building is designated under area 1. The other residential building is located on the main street of the Al-Fayha district, opposite Masjid and thereby the street is always busy with car traffic and people, and it is designated as a residential building in area 2. The commercial building chosen for study is a university located in the Al Fayha district and is close to the residential building of area 2. For all three buildings, the air quality parameter mentioned earlier is measured for 24 hours for 5 days and the average value is considered for comparison. The spaces chosen for study in residential buildings located in areas 1 and 2 are bedrooms, living room and kitchen. The spaces chosen for study in the commercial building are the physics lab, studio, lecture hall, café and offices.

Results and Discussions

Indoor Air Quality of Different Residential Buildings

The results of indoor air quality parameters of residential buildings located in area 1 and area 2 are discussed in this section. Figure 3 shows the air quality index (AQI) of different spaces of the residential building in area 1 and 2 and it is found the average value is 14 for area 1 and 12 for area 2 and it shows the quality of the air is clean. The permissible limit of fine particulate matter PM2.5 and PM10 is 15 and 45 μg/m^3, respectively. The maximum fine particulate matter, PM2.5 of the residential building is found to be 11 μg/m^3 and PM10 is found to be 16 μg/m^3 which is far below the permissible limits as shown in Figure 4. There is no infiltration of outdoor air pollutants to the indoors. It is found that among the residential buildings chosen for study, the one located in area 1 has a higher level of PM2.5 and PM10 because of the presence of soil/vacant area in front of the house. Also, it depends on the type of cooking and combustion activities inside the house (McGill et al., 2015). From Figure 5(a) it is found that the level of formaldehyde is below the acceptable range, where the total volatile compound is above the permissible limit in the kitchen of a residential building located in area 1 and the reason is due to excessive usage of cleaners, disinfectants, air fresheners, paints used in the kitchen taken for study.

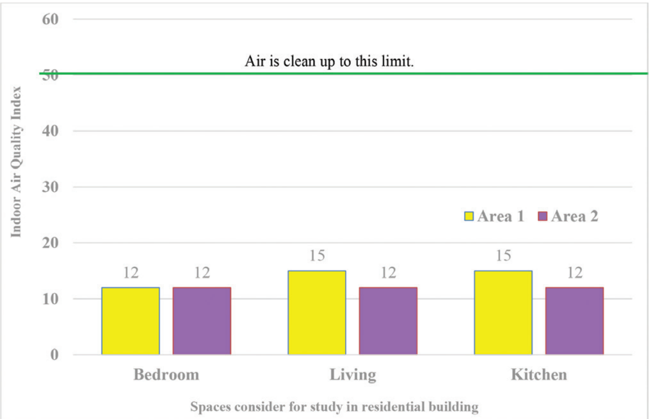


Figure 3: Indoor Air quality index of the residential building located in Area 1 and Area 2.

The ratio between the relative humidity and temperature for both residential buildings is below 3 (Figure 6) and thereby it offers comfort to the occupants of the buildings. Also, it is found that both HCHO and TVOC of the residential building in area 1 are comparatively higher than area 2 and it may be due to the wood-based products, smoke from mud, paints, varnishes and floor finish.

Based on the above comparative study, it is found that though the outdoor space is busy or calm, its effects on indoor air quality are negligible and may be due to the usage of an active HVAC system provided with air filters and the presence of airtight building envelope and windows. However, the high tightness of modern residential areas forces the designers and constructors of buildings to constantly improve the efficiency of the ventilation system but in the long run, tight residential areas and apartments result in a lack of sufficient air exchange and ventilation system.

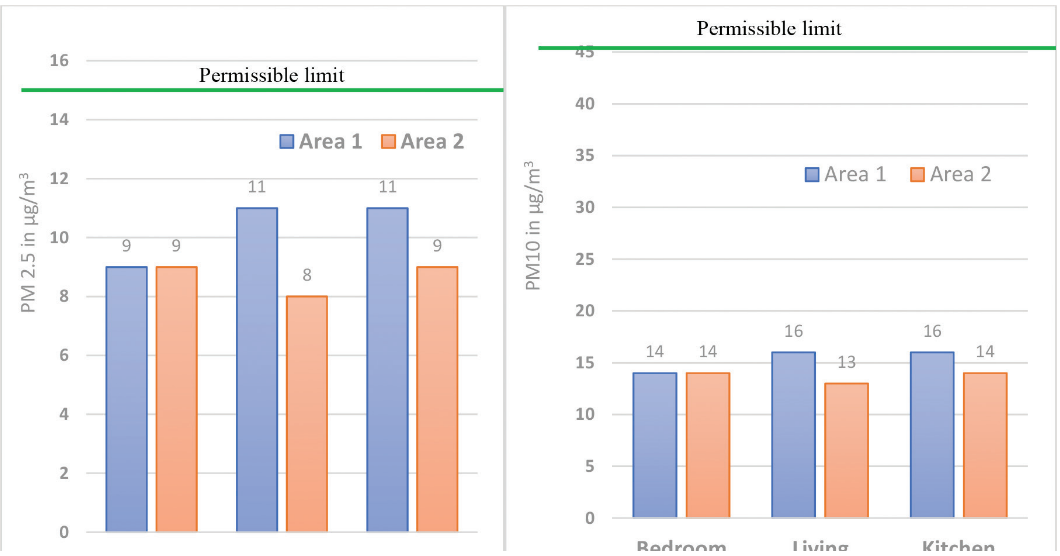
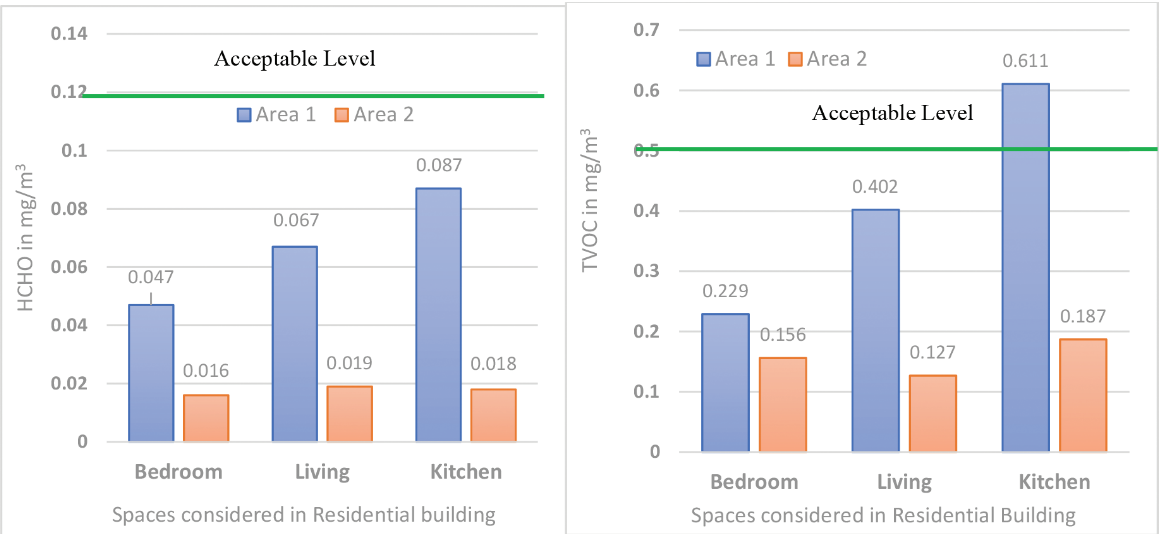


Figure 4: Fine particulate matter of residential building located in area 1 and 2.



a) HCHO in mg/m^3 b)TVOC in mg/m^3

Figure 5: Levels of (a) Formaldehyde (HCHO) and (b) Total Volatile Compounds (TVOC).

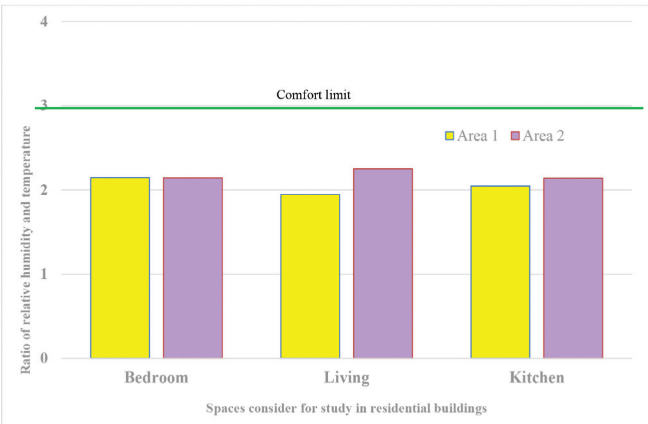


Figure 6: Ratio of relative humidly and temperature of the residential buildings.

Comparative Study on Indoor Air Quality of Commercial and Residential Building

The results and discussions of the indoor air quality of different spaces of the residential and commercial buildings located in the Al-Fayha district are compared. The spaces chosen for study in the residential building are bedroom, living room and kitchen. The spaces chosen from the commercial building are a physics lab, studio, lecture hall, café, and offices.

The carbon dioxide level varies from one place to another depending on the function of the space of the residential building as shown in Figure 7(a). It found that the level of CO_2 is high in the bedroom from 1 am to 3 pm, as it is the nap time of all the members of the family and is less during 8-10 am due to very few occupants in the bedroom. The same in the living room, which exceeds the allowable average of 800 ppm at 1-3 pm, reaching 830 ppm, and it reduces at 11-1 pm and 8-10 am. The situation is changed in the kitchen since the rate increases in the early morning and is reduced in the afternoon and is very clear the kitchen is used for preparing the food during morning hours.

Figure 7(b) shows the level of CO_2 in different spaces of the commercial building, and it is found that all the spaces exceed the permissible limits of CO_2 at 1-3 pm, reaching nearly 900 ppm since it is the break time for the students in the university and thereby there is the possibility of a greater number of occupants in different functional spaces. The studio spaces show a relatively equal amount of CO_2 at all times and the reason is due to the limited capacity of students in this space and thereby there is a restriction in the entry of students whereas in the café there is a lot of seating capacity and there is no restriction and thereby it results in higher carbon dioxide level.

Figure 8a shows the highest measure of carbon dioxide is in the bedroom (828 ppm) which exceeds the acceptable limit of 800 ppm whereas the kitchen and the living room has level ranging from 778 to 756 ppm. The level of carbon dioxide is highest at the café in the commercial building (Figure 8(b)) and is always at full capacity of the space. This is followed by the air quality in the physics lab because it is relatively small in size and did not have enough ventilation. The level of CO_2 in the offices is higher than lecture hall and the studio, which is due to personal computers located in the office which generate heat. The studio and lecture hall record

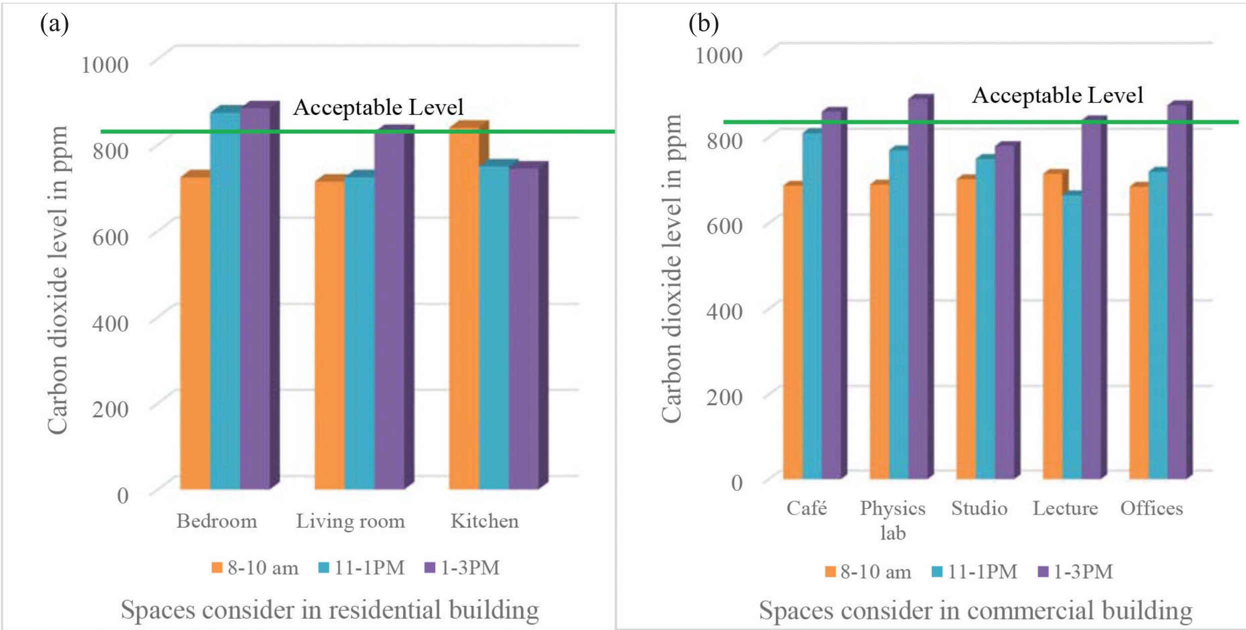


Figure 7: Carbon dioxide level (Co_2) in ppm of different spaces of: (a) residential and (b) commercial buildings at different times.

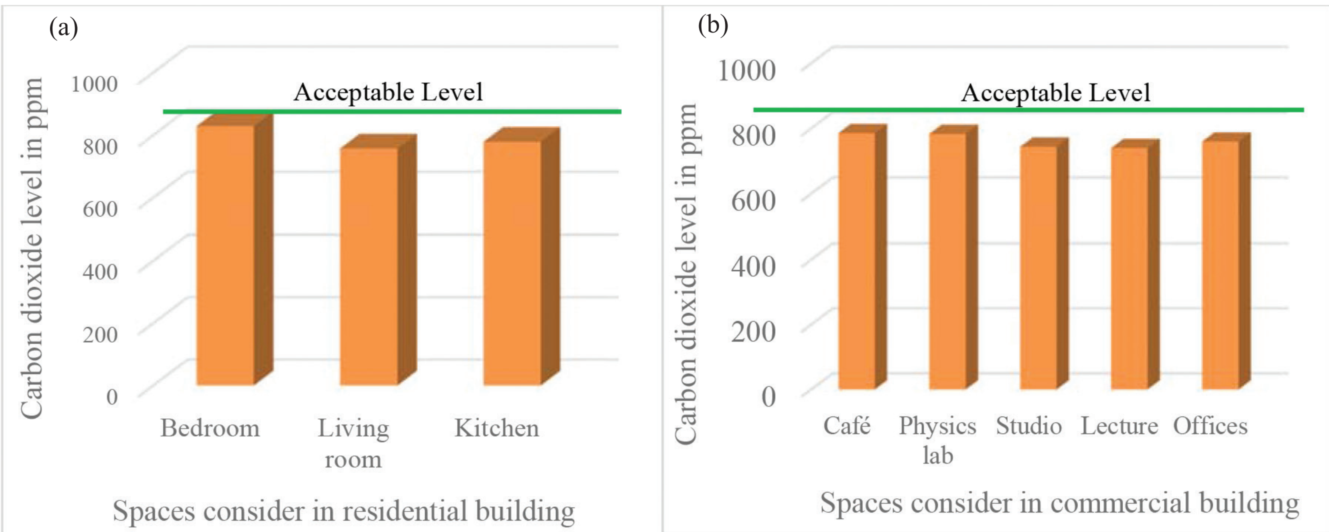


Figure 8: Twenty-four hours measurement of carbon dioxide level (CO_2) in ppm in different spaces of: (a) residential and (b) commercial buildings.

the lowest level of CO_2 and the reason being the limited seating capacity and adequate ventilation of the spaces.

Table 1 shows the comparison of Indoor air quality of residential and commercial buildings with the acceptable limit. All the parameters are measured for 24 hours, and the function of all the spaces of the buildings are combined, and it is found that all the parameters are within the acceptable or permissible limit and are close to each other. But the study of individual spaces at different times, shows a major variation in the quality of the air, and it depends on the size of the space, the equipment's place inside the room and the number of occupants. Thereby it is essential to improve the indoor air quality of bedrooms in residential buildings, café and laboratories in commercial (university) areas.

Based on the study, it is recommended to keep more indoor plants in the bedroom and in the café to increase the air quality. It is suggested to design a café outdoors or indoors with skylights or increase the ceiling height to enhance ventilation. It is recommended

Table 1: Comparison of Indoor air quality of residential and commercial building with the acceptable limit

Parameters	*Residential building*	*Commercial building*	*WHO, 2010*	*US EPA, 2009*	*Other references*
AQI	12	12	-	-	<50 (IQ air, Saudi Arabia, 2021
PM2.5 µg/m^3	9	9	25 (24 h avg.)	65 g/m^3 (24 h)	15 (Wang et al., 2005)
PM10 µg/m^3	14	14	50 (24 h)	150 g/m^3 (24 h)	45 (Heal et al., 2012)
HCHO mg/m^3	0.02	0.053	0.120 (8 h avg.)	0.920 (8 h)	-
TVOC mg/m^3	0.16	0.265	-	-	0.3-0.5 (EPA, 2021)
CO_2 ppm	762 ppm	715 ppm	1000 mg/m^3 (15 min)	800 ppm	800 ppm (Encyclopedia of BEC, 2021)
Ratio of Humidity and Temperature	2	2	-	-	3 (Wolkhoff, 2018)

to use eco-friendly materials to reduce the amount of HCHO and TVOC compared to conventional materials for construction.

Conclusions

Air pollution is a major concern of the new civilised world, and has a serious toxicological impact on human health and the environment; hence, it is important topic of research. In this study, air pollution is assessed in different indoor spaces at different times of a residential building and commercial located in different districts of Jeddah.

From the research, it is found that the average level of all indoor air quality parameters in both commercial and residential spaces are within the permissible limits but if each space of the building is studied individually shows major effects on the health of the individual. This study recommends studying the spaces individually rather than finding the average values for all the spaces. All the parameters of air pollution are to be measured at different times for a period of a week or more.

It is found that buildings constructed with eco-labelled materials emitted fewer TVOCs compared to buildings constructed with conventional materials. Insufficient ventilation was indicated as the major reason for elevated CO_2 levels in the kitchen, whereas the impact of outdoor air infiltration, infrequent housekeeping, and mode of cleaning was found to have significant relation with higher PM10 levels. The influence of cooking using liquefied natural gas was considerably higher in the case of VOC release when compared to natural gas-based cooking.

It is found that indoor air quality needs to improve in residential spaces compared with commercial spaces by keeping indoor plants, usage of eco-friendly materials and enhancing ventilation. Also, it is found that the infiltration of outdoor pollutants into the indoor air is very minimal in both the areas considered for the study. It is recommended to create basic law regulations, policies or national directives concerning indoor air quality in residential buildings (villas and apartments) and commercial buildings to enhance the well-being of the inhabitants. It is equally important to continue in order to expand the awareness of the users of residential buildings.

Recommendations for Further Research

This study recommends performing a pollution assessment in at least two different time periods during a year along with an assessment of both ground and other floor levels, formaldehyde, VOC levels, and factors associated with building structures and resident behaviour. Household characteristics such as occupants' age, family size, types of kitchens and fuel, and window opening facilities have been described in this study. However, the information related to building structures and arrangements (e.g., flooring type, furniture used) was not mentioned. Also, the age of the building is not considered while measuring because new or renovated buildings yield higher VOC emissions as compared to established buildings.

Improvement of indoor air quality in residential buildings requires the implementation of programs, including periodic monitoring of air pollutants. In addition, there should be undertaken actions aiming at raising public awareness about the possibility of the occurrence of pollutant emissions from equipment elements placed in buildings and apartments.

An important issue is also the use of effective ventilation systems, and if this is not possible ventilation through frequent airing of the indoor areas. These actions enable the transport of accumulated pollutants into the atmospheric air, which in turn reduces (dilutes) their content in rooms designed to accommodate people.

Funding
The present research did not receive any financial support.

Conflict of interest

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

References

Airnow, Air Quality Index (AQI) Basics. Retrieved December 31, 2022, from https://www.airnow.gov/aqi/aqi-basics/

Calderon-Garciduenas, L., Azzarelli, B., Acuna, H.,Garcia, R., Gambling, T.N., Osnaya, N., Monroy, S., Tizapantzi, T.M., Carson, J.L., Villarreal-Calderon, A. and B. Rewcastle (2002). Air pollution and brain damage. *Toxicol. Pathol*., **30:** 373-389. https://doi.org/10.1080/01926230252929954

Encyclopedia of Building & Environmental Construction, Diagnosis, Maintenance & Repair (2021). Typical Levels of Carbon Dioxide Gas CO_2 Normal Levels in Air Indoors & Outside. Retrieved December 30, 2022, from https://inspectapedia.com/hazmat/CO2_Typical_Levels.

Environmental Protection Agency (2009). Typical Indoor Air Pollutants. Available online: https://www.epa.gov/sites/production/files/2014-08/documents/refguide_appendix_e.pdf (accessed on 15 August 2021)

Environmental Protection Agency (EPA). Indoor Air Pollution—Volatile Organic Compounds. Retrieved January 2, 2023, from https://www.epa.gov/indoor-air-quality-iaq/technical-overview-volatile-organic-compounds.

Ghorani-Azam, A., Riahi-Zanjani, B. and M. Balali-Mood (2016). Effects of air pollution on human health and practical measures for prevention in Iran. *J Res Med Sci*., **21:** 65. https://doi.org/10.4103/1735-1995.189646

Heal, M.R., Kumar, P. and R.M. Harrison (2012). Particles, air quality, policy and health. *Chem Soc Rev*., **41:** 6606-6630. https://doi.org/10.1039/c2cs35076a

Hollbacher, E., Ters, T., Rieder-Gradinger, C. and E. Srebotnik (2017). Emissions of indoor air pollutants from six user scenarios in a model room. *Atmos Environ*., **150:** 389-394. https://doi.org/10.1016/j.atmosenv. 2016.11.033.

https://www.euro.who.int/data/assets/pdf_file/0009/128169/e94535.pdf

IQAir, Air quality in Saudi Arabia. Retrieved December 31, 2022, from https://www.iqair.com/saudi-arabia

Kaden, D.A., Mandin, C., Nielsen, G.D. and P. Wolkoff (2010). Formaldehyde. *In:* WHO Guidelines for Indoor air quality: Selected pollutants by. World Health Organization: Geneva. Retrieved December 31, 2021. Available from https://www.ncbi.nlm.nih.gov/books/NBK138711/

Kelishadi, R. and P. Poursafa (2010). Air pollution and non-respiratory health hazards for children. *Arch Med Sci*., **6:** 483-495.

Klepeis, N.E., Nelson, W.C., Ott, W.R., Robinson, J.P., Tsang, A.M., Switzer, P., Behar, J.V., Hern, S.C. and W.H. Engelmann (2001). The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. *J Expo Analysis Environ Epidemiol*, **11(3):** 231-252. https://doi.org/10.1038/sj.jea.7500165

Lowther, S.D., Dimitroulopoulou, S., Foxall, K., Shrubsole, C., Cheek, E., Gadeberg, B. and O. Sepai (2021). Low level carbon dioxide indoors—A pollution indicator or a pollutant? A health-based perspective. *Environments*, **8:** 125. https://doi.org/10.3390/ environments8110125

Manisalidis, I., Stavropoulou, E., Stavropoulos, A. and E. Bezirtzoglou (2020). Environmental and health impacts of air pollution: A review. *Front Public Health*., **8:** 14.

McGill, G., Oyedele, L.O. and K. McAllister (2015). Case study investigation of indoor air quality in mechanically ventilated and naturally ventilated UK social housing. *Int. J. Sustain. Built Environ*., **4:** 58-77. https://doi.org/10.1016/j.ijsbe.2015.03.002

Molhave, L., Clausen, G., Berglund, B., Ceaurriz, J., Kettrup, A., Lindvall, T., Pickering, U., Risse, H., Rothweiler, B., Seifert, M. and M. Younes (2004). Total volatile organic compounds (TVOC) in indoor air quality investigations. *Indoor Air.*, **7:** 225-240. https://doi.org/10.1111/j.1600-0668.1997.00002.

National Pollutant Inventory (2019). Department of Agriculture, Water and the Environment of Australian Government, Particulate matter (PM10 and PM2.5). Retrieved on December 30, 2022, from http://npi.gov.au/resource/particulate-matter-pm10-and-pm25 .

NEPIS (National Service Center for Environmental Publications) (2017). US EPA (Environmental Protection Agency) Retrieved December 31, 2022 from https://www.epa.gov/clean-air-act-overview/air-pollution-current-and-future-challenges **.**

Wang, X., Bi, X., Sheng, G. and J. Fu (2006). Hospital indoor PM10/PM2.5 and associated trace elements in Guangzhou, China. *Science of the Total Environment*, **366(1):** 124-135. https://doi.org/10.1016/j.scitotenv.2005.09.004

WHO (2010). New Guidelines for Selected Indoor Chemicals Establish Targets at Which Health Risks are Significantly Reduced. Available from ttps://www.euro.who.int/__data/assets/pdf_file/0004/128605/Factsheet_indoor_chem_15_Dec_10.pdf (accessed on 29 April 2021).

Wolkoff, P. (2018). Indoor air humidity, air quality, and health – An overview. *International Journal of Hygiene and Environmental Health*, **221(3):** 376-390. https://doi.org/10.1016/j.ijheh.2018.01.015