Environmental Science and Pollution Research (2021) 28:65822–65831
https://doi.org/10.1007/s11356-021-15534-6

RESEARCH ARTICLE

Particulate matter concentration and health risk assessment for a residential building during COVID-19 pandemic in Abha, Saudi Arabia

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Received: 26 May 2021 / Accepted: 16 July 2021 / Published online: 28 July 2021

Abstract
Building and its environment are in focus owing to health impact attributed to indoor air quality. This study was carried out to assess indoor air quality in terms of particulate matter (PM) and carbon dioxide in a residential building, during COVD-19 pandemic lockdown from March 25 to April 23, 2020, Abha, Saudi Arabia. The PM concentration range for kitchen, bedroom, and hall were 40,000–81000 μg/m^3 ($PM_{0.3}$), 15,000–26000 μg/m^3 ($PM_{0.5}$), 4000–6000 μg/m^3 (PM_1), 1100–1500 μg/m^3 ($PM_{2.5}$), 160–247 μg/m^3 (PM_5), and 60–95 μg/m^3 (PM_{10}). The results of this study suggest that bedroom needs to be ventilated as CO_2 concentration was reaching 700 ppm during sleep hours. PM concentration was exceeding 300 μg/m^3 (unhealthy) for all particle sizes of $PM_{0.3}$, $PM_{0.5}$, PM_1, and $PM_{2.5}$ except for PM_{10} which was also above safe limits (0–50 μg/m^3). Also, with influential habit (aromatic smoke), these concentrations increased 2–28 times for PM. The hazard quotient value greater than 1 revealed potential health risk to the inhabitants. Hence, future studies are needed for developing indoor air quality guidelines for residential buildings in Saudi Arabia and better planning and management of energy consumption.

Keywords Indoor air quality · COVID-19 · Carbon dioxide · Particulate matter · Hazard quotient

Introduction

The urban population tends to spend more time indoors than outdoors (Huang et al. 2020). Additionally, ongoing COVID-19 pandemic has put world population indoors for months. Growing concerns over impact of indoor air quality (IAQ) on human health has led to several studies for various categories of buildings worldwide (Dionova et al. 2020; Huang et al. 2020; Kozielska et al. 2020; Yu et al. 2020). Indoor air quality is directly affected by occupant behaviours and material of the building (especially in extreme climatic conditions). However, in regions with moderate climatic conditions, this effect is reduced. Also, air tightness in buildings with lack of ventilation directly affects IAQ. This relationship is primarily dominant in low-cost housing, contrary to higher income homes, public buildings or multi storeyed buildings with efficient HVAC (Heating, ventilation, and air conditioning) systems, which may reduce or eliminate IAQ dependence on natural ventilation (Fernández-Agüera et al. 2019). IAQ has been studied with respect to various parameters experienced in building environment, viz. carbon dioxide CO_2, particulate matter (PM), temperature, humidity, and volatile organic compound (VOCs) (Huang et al. 2004; Yang Razali et al. 2015; Kozielska et al. 2020; Schwela 2020; Yu et al. 2020).

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Primary source of CO_2 in indoor environments is human respiration. Also, its increased concentration indicates lesser oxygen concentration. Amoatey et al. (2019) reviewed fate, exposure, and risk to exposed population for emission from oil industries with respect to SOx, NO_x, PM, and trace elements. Mokhtar et al. (2014) assess human health risk from emission from coal fired power plants. Khaniabadi et al. (2017) studied impact of air pollution on human health in the urban area of Khorramabad, Iran. However, previous literature has reported health impact for concentrations above 1000 $\mu g/m^3$ (Robertson 2001; Hepple 2005). But, recent literature has revealed health impact at lesser concentrations of 500 $\mu g/m^3$ (Azuma et al. 2018). PM can be classified as coarse inhalable particles (2.5–10 μm), fine particles (<2.5 μm), and ultrafines (<0.1 μm) (Fromme 2019; Bralewska and Rogula-Kozłowska 2020). Also, it was deduced that inhalable particles are only retained in lungs, while other particle sizes were carried out through respiration (Kim et al. 2015). Therefore, $PM_{2.5}$ and PM_{10} in majority have been investigated for impact on human health (Bari and Kindzierski 2016; Fromme 2019). However, recent studies have revealed that the finer the particle size, the more impact it will cause on various metabolism in human body (Fig. 1) (Madureira et al. 2020; Deng et al. 2019; Basińska et al. 2019). High concentration of PM is experienced in regions experiencing dust storms such as Saudi Arabia.

In Saudi Arabia, buildings account for 80% of energy consumption of which 50% is attributed to residential buildings, which can be understood from the fact that majority of the country experiences arid climatic condition owing to vast deserts spanning across the country. In addition to the building envelope, poor insulation where more than 70% of the existing building is not insulated contributes significantly to energy consumption. Central HVAC systems in the country are primarily used in public and commercial buildings. However, residential buildings in urban areas across the country are primarily dominated through decentralized air conditioning without mechanical ventilation.

Even though arid climatic conditions are dominant in the country, mountain ranges with an altitude around 2000 m experience semi-arid moderate climatic conditions especially in the southern region. Irrespective of this, majority of residential old buildings feature small windows attributed to regular dust storm especially during summer season. However, literature on IAQ for Saudi buildings is still lacking. Also, existing literature primarily investigates mechanically ventilated buildings (public and commercial). Additionally, literature on indoor air quality assessment for residential buildings depending primarily on natural ventilation is still lacking not only in Saudi Arabia but also gulf countries, especially when they regularly experience dust storm which is a normal weather pattern experienced in these countries.

This necessitates indoor air quality assessment of residential buildings in Saudi Arabia with decentralized air conditioning or partial mechanical ventilation. Additionally, health risk needs to be assessed. Hence, objectives of this study are as follows: (1) investigate PM and CO_2 concentration during COVID-19 lockdown, (2) determine impact of influential habits (aromatic smoke, smoking, etc.) on indoor air quality, and (3) assess potential health impact from increased concentrations of parameters in concern. Additionally, primary focus in literature for air pollution and health impact is on outdoor air quality and industrial emissions. However, COVID-19 pandemic has presented a scenario which prioritizes impact of indoor air quality on human health. Especially if in the future, the world experiences other similar situations. Also, urban air quality and industrial emissions are restricted to the population who come in contact with it. However, indoor air quality impacts each and every individual

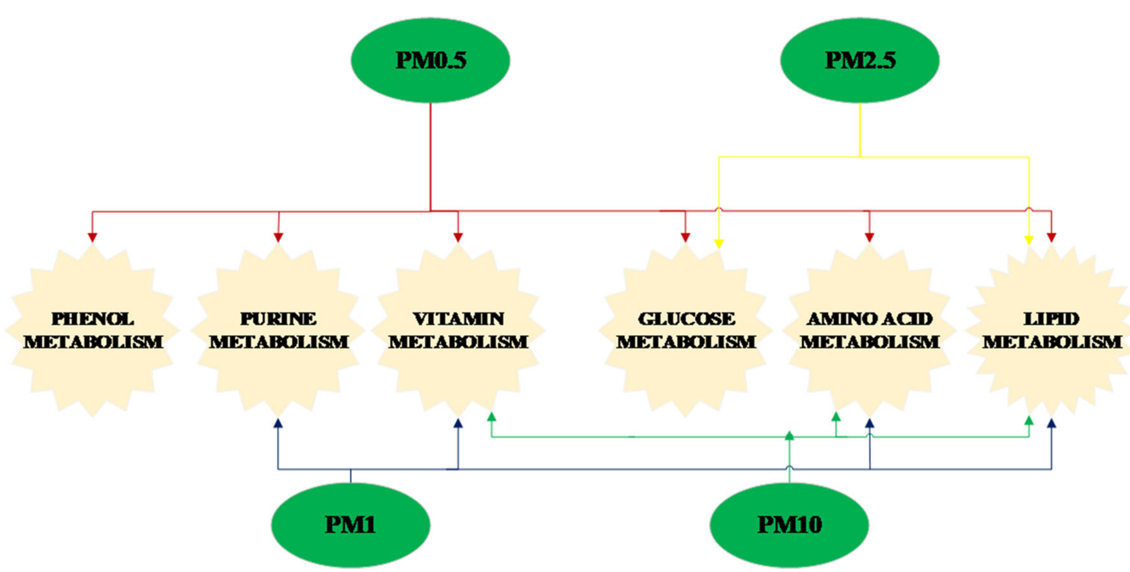

Figure 1 Particulate matter and their identified impact on human metabolism

on the surface of earth residing in a building. Hence, even if the indoor emission is not high, the exposed population and duration of exposure are much higher.

Methods and data used

Study area

The city of Abha is located in the southwest of the Kingdom of Saudi Arabia (18.28N latitude and 42.58E longitude) at 2200 m above sea level. The city is a prime tourist location in Saudi Arabia. However, with ongoing pandemic of COVID-19, the city underwent lockdown, and population was asked to stay indoors. Nevertheless, it provided an optimum time period for indoor air quality assessment with lesser interference from outdoor environmental conditions (i.e. natural environmental conditions were experienced with less interference of anthropogenic activities owing to ongoing lockdown). Also, this provided a unique opportunity to study influence of influential habits (aromatic smoke, smoking, etc.) on IAQ.

Climatic condition

Abha experiences semi-arid climatic conditions. Contrary to arid climatic conditions prevailing in majority of Saudi Arabia, Abha enjoys relatively milder weather throughout the year. With December and January reaching minimum temperatures of 11.9°C and 12.7°C, sporadic heating is required especially during nights building. While for summer in month of June and July with temperatures reaching maximum of 25.14°C, sporadic cooling is required.

Building information

The building under study is a residential building. The building is located in a residential neighbourhood undergoing construction activities. The building is crossed by several streets, and main approach is a vital main road for the neighbourhood. The building is surrounded by residential buildings on east, west, and south. The residential building is a frame structure with walls made up of hollow cement concrete blocks. Three units in the residence, viz. kitchen (8 m^2), bedroom (16 m^2), and hall (20m^2), were selected for the study. The residential house was used during the study shown in Fig. 2.

Measurement of CO_2 and PM

The IAQ assessment was conducted in kitchen, bedroom, and hall of the residential house. The measurements were taken during the ongoing pandemic of COVID-19 from March 25 to April 23, 2020. It has to be noted that after this duration of time, the month of Ramadhan came which means the lifestyle of the inhabitants and their timing changes totally with respect to other 11 months of the year. Hence only, 1 month of the study was possible technically. Additionally, Saudi Arabia only experienced 2 months of full and partial lockdown after which it was lifted and no other lockdown has been put in place till date. The instrument was placed at 1 m height from floor level to record airborne concentrations of CO_2 and PM and avoid readings of depositions concentration especially for PM (Yang Razali et al. 2015). The instrument was placed in each room taking into consideration not to obstruct daily activity and also not to compromise the data quality. Hence, optimized location was identified for each room, and instrument was placed accordingly. Particulate matter ($PM_{0.3}$, $PM_{0.5}$, PM_1, $PM_{2.5}$, PM_5, and PM_{10}) and carbon dioxide were measured along with temperature and humidity. In order to determine variation in concentration of parameters in concerned owing to influential habits, readings were taken either with closing natural ventilation or by burning of incense.

Health risk assessment

Non-carcinogenic risk assessment was calculated to sum up possible adverse impact on health owing to exposure. The risk was estimated based on chronic exposure and acute exposure. Health risks from $PM_{2.5}$ and PM_{10} were calculated as per US EPA (US EPA 2009). Non-carcinogenic risk was calculated using Eq. 1

$$HQ = ADI/RfD \tag{1}$$

where HQ is hazard quotient which is unitless, ADI is average daily inhalation calculated as mg/kg body per day weight, and RfD is reference dose in mg/kg body weight per day. RfD value for $PM_{2.5}$ was taken as 0.008.

The chronic exposure was calculated for duration of 1 month, and average daily inhalation (ADI_m) was obtained using Eq.2.

$$ADIm = \frac{C\ X\ IR\ X\ ET\ X\ EF\ X\ ED}{BW\ X\ AT} \tag{2}$$

where C is concentration of $PM_{2.5}$ and PM_{10}, IR is inhalation rate in m^3h^{-1}, ET is exposure time (h day^{-1}), EF is exposure frequency (days $years^{-1}$), ED is exposure duration (years), BW is body weight (kg), and AT is average time (years).

Acute exposure from $PM_{2.5}$ and PM_{10} was calculated based on average hourly inhalation (AHI) using Eq. 3.

$$AHI = \frac{C\ X\ IR}{BW} \tag{3}$$

The values of parameters were obtained from US EPA and published literature (US EPA 2009; K. Huang et al. 2020; Di Vaio et al. 2018; Wang et al. 2015; Gruszecka-Kosowska 2018; De Donno et al. 2018).

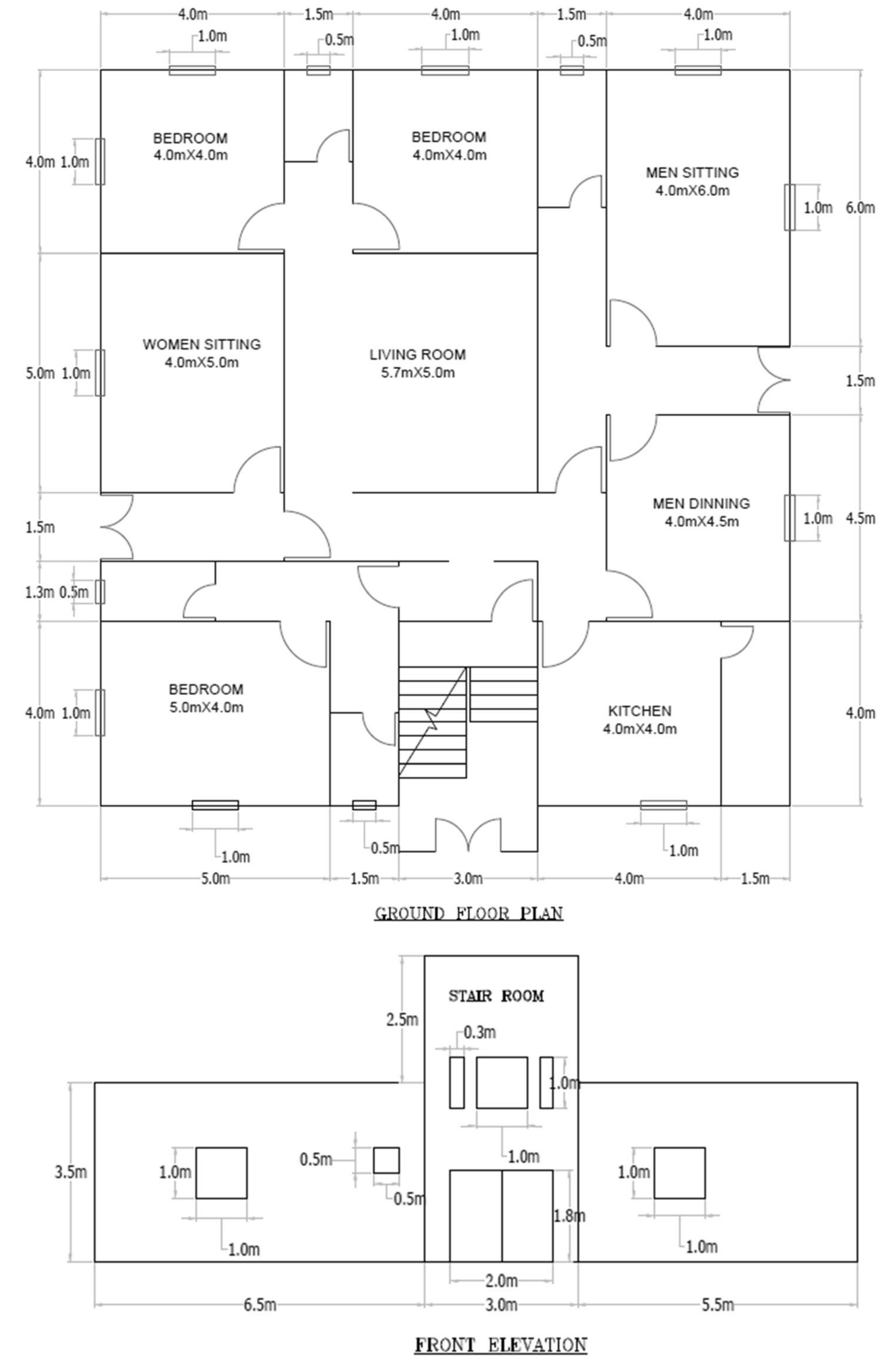

Figure 2. Floor plan and front elevation for the study building

Results and discussion

This study was conducted to evaluate particulate matter and carbon dioxide concentration in residential building in Saudi Arabia, during COVID-19 lockdown, to estimate their potential health risk to the building residents. Three units in the building (kitchen, bedroom, and hall) were investigated using air quality monitors to record the PM and CO2 concentration. The results are presented for indoor air quality with/without number of occupants present in each unit of house for daily activities. The most probable hours of natural ventilation (NV) have been included in the study based on occupant's preference which again was primarily influenced by outdoor temperature (owing to lower temperatures during night and early morning hours). The natural ventilation hours are presented in the study only to present it as a probable solution to address indoor air quality issue.

Carbon dioxide concentration in kitchen, living room, and hall

Carbon dioxide hourly concentration is presented in Fig. 3 for kitchen, hall, and bedroom. The CO_2 concentration fluctuation was significantly affected by number of occupants. Kitchen area experienced minimum CO_2 level of 328 μg/m^3 during night, while in daytime, it reached maximum concentration of 425 μg/m^3. The bedroom area on other hand experienced lower level of CO_2 concentration of 380 μg/m^3 during daytime, while in night, concentration reached levels of 770 μg/m^3. Hall area followed similar pattern of bedroom with 390 μg/m^3 CO_2 concentration during daytime, and in night, it increased to 690 μg/m^3. However, hourly concentration indicates that CO_2 concentration variation is directly dependent on number of occupants. In kitchen area, CO_2 concentration increased at breakfast, lunch, and dinner hours. However, for other hours, the concentration was low irrespective of day- or nighttime. Also, similar patterns can be observed for hall and bedroom. However, bedroom concentration reaching 700 μg/m^3 for prolonged duration is of concern as sleeping is a basic human necessity and over life time exposure can lead to health implications.

Several studies have accepted CO_2 concentration of 1000 μg/m^3 as healthy based on the existing guidelines (Griffiths and Eftekhari 2008; Yang Razali et al. 2015; Fernández-Agüera et al. 2019). The guidelines were developed based on the health data available which limited the number of studies for health implications at lower concentrations of CO_2. Additionally, with natural and mechanical ventilation CO_2 concentration can be easily regulated. This again has contributed to lesser focus on considering impact on health from lower concentration of CO_2. However, with new studies reporting health implications at those acceptable concentrations as per existing IAQ guidelines puts them as unhealthy concentration (Azuma et al. 2018). Hence, more studies are required to analyse and determine impact of CO_2 at lower concentrations.

Impact of influential habits on carbon dioxide concentration

The influential habits covered in this study are subjected to smoking; it may be due to smoking habit or aromatic smoke. Aromatic smoke is a cultural aspect of Saudi Arabia and exists in their daily activities. From honouring a guest to personal amusement, burning of aromatic wood primarily agarwood is a cultural aspect deeply rooted in the country. Fig. 4 presents carbon dioxide concentration with respect to influential habits for kitchen, bedroom, and hall. The increase in concentration was calculated with respect to minimum carbon dioxide concentration in each unit so as to differentiate between increase with respect to occupants and influential habits with same reference point. In kitchen, an increase of 27%, 63 % (bedroom), and 101% (hall) was attributed to influential habits. The variation in increased concentration can be followed as follows: aromatic smoke was fired and prepared in kitchen where it just stayed for 10–15 min; then with prime combustion conditions, it reached hall; and afterwards when the aromatic wood was past its prime condition, it was transferred to bedroom to create pleasant sleeping and resting environment. The dying combustion conditions in bedroom can also be verified with the fact that carbon dioxide concentration increased to 770 μg/m^3 which is more than 621 μg/m^3 as observed from influential habits. However, aromatic smoke is not a regular affair but is in majority restricted to special occasion and major affairs in house. Nevertheless, owing to pandemic succeeding with lockdown forced the occupants

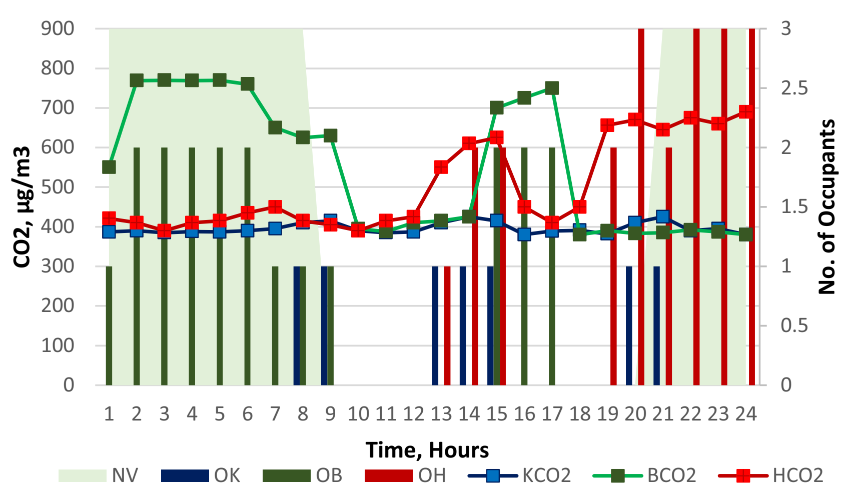

Figure 3. Carbon dioxide hourly concentration with respect to number of occupants (NV natural ventilation, OK occupants kitchen, OB =occupants bedroom, OH occupants hall, K = kitchen, B bedroom, H hall; missing bar means there is no occupancy in either of the three units under study)

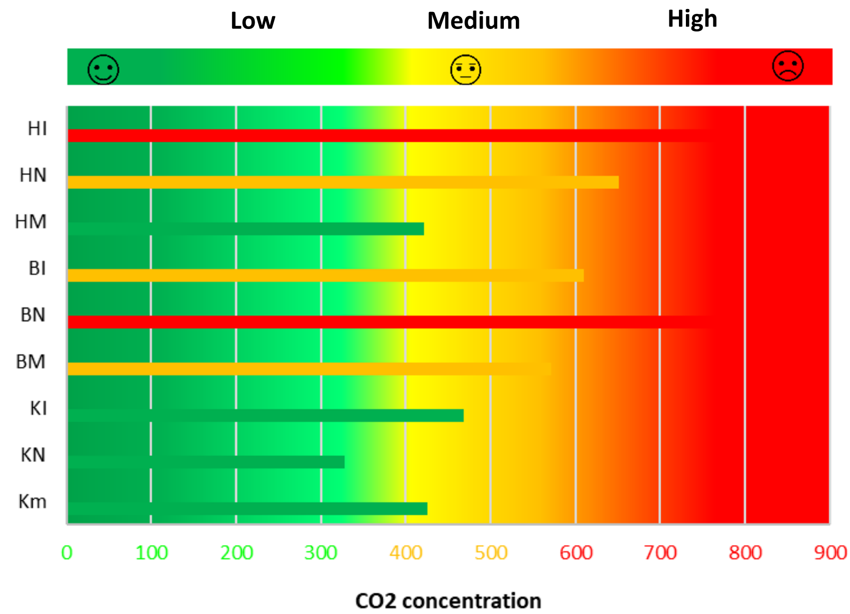

Figure 4 CO_2 concentration and their health impact zone (HI hall influential habits, HN hall night, HM hall morning, BI bedroom influential habits, BN bedroom nights, BM bedroom morning, KI kitchen influential habits, KN kitchen night, KM kitchen morning)

indoors for majority of hours, especially women and children. Hence, occupants adopted and created pleasant atmosphere to ease new restricted indoor lifestyle.

Concentration of CO_2 in this study (Fig. 4) was within the permissible threshold limits. However, in bedroom and hall, CO_2 concentration was exceeding 600μg/m^3 and 700 μg/m^3, respectively, due to influential habits. CO_2 concentration above 500 μg/m3 has been reported to cause increase in heart rate, variation in heart rate, increase in peripheral blood circulation, and blood pressure (Azuma et al. 2018). The exposure over long period of time might result in health issues for the occupants. Irrelevant to hall, the bedroom concentration of CO_2 calls for adopting appropriate ventilation method as they are regularly exposed to these concentrations as compared to visitors in hall.

Particulate matter

This study intends to identify impact of influential habits on IAQ. The IAQ was analysed in terms of particulate matter with respect to number of occupants in each unit (kitchen, bedroom, and hall) covered in this study. The particulate matter concentration for various particle size is present in Fig. 5. The minimum PM concentration ranged between 80 (PM_{10}) μg/m^3 and 35640 ($PM_{0.3}$) μg/m^3. The maximum concentration for all particulate matter for kitchen ranged between 120 (PM_{10}) μg/m^3 and 47380 ($PM_{0.3}$) μg/m^3. For bedroom, minimum range was 39 (PM_{10}) μg/m^3–29381 ($PM_{0.3}$) μg/m^3, and maximum range was 90 (PM_{10}) μg/m^3–139786 ($PM_{0.3}$) μg/m^3. The hall area depicted minimum range of 40 (PM_{10}) μg/m^3–36457 ($PM_{0.3}$) μg/m^3 and maximum range of 115 (PM_{10}) μg/m^3–43745 ($PM_{0.3}$) μg/m^3. The obtained values of particulate matter are way higher than reported in other studies.

In outdoor conditions, Edmonton (Canada) has reported $PM_{2.5}$ concentration of 7.11 μg/m^3 for a study of 6 years duration (Bari and Kindzierski 2016). Also in another study of 26 Chinese cities have reported PM_1 concentration of 42.5 μg/m^3, and for $PM_{2.5}$, it was reported as 51.9 μg/m^3 (Chen et al. 2017). In indoor climate, Changchun (North East China) indoor $PM_{2.5}$ concentration was observed as 41.59 μg/m^3 (winter) and 11.15 μg/m^3 (summer) (Bai et al. 2020). In a study from honking covering 6 residential homes reported PM_{10} concentration between 100 and 180 μg/m^3 for living room and 102 and 450 μg/m^3 for kitchen (Lee et al. 2002). It is evident that the particulate matter concentration observed in this study is way more than reported in literature. Additionally, previous literature with much lower concentration has reported its direct relationship with human health. Hence, it can be deduced that IAQ is of poor quality.

Impact of influential habits on PM concentration

Particulate matter concentration was already exceeding safe limits. The increase in number of occupants further increased the PM concentration reaching to unhealthy conditions for kitchen, hall, and bedroom. This scenario further worsened with increase in PM concentration attributed to influential habits. Kitchen experienced increase of 79% for $PM_{0.3}$, 92% for $PM_{0.5}$, 96% for PM_1, 97% for $PM_{2.5}$, 96% for PM_5, and 92% for PM_{10}. In bedroom, an increase of 22%, 30%, 31%, 29%, 29%, and 30% was observed for $PM_{0.3}$, $PM_{0.5}$, PM_1, $PM_{2.5}$, PM_5, and $PM_{10,}$ respectively. In hall, an increase of 88% ($PM_{0.3}$), 92% ($PM_{0.5}$), 89% (PM_1), 81% ($PM_{2.5}$), 72% (PM_5), and 71% (PM_{10}) was observed.

The particulate matter is of concern owing to its deposition in the lungs. Primary mechanisms of deposition are impaction,

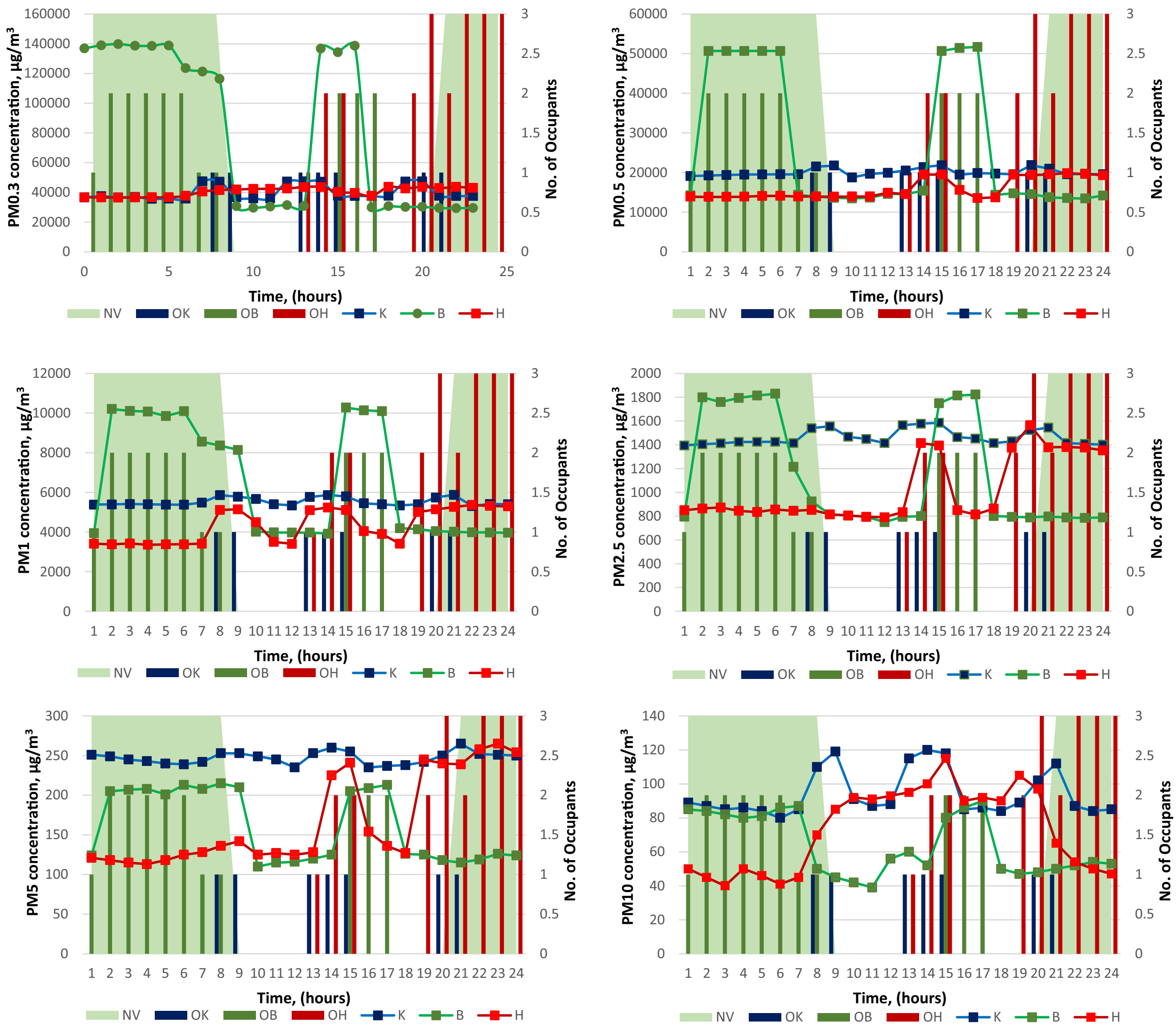

Figure 5. $PM_{0.3}$ hourly concentration with respect to number of occupants (NV natural ventilation, OK occupants kitchen, OB occupants bedroom, OH occupants hall, K kitchen, B bedroom, H hall)

sedimentation, and diffusion in the lungs through respiratory process. Ultrafine particles deposition in lungs ranging from 95 to 35% (0.01–0.1 μm) is primarily attributed to diffusion. Particulate matter >0.1–10 1μm sedimentation and impact are primarily responsible for deposition in lungs. For 0.02–10 μm range of particle sedimentation, deposition fraction ranges from 10 to 78% in lungs, while for impact, the range starts from 2 μm with 10% deposition fraction and reaches up to 90% for 10 μm particle size in lungs. The diffusion mechanism is responsible for 35% lung deposition at 0.1 μm and reduces to 5% at 0.8 μm particle size (Deng et al. 2019). As per air quality index, PM concentration >300 μg/m^3 is hazardous. This study observed except of PM_{10} concentration for all exceeding 300 μg/m^3 with respect to number of occupants and influential habits. The metabolism affected by PM is presented in Fig 6.

As per WHO, $PM_{2.5}$ acceptable 24-h mean concentration is 25 μg/m^3, and annual mean concentration is 10 μg/m^3 while for PM_{10} 20 μg/m^3 and 50 μg/m^3 for annual mean and 24-h mean concentration, respectively (WHO Regional Office for Europe 1998). The results of this study not only exceed but exceed by many times, the acceptable PM concentration by WHO in absence of natural or mechanical ventilation. Natural ventilation cannot be taken into account especially during COVID-19 owing to early speculations from WHO (airborne transmission of COVID 19) (WHO n.d., March 29, 2020); windows remained shut owing to health concerns. Even if COVID-19 threat was not to be considered, significance of ventilation and importance of IAQ guidelines for Saudi Arabia can be highlighted through this study. For CO_2 concentrations reaching 700 ppm especially in bedroom during

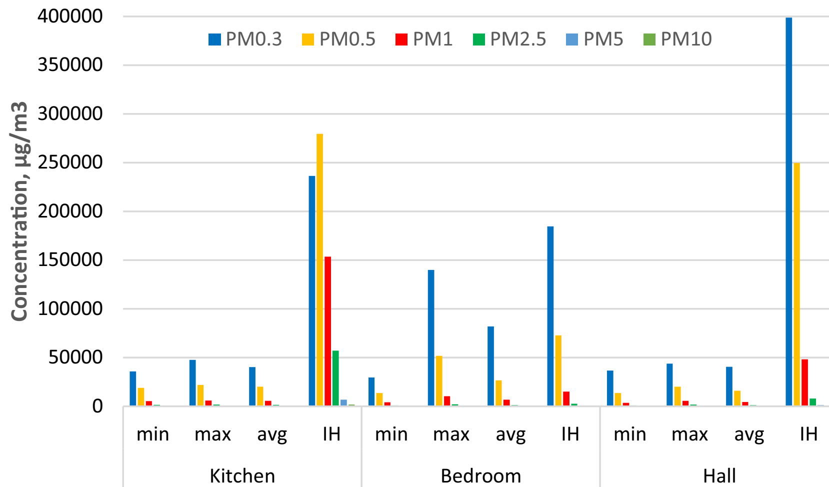

Figure 6 Minimum maximum average and influential habit PM concentration for kitchen, hall, and bedroom (min minimum, max maximum, avg average, IH influential habit)

night hour, natural ventilation system is an easy option. However, window size in buildings is a major concern, for kitchen and hall, as population has adopted to smaller window size across the Kingdom owing to regular dust storms. Also, kitchen is an area where homemakers spend most of the time in order to fulfil the nutritional requirement of their respective families. However, in general practice, kitchens are equipped with ventilation fans suitable for bathrooms, which obviously cannot meet the ventilation requirements and puts the homemaker's health at risk. Larger windows or Chimneys needs to be adopted to address this shortcoming.

Health risk assessment

Hazard risk quotient (HQ) was calculated from average hourly dose and average daily dose as described in "Measurement of CO2 and PM" section. Non-carcinogenic risk sums up all adverse impact on human health except for cancer. HQ value of < 1 infers no risk from exposure to the pollutant. However, HQ value > 1 infers potential health risk which is further increased with increase value of HQ. Hence, HQ >1 necessitates adoption and implementation of mitigation measures to minimize risk level.

HQ_m was calculated from ADI_m for $PM_{2.5}$ and PM_{10} for minimum and maximum concentrations. For $PM_{2.5}$, HQ was >1 for all three units. HQ based on ADI_m values for kitchen were in between 1.5 and1.71 and for bedroom 0.8–1.9, and for hall, the HQ value was 0.8–1.6 for $PM_{2.5}$. The HQ_m value for PM_{10} was calculated using ADI_m for kitchen ranged between 0.06 and 0.09, for bedroom 0.03–0.07, and hall 0.03–0.09. HQ_h calculated AHI for PM_{10} was in range of 135–202, 65–151, and 67–194 for kitchen, bedroom, and hall, respectively, while for $PM_{2.5}$, it was in range of 3238–3401, 1741–4248, and 1836–3633 for kitchen, bedroom, and hall, respectively. However, when influential habits are taken into consideration, the trend is similar. However for HQ_m value for PM_{10} gives a value of 1.24 which presents potential risk to the inhabitants.

The high values are a serious concern. However, this condition is primarily attributed to the absence of natural ventilation attributed to previous reports suggesting spread of COVID-19 through air. Also, no disease being reported during study period from such high concentrations can be attributed to the fact that Agarwood burning is part and parcel of life in Saudi Arabia. Hence, they are adapted to its exposure and are resistant against high concentration over short period of time. However, if these concentration results from other activities (smoking, barbeque, etc.), it may have adverse impact which needs further investigation to verify.

Conclusion

This study was carried out to assess IAQ during ongoing pandemic in terms of carbon dioxide and particulate matter concentration. Mean concentration of CO_2 was 396 µg/m^3, 551 µg/m^3, and 505 µg/m^3 for kitchen, bedroom, and hall. Maximum concentration of carbon dioxide was observed in bedroom during sleeping hours reaching up to 770 µg/m^3. The influential habit (aromatic smoke) added to the concentration of CO2 with observations of 483 µg/m^3, 621 µg/m^3, and 784 µg/m^3 for kitchen, bedroom and hall. Carbon dioxide concentration especially in bedroom, and hall (due to influential habit), may lead to health implications over long-term exposure. For carbon dioxide concentration in bedroom, resorting to natural ventilation will resolve the issue.

The mean concentration for PM in kitchen was observed to be 40012 µg/m^3 ($PM_{0.3}$), 20082 µg/m^3 ($PM_{0.5}$), 5533 µg/m^3 (PM_1), 1465 µg/m^3 ($PM_{2.5}$), 247 µg/m^3 ($PM_{2.5}$) µg/m^3, and 94 µg/m^3 (PM_{10}). In bedroom, it was 81873 µg/m^3 ($PM_{0.3}$), 26412 µg/m^3 ($PM_{0.5}$), 6587 µg/m^3 (PM_1), 1151 µg/m^3 ($PM_{2.5}$), 160 µg/m^3 ($PM_{2.5}$) µg/m^3, and 64 µg/m^3 (PM_{10}), and in hall, it was 40542 µg/m^3 ($PM_{0.3}$), 15926 µg/m^3

($PM_{0.5}$), 5367 μg/m^3 (PM_1), 1565 μg/m^3 ($PM_{2.5}$), 166 μg/m^3 ($PM_{2.5}$) μg/m^3, and 62 μg/m^3 (PM_{10}). When influential habit of aromatic smoke was taken into consideration, the PM concentration increased in times with respect to minimum concentration was observed; for kitchen, the increase ranged between 6 and 40 times and for bedroom range was 2–6 times, and for hall, it was 7–14. In terms of PM, the concentration exceeded more than 300 μg/m^3 putting IAQ under very unhealthy category. The influential habits only worsened the situation. However, in case of PM if not for aromatic smoke, combination of natural and mechanical ventilation needs to be adopted to maintain ambient air quality. Further research work is needed for investigating other indoor air parameters influenced from influential habits, intermittent increased number of occupants, and various seasons of the year and to develop IAQ guideline for Saudi Arabia.

Acknowledgements The authors are thankful to the Institute of Research and Consulting Studies at King Khalid University of supporting this research through grant number # 37-52-S-2020.

Author contribution Salem Algarni collected data and prepared first draft. Roohul Abad khan data curation and writing – review and editing, and Nadeem Ahmad Khan writing and review and editing, and Nabisab Mujawar Mubarak review and editing

Funding The authors are thankful to the Institute of Research and Consulting Studies at King Khalid University for supporting this research through grant number # 37-52-S-2020.

Data availability The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval and consent to participate This section is "not applicable" for this study as the study does not involve any human participants nor their data or biological material.

Consent for publication This section is "not applicable" for this study as the manuscript did not include any data from individuals.

Competing interests The authors declare no competing interests.

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