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Health impact of indoor air pollution in the gulf region: A review

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Abstract

Factors such as unfavorable meteorological conditions within the Gulf region force citizens to spend a considerable amount of time in their homes. Indoor air quality in the Arabian Gulf is rapidly becoming an issue of vital concern that requires urgent governmental intervention and control measures as well as increased in-depth research on likely health consequences. In this review, we surveyed the current literature on the potential health impact of daily household activities in Gulf Cooperation Council (GCC) countries like Qatar where practiced traditions such as burning incense and scented candles are commonplace. These may increase indoor pollution levels, and worsen the health conditions of residents. The main goal of this review is to assess the extent of common indoor pollutants and suggest strategies of pollution control that may alleviate pollution concentration in an indoor environment. Creating awareness about the most common sources of indoor air pollution in the GCC may help improve health promotion and lifestyle changes, especially with respect to reproductive health that is a major concern in the region. The government may also explore recommendations for more environmentally friendly incense and organic candles.

Keywords: Indoor Pollutants; Health Consequences; Arabian Gulf; Environment; Air quality

1. Introduction

Indoor air pollution is one of the world's largest environmental issues, being a risk factor for several of the leading causes of death such as heart disease, pneumonia, stroke and diabetes and lung cancer (1). The largest burden falls upon women living in low- and middle-income countries (2). In 2015 the United Nations (UN) adopted the 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs) that represent an urgent call to action by all member states (3). Targets of particular relevance to ambient and household air pollution include: SDG target 3.9.1 (calling for a "substantial reduction in deaths and illnesses from air pollution"); SDG target 7.1.2 (aiming to "ensure access to clean energy in homes") and SDG target 11.6.2 (aiming to "reduce the environmental impact of cities by improving air quality") (2).

Indoor exposure can potentially be a greater threat and may cause more harmful health effects than exposure to outdoor air, since indoor concentrations of many air pollutants are often higher than typically encountered outdoors (4). Globally, out of 3.2 million deaths from household air pollution exposure, 12% of all deaths due to ischemic heart disease can be attributed to exposure to household air pollution. Similarly, 12% of all deaths due to stroke can be attributed to the daily exposure to household air pollution arising from using solid fuels and kerosene at home (2).

While most studies in the Gulf Cooperation Council (GCC) countries address concerns over outdoor pollution, very few of them focus on indoor air quality and the relationship between the two, especially when findings show that outdoor air quality affects indoor air pollution (4). In the GCC region, there is a paucity of studies investigating how the outdoor pollution influences indoor air quality. During the COVID-19 pandemic, for example, Qatar witnessed a substantial

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improvement in outdoor air quality in 2020. The Qatar Environment and Energy Research Institute (QEERI) observed a 30% decrease in PM2.5 concentrations across Doha, which was associated with people staying indoors (5). Nevertheless, no study was conducted to determine the levels of indoor pollution during the same period. Shorter thereafter, at the beginning of 2021, Qatar experienced a period of poor outdoor air quality, with measurements of PM2.5 pollutants as high as 39.7 $\mu g/m^3$, placing it in the "Unhealthy for sensitive groups" category with a US air quality index (AQI) figure of 111 (6). With pollution at this level, sensitive groups should wear a mask outdoors while doors and windows should be closed to prevent the ingress of dirty air (6). As such, ventilation systems become essential when the doors or windows cannot be opened to refresh the air, due to either outdoor dirty air or hot weather. The scarcity of studies on ventilation levels and health endpoints makes it more difficult to determine the problems caused by ventilation levels. Nevertheless, respiratory symptoms and Sick building syndrome (SBS) were identified as common plausible health effects potentially attributed to poor ventilation levels in the GCC (7). A comprehensive understanding of ventilation system efficacy could help in developing plans to reduce the build-up of indoor air pollutants and improve human health and comfort in the region (7). This is of great importance, a fact illustrated by a study investigating the indoor air quality in 16 mechanically ventilated schools in Qatar during the winter season. The study found that high indoor CO2 and PM concentrations in many classrooms exceeded the ASHRAE standard and US-EPA air quality standards (4).

Some common indoor pollutants in the Gulf region are scented candles and burning incense. The practices of lighting scented candles and burning incense have been part of the local populations' way of life for centuries, dating back to the era of pre-Islamic Arabia (8). There are various types of incense such as "Oud" or Oudh (*Aquilaria agallocha agarwood*) and Bakhoor (*Sandalwood tree resin, agarwood*, etc.) (9). Incense burning and scented candles are sources of indoor air pollution as they slowly release smoke over a certain period (10). "Bakhoor" is the Arabic name given to powered incense, which is an aromatic biotic material that produces fragrant smoke immediately after it is burned. The powdered incense is a sticky and incombustible binder combined together with other materials such as honey, dried fruits and resin converted into balls or little pastilles. It is then burned in order to release fragrance as well as a thick smoke (9). To produce Bakhoor, a broad set of substances are utilized such as frankincense, aromatic wood, herbs, flowers, essential oils, and perfumes. These substances are burned using a charcoal burner. The substances produce continuous smoke because of their slow and incomplete combustion which leads to generating pollutants such as chemical particles and toxic gases. Some of the compounds emitted from burning incense include particulate matter (PM), carbon monoxide (CO), oxides of nitrogen (NO), formaldehyde (HCHO) and sulfur dioxide (SO2) (11).

Incense burning contributes to indoor air pollution and could be harmful to human health and potentially cause increased infertility (10). Infertility is a serious problem and source of worry to Gulf citizens. According to official births and deaths records in the state of Qatar in 2020, the Public Statistics Authority report showed a steady decrease in Total Fertility Rate (TFR) of Qatari women from 3.4 births per woman in 2011 to 2.5 births per woman in 2020 (12). Such a Total Fertility Rate decline impacts long-term population growth and accelerates the population aging process, putting increased pressure on public finances, pensions, care provision, and social security (13). Unfortunately, awareness of this health impact is very low especially in the Gulf. Most studies on health and environmental effects focus on outdoor activities like traffic (14).

In spite the proven adverse impact of burning incense and candles on human health, (15) and to the best of our knowledge, this current paper is the first attempt in Qatar to explore this topic. It aims to raise awareness about aforementioned negative impacts in a region ranked as among the most polluted globally. There is also limited application of epidemiological and/or toxicological studies on indoor air pollution across the GCC countries. Many of the current studies on indoor air pollution are based on prediction and/or estimates of exposure/health risk as compared to health/clinically based observational studies. A survey conducted by the family entertainment Centre Fun City found children in the GCC spend, on average, nearly 60% of their day indoors (16). Another study found that most people, including sensitive groups like the elderly and young children, spend more than 90% of their time indoors, so they are more exposed to air pollution indoors than outdoors (4). In Qatar, most of the population is concentrated in urban areas and so indoor pollution caused by using solid fuels is not as prevalent as in other countries. Instead, GCC regional populations' exposure to indoor air pollutants is a function of changes in construction designs, synthetic building materials and furnishings, volume of the indoor space, as well as application of cleaning agents, pesticides and personal care products (4).

Taking into consideration the potentially high public exposures to indoor air pollution in GCC, particularly for children, entities in the region should undertake and develop reliable data using health/clinically based observational studies within different indoor environments. This is of greater importance, especially when in the GCC, the environmental and climatic features are harsh due to the very hot climate, low rainfall and absence of fresh water. Such climatic features, especially during the hot season (May to October), lead to an increase in the time spent indoors, whether at home or

other closed spaces. Moreover, the rise in population results in increased urbanization and a need for more residential areas, which consequently leads to more indoor and outdoor pollution.

The main goal of this review is to assess evidence about common potential pollutants, raise awareness and provide some strategies to alleviate pollution concentration in an indoor environment. We examine various studies on indoor pollution in the Gulf and find incense burning and scented candles as primary sources for indoor pollutants in the region. The health impact, measures of indoor air quality and strategies to alleviate indoor pollution are also among the topics discussed.

2. Indoor air pollutants

Indoor air pollution is one of the world's largest environmental problems (17) caused by many factors and activities. Among these factors are household or building occupants' activities. These include cooking, burning, smoking, using electronic machines and other consumer products, and emissions from building materials (17). The aforementioned activities release pollutants in the form of gases (carbon monoxide, ozone, radon), volatile organic compounds (VOCs), PM with different aerodynamic diameter, total suspended particles, and fibers, organic and inorganic contaminants, biological particles (bacteria, fungi, pollen) and asbestos (18). Furthermore, indoor air pollution has become particularly important during the COVID-19 pandemic as household activities have great potential to affect indoor air quality. Increased domestic use of cleaning and disinfection products have contributed to the increase in VOCs and other chemicals in the indoor environment. Moreover, lack of suitable ventilation results in indoor pollutant levels being typically higher than recommended for a healthy environment (19).

Smoke is a major source of indoor pollution. Studies have found that anthracnosis particles have the most frequent occurrence in lung tissues throughout history (20). For instance, Al Mulla et al. (21) analyzed the emissions of tobacco water pipe exposure (also known as shisha) in Qatar and concluded that water pipe cafes contained elevated levels of particulate pollution, potentially risking employees and patrons' health. A study by Argyropoulos et al. (22) on PM building infiltration during a dust storm event in Qatar showed that the airborne particulate matter levels can be critical on many such occasions and above recommended limit values. Recently, indoor air quality in Qatar has been negatively altered by the large scale preparations for the World Cup that will be hosted in November and December 2022. An increase in industrial work and infrastructure construction led to a rise in variables associated with higher air pollution in the country, including noise, dust, traffic density, and construction/road work (14). Together with poor ventilation of rooms, burning of biomass (Arabian incense), and overcrowding, ambient air pollutants infiltration into residential buildings contributes significantly to indoor pollution in cities across the Arabian Gulf region (15).

Manoukian et al. (23) assessed the VOCs and particles released by incense sticks and candles combustion in an experimental room, and showed how the degree of ventilation and deposition contributed to removal of the particles in an indoor environment. A study by Bootdee et al. (24) at a shrine located in Thailand showed incense burning as the main source of PM2.5 and PM2.5- bound polycyclic aromatic hydrocarbons (PAHs) where carcinogenic compounds were prevalent in the PM. Ahn et al. (25) investigated the VOCs from six candles types (clean cotton, floral, kiwi melon, strawberry, vanilla, and plain). The study found specific types of scented candles products could be strong sources of VOC emission indoors even when they were not lit. Various esters demonstrated the strongest emissions before lighting. However, formaldehyde was found to have the highest emission concentration when lit. Karr et al. (26) made a health risk assessment of scented candles and incense based on physiochemical characterization of particulate and gaseous emissions. The emissions from 9 scented candles and 10 kinds of incense were tested under real conditions albeit in an experimental house. The emitted substances were similar but in different proportions. From incenses, substances emitted included PM, benzene, acrolein and, to a lesser extent, formaldehyde. The emitted substances from lighting scented candles included formaldehyde, acrolein and, to a lesser extent, PM. Findings showed that the chronic exposures could exceed usual health reference values even where exceedances happen for short term exposures (1 hour). A study by Cohen et al (27) showed how the release of PM changes with burning times of incense sticks, charcoal, candles, Bakhoor, and Oudh. The study demonstrates that the first few minutes of burning Bakhoor and Oudh produce around 1.4 mg/m3 of PM concentration compared to the last minutes of burning. Slow-burning incense and candles require a longer time to be fully utilized, showing that an indoor space is being impacted by smoke for a long period.

One method to improve the quality of air in buildings located near traffic highways and roads is to use particle filtration. Zee et al. (28) reported from their experiment that the use of a fine filter at a classroom in Amsterdam reduced PM10 and PM2.5 exposures by around 34% and 30%, respectively. Moreover, there was an average 36% less exposure of black carbon recorded. The system installed for the study was a "Unifan Octo 10" ventilation system. Zee et al. (28) suggested that the use of a fine filter can lower the pollution emanating from traffic.

3. The impact of indoor pollution on health

Household air pollution is a risk for acute lower respiratory infections in adults and contributes to 22% of all adult deaths due to pneumonia, while 23% of all deaths from chronic obstructive pulmonary disease (COPD) in adults in low- and middle-income countries are due to exposure to household air pollution. Approximately 11% of lung cancer deaths in adults are attributable to exposure to carcinogens from household air pollution (2). Globally, around 2.4 billion people still cook using solid fuels such as wood, crop waste, charcoal, coal and dung and using kerosene in open fires and inefficient stoves. Most of these people live in low- and middle-income countries. The World Health Organization (WHO) found a large discrepancy in access to cleaner cooking alternatives between urban and rural areas: in 2020, only 14% of people in urban areas relied on polluting fuels and technologies, compared with 52% of the global rural population (2).

It is well known that one of the basic requirements to have a good life is clean air. Human activities indoors can produce hazardous substances that could cause a broad range of health problems. The World Health Organization found air pollution to be one of the leading causes of disease and premature death worldwide.

There is also evidence of linkage between indoor pollution and low birth weight, tuberculosis, cataracts and nasopharyngeal cancers. Minor irritation from the pollution can cause itchy and runny eyes, a runny and inflamed nose, and swollen sinuses. Exposure to indoor pollutants can also lead to irritation of eyes, nose and throat, headaches, dizziness, and fatigue (29).

The GCC region is no exception to the rest of the world when it comes to the impact of indoor air pollution on human health. The studies about the impact of Arabian incense on health are limited. A study explored the role of Arabian incense as a trigger of wheezing between a small case-control of 200 Qatari children (2 – 12 years old) with asthma and found that the 100 asthmatic children had significantly more exposures to Bakhoor and Oudh than the control group (30). Al-Rawas (10) found that Omani households that burn Bakhoor more than twice a week were three times more likely to have problems with child breathing compared to those that do not use any. Additionally, Bakhoor worsened wheezing in 38% of asthmatics, making it the fourth most common trigger factor after dust. The study did not find a clear cause of the higher effect of Bakhoor on children from Sharqiya, but suggested that it might be due to higher susceptibility or Bakhoor's structure, which vary in different regions of Oman (10). This could also be due to the fact that Muscat, the capital of Oman, would have better infrastructure and ventilation systems, which support better indoor air quality (IAQ).

A study conducted in the United Arab Emirates (UAE) found that both popular incenses, Oudh and Bakhoor, release smoke that have particulate concentrations and levels of gases such as carbon monoxide, Sulphur dioxide, oxides of nitrogen and formaldehyde. After 24 hours of exposure to these gases, human lung cells showed an inflammatory response, a hallmark of asthma and other respiratory problems similar to that of lung cells exposed to cigarette smoke (31). Moreover, the impact of indoor pollution is worsened in cases where there is lack of ventilation, high humidity, high temperature, chemicals from inside the house (cleaning chemical "irritants"), pets and pests and microbes (mold) (32), (33). In addition, exposure to the indoor emissions of CO, PM10, PM2.5, PAHs, and black carbon are shown to cause health challenges to the majority of the population in the GCC region (15). Cohen et al. (27) evaluated the hazard resulting from incense burning in Emirati households and found it is harmful to human health. PM, CO, and NOx time-weighted averages were found to exceed government regulation values and emissions seen previously from environmental tobacco smoke (27).

A case study in the United Arabs Emirates (UAE) assessed the indoor environmental quality in some offices in Dubai. Researchers distributed a questionnaire to collect the office occupants' perceptions of their office air conditions. The study found that the indoor environmental quality was considered unhealthy as a significant number of participants reported complaining about coughing and headaches as well as nose, throat and respiratory irritation (34). Similarly, another study from within the GCC aimed at measuring the health and education impact of air pollution within the schools including that of asthma in children between 6 and 12 years of age. The findings of this study in Qatar showed that 10.4% of the pupils were diagnosed with asthma and wheezing and that pupils with asthma were missing more days compared to pupils with no asthma (35). Furthermore, another study conducted by Baraka-Haddad (36) in the UAE proposed to test the impact of air quality on adolescents and found that being exposed to poor air quality and behavioral factors such as smoking or smelling gasoline could be a significant predictor respiratory health issues among UAE adolescents such as chronic bronchitis, emphysema, asthma and dry cough. Overall, due to the nature of the GCC region where high temperatures and poor air quality force so much activity indoors, indoor air quality could be easily affected by inattention to such problems leading to a significant, negative impact on overall health and increasing the

rate of respiratory diseases. Moreover, common practices, which encourage the use of various indoor pollutants, including incenses, can further exacerbate broader public health issues.

Measuring the levels of pollutants in indoor spaces is also essential and a precondition to meet accepted pollutant levels in indoor spaces. With the development of technology, measuring indoor air quality is now accessible and easy for most individuals. For instance, air quality monitors connected to smart phone applications can be used to measure several types of pollution in a household. The benefits of these sensors are that they have high sensitivity (as concentration levels are lower indoors), long operating life, miniature sized, and have a low operating noise that allows them to be used discretely (37). Utilizing these monitors in households in the Arab region in order to monitor the pollutants released by incense and scented candles may ensure healthier levels of indoor air quality. A number of studies focused on the use of technology to monitor and reduce outdoor and indoor air pollution. Chung & Oh (38) worked on developing a wireless sensor module with many air quality-monitoring sensors for indoor environment monitoring system. The module contains many sensors for temperature, CO2, humidity, and flying dust. Tsow et al. (39) developed an integrated volatile organic toxicants sensor with a Bluetooth device interface. Jung et al. (40) designed an air pollution monitoring system that contains a context model and a flexible data acquisition policy. More recently, Al-Ali et al. (41) developed a mobile GPRS sensor array that reports real-time pollutant-level locations and measures how much these conform to local air quality standards in the metropolitan area for usage by public and private agencies in the city of Sharjah, UAE. Prasad et al. (42) designed an Ambient Air Quality Monitoring Instrument (AAQMI) for mobile monitoring of air quality in real time by using compact and less expensive solid-state gas sensors.

4. Strategies to alleviate indoor air pollution

Initiatives to improve the IAQ should prioritize steps to increase awareness of indoor air pollution as a significant threat to health. With people spending the majority of their time indoors (43), it is important to identify the sources of indoor air pollutants and to document the indoor concentrations of air pollutants that exceed recommended health thresholds. At a national level, policies and a sound legislative system that prohibits the import and use of hazardous construction materials (such as asbestos) will reduce exposure to chemical pollutants. As such, introducing environmentally friendly requirements in the construction sector will be an effective way to decrease the levels of indoor air pollutants.

The Covid-19 pandemic showed the importance of building design in minimizing the infectious agents in indoor settings, especially when it comes to recirculated air through heating, ventilation and air conditioning (HVAC) systems (44). Ventilation is an engineering system that contributes to the dilution and dispersion of aerosol particles through air movement (44), and it is the most crucial factor in ensuring adequate IAQ (17). In extreme climates, such as the GCC region, the mechanical ventilation systems are widely utilized. Thus, complying with international guidelines and standards for these systems is essential in restricting the indoor contaminants.

Nevertheless, in the GCC urban regions with high outdoor pollution, ventilation systems face critical challenges. As such, air filters should be used to remove the contaminants and then can be supplied into the indoor spaces (45). Application of mechanical air filters, such as MERV and HEPA filters, Electronic Air Cleaners, Gas-Phase Air cleaners, Ultraviolet disinfection devices, etc., is important in places with high outdoor pollution where natural ventilation is not efficient (46). Using all day HEPA filters has been found effective in reducing the PM2.5 concentrations (31%–72% reduction) in indoor spaces, and all-day use of air filters can result in an 8–37% reduction in mortality associated with indoor air pollution (47).

As part of the strategies to improve IAQ, conducting surveys regarding indoor pollution in residential, commercial and public closed spaces represents an important measurement tool for establishing baseline information about IAQ, especially in the GCC region where data are scarce. Moreover, implementing and enhancing systems for tracking diseases attributed to indoor pollutant exposures is crucial to appreciate fully the potential adverse health effects of IAQ (48). Further research should also be encouraged by both governmental and private entities to determine the factors that affect indoor air pollution concentrations and exposure.

Training programs should be offered at an institutional level for professional personnel concerned with IAQ and building engineers. Similarly, urban development programs can inform on material substitution, ventilation requirements and land use. Finally, supporting public participation in activities related to improving IAQ and initiating awareness campaigns are important steps in creating holistic strategies addressing the importance of IAQ.

5. Conclusion

Scented candles and burning incense are common indoor pollutants in Gulf region. As noted at the outset, such practices of lighting scented candles and burning incense have been part of the Arabs' way of life for centuries, dating back to pre-Islamic Arabia. So cultural resistance should be factored into any strategy for promoting better indoor air environments. This review explored the measurable evidence that connects incense and scented candles to indoor pollution and from there to a deleterious impact on individual health. The aim of the review is to raise awareness about such common potential pollutants but also to provide some strategies to alleviate pollution concentration in an indoor environment. As shown above, various research studies on indoor pollution in the Gulf provide guidance to help in promoting a healthy environment and lifestyle. In highlighting the toxicity of incense combustion materials, a health risk associated with scented candles and incenses has been observed, especially with slow burning. Public information on these and other ways to improve indoor environments could help in ameliorating health issues related to indoor pollution. Such campaigns help influence individual choices but also encourage policymakers to frame future policy towards promoting more ecofriendly incense manufacture and reduced usage.

More studies on indoor air pollution, especially household pollution, should be conducted in all GCC countries. Empirical studies can measure the types of incense and candles, the usage frequency per day and map these to rates of respiratory diseases and lower reproductive health. For instance, in Qatar, where outdoor pollution is one of the highest among all the Arab states, reproductive health promotion is positioned number one in Qatar's national strategy. Yet the lack of studies on indoor air quality inhibits the development of effective policies to fulfill the aims of Qatar's National Environment and Climate Change Strategy (QNE). Moreover, no serious study focusing on the levels of indoor pollution due to traditional practices such as burning Bakhoor, Oudh or candles could be found while reviewing the literature. In sum, more effective investigations on the various sources and activities and on the built environment conditions specific to the Gulf region and how these may contribute to the rise of indoor pollution will assist in developing not only optimal policies, but also mitigation measures that reduce exposure to indoor pollutants.

But the need for more studies does not mean there isn't already enough information to get started with mitigation. Many strategies can be used to decrease indoor pollution based on what is already known. These include identifying the sources of indoor air pollutants, introducing environmentally friendly requirements in the construction sector, especially with respect to building design and ventilation. In the Gulf, the strategies to fight indoor pollution are quite different given the fact that the level of pollution outdoors is quite high, and so ventilation systems face critical challenges. As such, air filters should meet stringent requirements to remove the contaminants before cooled air is supplied into indoor spaces. Governmental and private entities' support is essential to determine the factors that affect indoor air pollution concentrations and levels of exposure. For sustained efforts, urban development and training programs are critical along with initiating public awareness campaigns that emphasize enjoyment of better health in a cleaner living space while teaching the public practical activities related to improving their IAQ.

Finally, the World Health Organization has offered technical guidance on monitoring and measuring progress on some key health indicators related to household air quality that were outlined in the UN 2030 Agenda for Sustainable Development. As mentioned at the beginning of this paper, sustainable development goals (SDGs) 3, 7 and 11 are particularly relevant and worth reiterating as important targets for all governments to aim for:

- Reducing deaths and illnesses attributable to air pollution (SDG target 3.9.1)
- Promoting clean energy at the household level (SDG target 7.1.2)
- Improving air quality in the city to reduce the environmental impact of urban spaces (SDG target 11.6.2)

Compliance with ethical standards

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Author Contributions

Sana Abusin is the main author responsible for conceptualization, manuscript writing; Noor Al-Thani; Noor Al-Emadi and Catalina Petcu contributed equally for the literature review. All authors have read and agreed to the published version of the manuscript.

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