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Impact of building ventilation systems and habitual indoor incense burning on SARS-CoV-2 virus transmissions in Middle Eastern countries

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ABSTRACT

Majority of countries across the globe have employed improving building ventilation, quarantine, social distancing, and disinfections as a general measure of preventing SARS-CoV-2 virus transmissions. However, arid Middle Eastern countries with hot climate (elevated outdoor temperature and humidity levels) are experiencing a different situation. Unfortunately, these harsh ambient climatic conditions in Middle Eastern countries make it impossible for most buildings to utilize natural/mechanical ventilation systems. Besides, indoor air temperatures of most buildings are very low due to overconsumption of air conditioning, thereby, it can be a potential factor of virus spread in most residential homes and public buildings. Most importantly, habitual indoor burning of incense which is the major source of coarse (PM_{10}; aerodynamic diameter <10 μm) and fine ($PM_{2.5}$; aerodynamic diameter <2.5 μm) particulate matters (PM) could facilitate the transmission of SARS-CoV-2 virus droplets and particles in indoor environments. In fact, it increases the spread of the virus via inhalation in these countries, especially where the wearing of masks is not regulated in public, commercial and residential buildings. It is therefore highly recommended for the relevant public health agencies to critically assess the role of poor indoor environmental conditions including the burning of incense on virus transmissions, which may help to develop control measures for the future viral outbreak effectively.

1. Discussion

World Health Organization (WHO) declared severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), hereafter virus, which causes novel Coronavirus disease 2019 (COVID-19), as a global pandemic on 12 March 2020 (WHO/Europe, 2020). As of 22 April 2020, this disease has infected 2,558,959 people and causing 177,704 mortalities across 210 countries and territories, making it one of the most serious public health threat to humanity in the world's history (Worldometer, 2020). Till current, there are no therapeutic drug and vaccines to treat/stop the spread of COVID-19, thereby, the only approach would reduce the transmission of the virus by practicing protective measures. Social distancing, quarantine, handwashing and disinfection, especially in outdoor environments are among some of the common preventive approaches that the world could use (WHO, 2020a). Following these measures, the US Centers for Disease Control and Prevention (CDC) recommended wearing of locally made facial cloth covers in public settings except for children with less than two years old and those with breathing difficulties (CDC – National Center for Health Statistics, 2020). Public Health Agency of Canada (PHAC) advised that respiratory droplets are deemed as one of the main routs of virus transmission (yet does not constitute the cause of all COVID-19 diseases) (PHAC, 2020). This has been further confirmed by WHO (2020c) that droplet particles with aerodynamic diameter of >5 to 10 μm of someone who has respiratory symptoms (e.g. coughing or sneezing) could carry the virus and may cause COVID-19 disease. However, a study has argued that liquid droplet aerosols (>0.8 μm) generated during exhalation could evaporate, become smaller (by shrinkage) and easily transported by airflow (Morawska et al., 2009). The subsequent study concluded that the virus is transmitted by air and could serve important information in developing more reliable measures of reducing the spread of the virus in amid of vaccine developments (Morawska and Cao, 2020). Based on the above findings, the following measures of removing liquid droplets and airborne particles in indoor environments have been recommended. These include (1) improving ventilation rates, (2) adoption of natural ventilation, and (3) personalized-ventilations personalized-exhaust system (PV-PE) for micro-environments such as workplaces (Qian and Zheng, 2018). While these measures may work well in countries with tropical and

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temperate climatic conditions, the situation in most Middle Eastern arid countries with extremely high predicted maximum ambient temperate (about 38–42 °C) and humidity (>90%) levels during the long summer (April–September) season will be different (AccuWeather, 2020; NCSI, 2018).

This is because of the buildings in these countries have been designed to suit these harsh outdoor weather conditions. The architectural designs of these buildings do not allow natural and mechanical ventilations but rather only air conditioning systems to maintain indoor thermal comfort (Aljofi, 2016). Several studies from these Middle Eastern countries have revealed poor indoor building ventilation levels in most homes, public settings and offices (Amoatey et al., 2020; Amoatey et al., 2018). The maximum ventilation rates in liter per second per person (l/s/p) of 5 (Behzadi and Fadeyi, 2012), 3 (Fadeyi and Taha, 2013) and air exchange velocity of 0.04 m/s (Indraganti and Boussaa, 2017) in most school buildings, restaurants and offices failed to meet the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) limits of 8 l/s/p and 0.18–0.25 m/s, respectively. Besides, the average low indoor temperature of 23.1 °C in most public buildings due to overconsumption of air-conditioners may be an important factor for viral activation (Indraganti and Boussaa, 2017). Similar findings have been revealed by another study, where most severe acute respiratory syndrome coronavirus (SARS-CoV-1) seems inactivated on surfaces at the temperature of 40 °C compared to 20 °C (Casanova et al., 2010). These limited buildings ventilation systems and favorable cold indoor environments from Middle Eastern countries may be a major contributor to the spread of the virus especially in airports, shopping malls, mosques, offices and residential buildings. While there are not any current scientific data supporting this assertion, additional research works are urgently needed to understand the impact of building ventilation rates and the transmission of the virus in indoor environments in these countries.

Recent epidemiological studies have evident the transmission of SARS-CoV-2 viruses in several indoor environments. On 26 January 2020, Jianyun et al. (2020) assessed air-conditioning system (airflow) and transmission of the virus in an indoor environment (restaurant) in China. The results indicated that most people who ate at the restaurant contracted the virus due to high airflow of the central air-conditioning system, and recommended the need for improvement of indoor air temperature and ventilation rate (Jianyun et al., 2020). Also, from 4 January to 11 February 2020, among a total of 318 COVID-19 disease outbreaks constituting 1245 active cases, outbreaks from indoor environments (79.9%) were found to be the highest compared to transport environments (34%), therefore, it emphasizes the need for epidemiological studies to concentrate on indoor environments (Qian et al., 2020). However, it is difficult to conclude that such transmissions were mainly attributed to poor indoor environmental conditions.

In Italy, it was revealed that the expiratory viral load (based on quanta emission rate estimates) of a virus-infected person due to speaking and breathing were 320 and 10.5 quanta/h, respectively. However, depending on the nature of activities including resting, standing and light exercises, the viral load could range from 33.9–1030 quanta/h (Buonanno et al., 2020). Based on the above scientific findings, it is evident that indoor transmissions of the virus in Middle East countries may be high, especially could be exacerbated by their unfavorable indoor environmental conditions (low ventilation and low indoor air temperature) (Amoatey et al., 2020). Now the question is, what will be the behavior (e.g. durations, survival rate and inactivation) of SARS-CoV-2 virus droplets under a typical indoor environment in Middle Eastern countries?. The research question is very crucial in providing novel strategies and intervention approaches to tackle the transmission of the deadly virus not only in Middle East, but also in other countries/states/territories across the globe where similar poor indoor environmental conditions as a result of their harsh ambient weather conditions exist.

According to WHO (2020b), the major determinants of incidence/transmission of disease in the population include customs, traditions and social environmental factors. In the case of Middle Eastern countries, burning of incense (locally called Bakhour or Oud) in indoor environments (homes, restaurants, shopping malls, and offices) are the most common cultural practices (Al-Rawas et al., 2009; Amoatey et al., 2018; Mesallam et al., 2015). There is a piece of evidence that incense burning produces large amount of fine ($PM_{2.5}$) and ultrafine particles (UFPs; aerodynamic diameter <100 nm). For example in United Arab Emirates (UAE), burning of incense produces a median concentration of 36.95 and 6.20 μg/m^3 for $PM_{2.5-10}$ and $PM_{2.5}$, respectively (Yeatts et al., 2012). Cohen et al. (2013) also found 1420 μg/m^3 of PMs, including $PM_{2.5}$ and PM_{10}, during the peak period of Arabian incense burning in a living room. This habit is rampant and it deems as cultural practices without any consideration for future health impacts since there are no current regulations on the duration, intensity and type of incense burning in these countries (Vallès et al., 2019). For more than two months now following the outbreak of COVID-19 disease from Wuhan, China, the world including Middle East countries are still reporting of high cases of COVID-19 disease with very low recovery rate (Worldometer, 2020). In the case of Middle East countries, it is imperative to assess the impacts of PM emissions due to incense burning and the virus transmission in indoor environments. Morawska and Cao (2020) have mentioned that there is a possibility of inhaling PM bearing solid materials (with aerodynamic diameter of >5 μm) produced from virus-laden droplets after evaporation. There is still an unanswered question about whether indoor $PM_{2.5}$ and PM_{10} emissions due to the burning of incense could carry SARS-CoV-2 virus and increase the spread of COVID-19 disease in Middle East countries?

While recent findings have demonstrated the transmission of the virus through bioaerosols produced from an infected person (National Research Council, 2020), it is important to critically evaluate how PM emissions from incense burning could increase the spread of the virus. In Italy, which was an epicenter for COVID-19 disease, the contribution of daily ambient PM exposure levels and rate of the virus infections were investigated. The study found a strong positive correlation ($R^2 = 0.97$) between a number of infected people with the virus and exceedance of PM_{10} levels (50 μg/m^3) across seven provinces based on lag14 days (Setti et al., 2020). According to Gaddi and Capello (2020), the virus infection could mimic the spread of other air pollution-related diseases, and thus, SARS-CoV-2 virus droplets of 0.3–2.5 μm and 2.5–10 μm could be carried by $PM_{2.5}$ and $PM_{10,}$ respectively. Therefore, indoor environments of Middle Eastern countries, where $PM_{2.5}$ and PM_{10} are mainly produced by incense burning (Amoatey et al., 2018; Elsayed et al., 2016; Vallès et al., 2019), have the potential to spread the virus despite lockdown strategies adopted by these countries. This situation may be exacerbated as wearing of masks have not been currently regulated in homes and public places (malls, restaurants and offices) in most Middle Eastern countries. Furthermore, the building architectural design in these countries which do not support natural/mechanical ventilation, may lead to buildup of PMs carrying virus droplets/particles and increase the spread of the disease due to lack of ventilation.

Based on the above pieces of evidence and assumptions, it is imperative for the governments of Middle Eastern countries to acknowledge that SARS-CoV-2 virus prevention measures need to also consider indoor local environmental conditions due to building architectural designs and socio-cultural practices. It is highly recommended that these countries need to recognize that lack of indoor building ventilation, low indoor air temperature due to excessive use of air conditioning systems and burning of incense (causing PM emissions) will increase the infection of SARS-CoV-2 virus unless immediate actions are taken. We advise that datasets that will be gathered through research concerning the above potential cofounders in the course of this pandemic will provide valuable knowledge on combat the future viral outbreak.

To sum up, based on the theoretical knowledge from computational fluid dynamics, aerosol science and ventilation inbuilt environment technology, we wish to draw the hypothesis to Middle Eastern countries that PM emissions due to indoor burning of incense, poor building ventilation and low indoor temperature may increase the spread of SARS-CoV-2 virus. In view of this, we highly recommend the relevant government agencies and scientific research communities to assess these factors so as to better understand how they affect viral transmissions of the virus to help control of future viral infections.

Declaration of competing interest

Authors declared no potential conflict of interest.

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References

AccuWeather, 2020. Middle East weather conditions. AccuWeather.
Aljofi, E.K., 2016. The measures of light performance of wind catchers in hot climatic zones. International Journal of Engineering and Technology 8, 45–49.
Al-Rawas, O.A., Al-Maniri, A.A., Al-Riyami, B.M., 2009. Home exposure to Arabian incense (bakhour) and asthma symptoms in children: a community survey in two regions in Oman. BMC Pulmonary Medicine 9, 23.
Amoatey, P., Omidvarborna, H., Baawain, M.S., Al-Mamun, A., 2018. Indoor air pollution and exposure assessment of the gulf cooperation council countries: a critical review. Environ. Int. 121, 491–506.
Amoatey, P., Omidvarborna, H., Baawain, M.S., Al-Mamun, A., Bari, A., Kindzierski, W.B., 2020. Association between human health and indoor air pollution in the Gulf Cooperation Council (GCC) countries: a review. Rev. Environ. Health https://doi.org/10.1515/reveh-2019-0065.
Behzadi, N., Fadeyi, M.O., 2012. A preliminary study of indoor air quality conditions in Dubai public elementary schools. Architectural Engineering and Design Management 8, 192–213.
Buonanno, G., Stabile, L., Morawska, L., 2020. Estimation of Airborne Viral Emission: Quanta Emission Rate of SARS-CoV-2 for Infection Risk Assessment (medRxiv, 2020.2004.2012.20062828).
Casanova, L.M., Jeon, S., Rutala, W.A., Weber, D.J., Sobsey, M.D., 2010. Effects of air temperature and relative humidity on coronavirus survival on surfaces. Appl. Environ. Microbiol. 76, 2712.
CDC – National Center for Health Statistics, 2020. Use of Cloth Face Coverings to Help Slow the Spread of COVID-19. Centres for Disease Control and Prevention (CDC), United States.
Cohen, R., Sexton, K.G., Yeatts, K.B., 2013. Hazard assessment of United Arab Emirates (UAE) incense smoke. Sci. Total Environ. 458–460, 176–186.
Elsayed, Y., Dalibalta, S., Gomes, I., Fernandes, N., Alqtaishat, F., 2016. Chemical composition and potential health risks of raw Arabian incense (Bakhour). Journal of Saudi Chemical Society 20, 465–473.
Fadeyi, M.O., Taha, R., 2013. Provision of environmentally responsible interior design solutions: case study of an office building. J. Archit. Eng. 19, 58–70.
Gaddi, A., Capello, F., 2020. Particulate Does Matter: Is Covid-19 Another Air Pollution Related Disease?
Indraganti, M., Boussaa, D., 2017. Comfort temperature and occupant adaptive behavior in offices in Qatar during summer. Energy and Buildings 150, 23–36.
Jianyun, L., Jieni, G., Kuibiao, L., Conghui, X., Wenzhe, S., Zhisheng, L., Deqian, Z., Chao, Y., Bin, X., Zhicong, Y., 2020. COVID-19 outbreak associated with air conditioning in restaurant, Guangzhou, China, 2020. Emerging Infectious Disease journal 26.
Mesallam, T.A., Farahat, M., Shoeib, R., Alharethy, S., Alshahwan, A., Murry, T., Almalkia, K., 2015. Acute effects of inhaling Oud incense on voice of Saudi adults. Annals of Saudi Medicine 35, 111–119.
Morawska, L., Cao, J., 2020. Airborne transmission of SARS-CoV-2: the world should face the reality. Environ. Int. 139, 105730.
Morawska, L., Johnson, G.R., Ristovski, Z.D., Hargreaves, M., Mengersen, K., Corbett, S., Chao, C.Y.H., Li, Y., Katoshevski, D., 2009. Size distribution and sites of origin of droplets expelled from the human respiratory tract during expiratory activities. J. Aerosol Sci. 40, 256–269.
National Research Council, 2020. Rapid Expert Consultation on the Possibility of Bioaerosol Spread of SARS-CoV-2 for the COVID-19 Pandemic (April 1, 2020). The National Academies Press, Washington, DC.
NCSI, 2018. 2018 Statistical Year Book. National Centre for Statistics & Information (NCSI), Muscat, Oman.
PHAC, 2020. Coronavirus Disease (COVID-19): Summary of Assumptions. Public Health Agency of Canada (PHAC), Ontario, Canada.
Qian, H., Zheng, X., 2018. Ventilation control for airborne transmission of human exhaled bio-aerosols in buildings. Journal of Thoracic Disease 10, S2295–S2304.
Qian, H., Miao, T., Liu, L., Zheng, X., Luo, D., Li, Y., 2020. Indoor Transmission of SARS-CoV-2 (medRxiv, 2020.2004.2004.20053058).
Setti, L., Passarini, F., Gennaro, G.d., Gilio, A.D., Palmisani, J., Buono, P., Fornari, G., Perrone, M.G., Piazzalunga, A., Barbieri, P., Rizzo, E., Miani, A., 2020. Evaluation of the potential relationship between particulate matter (PM) pollution and COVID-19 infection spread in Italy. Italian Society of Environmental Medicine 1–6.
Vallès, Y., Inman, C.K., Peters, B.A., Wareth, L.A., Abdulle, A., Alsafar, H., Anouti, F.A., Dhaheri, A.A., Galani, D., Haji, M., Hamiz, A.A., Hosani, A.A., Houqani, M.A., Aljunaibi, A., Kazim, M., Kirchhoff, T., Mahmeed, W.A., Maskari, F.A., Alnaeemi, A., Oumeziane, N., Ramasamy, R., Schmidt, A.M., Vallès, H., Zaabi, E.A., Sherman, S., Ali, R., Ahn, J., Hayes, R.B., 2019. Incense burning is associated with human oral microbiota composition. Sci. Rep. 9, 10039.
WHO, 2020a. Coronavirus Disease (COVID-19) Advice for the Public. World Health Organisation, Geniva, Switzerland.
WHO, 2020b. The Determinants of Health. World Health Organisation Geneva, Switzerland.
WHO, 2020c. Modes of Transmission of Virus Causing COVID-19: Implications for IPC Precaution Recommendations: Scientific Brief. World Health Organization Geneva, Switzerland.
WHO/Europe, 2020. WHO Announces COVID-19 Outbreak a Pandemic. WHO Regional Office for Europe Denmark.
Worldometer, 2020. COVID-19 Coronavirus Pandemic. Worldometer.
Yeatts, K.B., El-Sadig, M., Leith, D., Kalsbeek, W., Al-Maskari, F., Couper, D., Funk, W.E., Zoubeidi, T., Chan, R.L., Trent, C.B., Davidson, C.A., Boundy, M.G., Kassab, M.M., Hasan, M.Y., Rusyn, I., Gibson, J.M., Olshan, A.F., 2012. Indoor air pollutants and health in the United Arab Emirates. Environ. Health Perspect. 120, 687–694.