ARTICLE REVIEW

Housing and Indoor Factor Influencing Spread of COVID-19 – A Review

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ABSTRACT

Introduction	There has been growing recognition linking spread of COVID-19 with environmental factors. One of the environmental factors with robust epidemiological literature supporting its role in diseases is the housing or built environment. COVID-19 spread has been found to occur mostly at homes through secondary household transmission. As most people spend more times inside homes during the pandemic, household remains an important site of COVID-19 spread. The aim of this study is to examine how housing and indoor factors affect the transmission and spread of COVID-19.
Methods	This review employed a comprehensive search strategy to gather a broad range of scholarly articles and grey literature to provide a comprehensive understanding of the housing-related aspects of COVID-19 transmission.
Results	Three electronic databases (Web of Science, Scopus, and PubMed) were searched using specific keywords related to COVID-19, housing, residents, neighborhoods, and indoor environments. Additionally, a supplementary literature survey was conducted to include relevant grey literature sources.
Conclusions	This article summarizes the housing indoor factors involved in COVID-19 transmission, including the role of transmission from contaminated household surfaces. Indoor transmission of COVID-19 is found to be more likely due to contact transmission and close-contact aerosol transmission in a crowded, confined, and poorly ventilated indoor environment, related to poor housing condition. Whilst role of spread through contaminated household surfaces is of low probability. Based on this review, it can be suggested that besides the existing measures including avoiding crowding, close contacts and proper ventilation, specific standards for indoor environmental quality control and housing condition might be required. Housing is a public health issue and healthy housing is of universal concern.
Keywords	Housing - Indoor - Transmission - Fomite - COVID-19 - Infectious Disease.

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INTRODUCTION

Emerging evidence strongly supports the association between environmental factors and the susceptibility and severity of diseases. Over the years, it has been widely acknowledged that climate, pollution (including air and water pollution), and chemical exposures can significantly impact various diseases.[1] Notably, previous studies have also established similar associations between environmental factors and COVID-19.[2–6] Since the onset of the COVID-19 pandemic, there has been a growing global recognition of the link between COVID-19 and environmental factors.[7]

The quality and environmental context of housing are some of the main dimensions of environmental inequalities that can influence health outcome. Housing plays a crucial role in maintaining good health. Adequate and healthy housing conditions have the potential to save lives, reduce disease burden, improve quality of life, and alleviate poverty. Conversely, poor housing conditions can expose individuals to various health risks, including increased susceptibility to infectious diseases.[1] Epidemics throughout history have led to the constant improvements in built environment, architectural design, and the urban planning towards healthier models. WHO Housing and Health Guidelines published in 2018, has brought together the most recent evidence, by systematic reviews of scientific literature, to provide practical recommendations to reduce the health burden due to unsafe and substandard housing conditions[1]

A substantial portion of COVID-19 transmissions has occurred within households, with a high secondary attack rate.[8–10] A meta-analysis of 54 relevant studies with 77,758 participants reporting household secondary transmission estimated that household secondary attack rate was 16.6%.[8] Furthermore, there was evidence of increased risk of household transmission with the newer discovered COVID-19 variant such as with the emergence of delta[11] and omicron[12,13]. Stringent measures to control and prevent the rapid spread of COVID-19 such as social-distancing, stay-at-home orders, and lock-down has resulted in extended periods of time spent at home for most individuals. In addition, due to the limited capacity in medical and quarantine facilities, asymptomatic COVID-19 patients and those with mild to moderate symptoms, not requiring hospitalization, are advised to isolate themselves at home. Consequently, these patients may reside together with healthy individuals who are quarantined at home. The COVID-19 pandemic and its household transmission have reignited the importance of housing and indoor environments, thus motivating the focus of this review. The aims of this study are to examine and comprehend the potential transmission dynamics of SAR-CoV-2 within buildings, with a particular emphasis on houses or residential units, to identify factors that either promote or mitigate the transmission and spread of COVID-19.

METHODOLOGY

To identify relevant literature for this review, a comprehensive search strategy was employed. Three electronic databases, namely Web of Science (WOS), Scopus, and PubMed, were searched using the keywords 'COVID-19 OR Coronavirus OR SARS-CoV*' AND 'house OR housing OR resident* OR neighborhood* OR indoor'. The search was limited to articles published between 1st January 2020 and the most recent available literature at the time of the search (conducted in early November 2022). The initial search yielded a substantial number of articles, with WOS revealed 870 articles, Scopus 898 articles, while PubMed revealed 787 articles. After removing duplicates, the titles and abstracts of 1,844 articles were screened for relevance. During the screening process, several themes emerged from the literature. The most prevalent theme was on housing factors influencing psychological well-being, including mental and emotional health during the COVID-19 lockdown. Additionally, a considerable number of articles explored the impact of the COVID-19 pandemic on the housing and real estate sectors. For the purpose of this review, only studies specifically related to housing or indoor factors influencing the transmission of the COVID-19 virus were included and discussed. In addition to the electronic databases, a supplementary literature survey was conducted to include relevant grey literature sources. This approach ensured a comprehensive review of the existing literature on the subject matter. Overall, the methodology employed in this review aimed to gather a broad range of scholarly articles and grey literature to provide a comprehensive understanding of the housing-related aspects of the COVID-19 transmission.

Household Transmission Due to Poor Housing Conditions

In a cross-sectional analysis of county-level data from the US Centers for Disease Control, US Census Bureau and John Hopkins Coronavirus Resource Center for 3,135 US counties, it was found that with each 5 percent increase in percent households with poor housing conditions (one or greater of: overcrowding; high housing cost; incomplete kitchen facilities; or incomplete plumbing facilities), there was a 50 percent higher risk of COVID-19 incidence and a 42 percent higher risk of COVID-19 mortality.[14]

Overcrowding

Household overcrowding increases the risk of exposure to infectious disease.[1] Several studies have reported a direct association between crowding and adverse health outcomes in infectious diseases, with

increased infections and mortality rates. It has been associated with spread of respiratory illnesses like tuberculosis and influenza which have aerosol and droplet transmissions, both of which are potential modes of transmission for COVID-19.[1,15]

Household crowding is a condition when there is a mismatch between the dwelling and the household. It is when the number of occupants exceeds the capacity of the dwelling space available, whether measured as rooms, bedrooms, size or floor area.[1] Overcrowding can raise COVID-19 transmission risk by increasing the interpersonal contact frequency and duration. Overcrowding also means that it is not conducive to maintain physical distancing or abide to the quarantine order.

An ecological time series analysis in New York City using NYC Department of Health Syndromic Surveillance data in March 2020 found that areas with higher proportions of overcrowded households, defined as housing units with more than one occupant per room, were independently associated with higher suspected COVID-19 case rates.[16] Another ecological study using data on housing and demographics from cities in Los Angeles County up until 28th July 2021 revealed that household overcrowding is a significant risk factor for COVID-19 mortality. Household overcrowding was found to be an even stronger predictor of increased mortality rates than the total number of COVID-19 cases. Additionally, their findings emphasize that elderly citizens residing in overcrowded households are at a particularly elevated risk of mortality from COVID-19.[17]

Crowding in prison facilities has resulted in several large COVID-19 outbreaks. The case rate among US prisoners has been estimated at 5.5 times higher than that of the general US population.[18] Increased crowding in Massachusetts prisons, defined as a 10 percent increase in occupancy over design capacity, was also associated with a 14 percent increase in COVID-19 incidence. It was even evidenced that COVID-19 incidence was significantly higher in prisons where the incarcerated population was a larger percentage of the prison's design capacity, and was lower in prisons where a higher proportion were housed in single-cell units.[19]

At the neighborhood scale, living in neighborhoods with high population density was associated with higher COVID-19 incidence and mortality. A case study inferring the spatial distribution pattern of the COVID-19 epidemic situation in Wuhan showed that from Hua'nan Seafood Market, in which the outbreak was detected, the epidemic situation greatly developed along the highly concentrated commercial areas and the high residential density areas with high-rise buildings.[20] Another study concerning the impacts of population density on the spread and severity of COVID-19 in Malaysia collected data on the cumulative COVID-19 cases and infection rates of COVID-19 cases between 19 January 2020 and 31 December 2020 and plotted them against the population density data of 143 districts in Malaysia. Based on the observations, districts with high population densities and are highly interconnected with neighboring districts, whether geographically, socio-economically, or infrastructurally was found to have a moderately strong relationship to cumulative COVID-19 cases and a weak relationship to COVID-19 infection rates.[21]

Air Circulation and Ventilation

Reviews on the relationship between ventilation and infectious diseases indicate that ventilation plays a key role in infectious disease transmission..[22] Since the Spanish flu pandemic in 1918, the importance of air circulation for the mitigation of airborne contagious diseases has been highlighted. The inflow of fresh, outdoor air helps to minimize the accumulation of virus particles in indoor spaces. Epidemiological studies have shown that low ventilation was associated with the transmission of measles, tuberculosis, rhinovirus, and influenza.[22] The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has established ventilation guidelines for most interior environments to achieve basic levels of acceptable indoor air quality, which are available on their websites. However, those were not meant for passive infection control.[23] Infection control is achieved by encouraging the air-exchange rate in a space, commonly expressed in units of air changes per hour (ACH). Optimal ventilation rates for transmission prevention are challenging to define because they vary based on individual risk, occupancy, and activity. However, ventilation that achieves 4 to 6 air changes per hour (ACH) is thought to be able to reduce the airborne concentrations and mitigate airborne spread of COVID-19. It can also be measured as total volumetric flow, volumetric flow per person and area, or outdoor air ventilation rates.[22] According to ASHRAE Standard, a single-family home with three bedrooms, a default occupancy of 213.77 m^2 (2301 sqft), and 2.4 m (8 ft) spatial height is recommended to have an ACH rate of at least 4 to 6 ACH, or 0.32–0.35 ACH per person. However, many indoor settings do not achieve this infection-risk-based ventilation targets. Many studies have indicated that indoor airflow is poor in most of the residential setting.

Despite the recognition of the importance of air circulation and ventilation with infectious disease, from the literature search done, there was no research done specifically on the association of level of air circulation in a housing or residential building with the spread of COVID-19 cases, beyond the need to increase the air-exchange rate.

Housing Water

Another aspect of poor housing conditions is lack of access to adequate plumbing or sanitation facilities.[1,14] Lack of access to sufficient water and the inherent need to utilize communal appropriate facilities (i.e. bathrooms or kitchens facilities) interferes with the ability to practice good hygiene. This discourages hygiene practices, which further worsens the outcomes related to COVID-19.[14]

It was found that COVID-19 cases among the slum dwellers in Africa and India was particularly poignant not just due to crowding and social distancing impossibility, but also triggered by structural inequalities, and as they depend on a common water source.[24,25] The United Nation-Habitat defines a slum household is a group of individuals living under the same roof, in an urban area, that often lacks one or more of the following: durable housing; sufficient living space; security of tenure; sanitation and infrastructure; and access to improved uncontaminated water sources.[1]

Indoor Temperature and Humidity

Temperature and humidity may influence the stability of a virus, the transmission pathway, and the reactions of the body's receptors.

Empirical evidence suggests that virus environmental stability depends strongly on ambient temperature and humidity. SARS-CoV-2, like other human coronaviruses, can survive in typical climate-controlled conditions of moderate temperature and humidity. Inactivation rate increases with increased temperature and shows a U-shaped dependence on relative humidity.[26] At high temperatures, the virus may lose its infectivity as its protein coat may be impaired.[27] Several studies on the viability of SARS-CoV-2 virus on surfaces have indicated that the virus viability decrease with temperature.[28,29] A study using a UK variant of SARS-CoV-2, SARS-CoV-2 England-2, investigated the ability of the virus to survive at two different relative humidity values, within tissue culture media and artificial saliva. In the tissue culture mediums, this study illustrated that the virus was more susceptible at a higher relative humidity, with the decay rate increasing from 0.91% per min in medium relative humidity (40%–60%) to 2.27% per min in high relative humidity (68%–88%). However, in the artificial saliva, the decay rate was higher at medium relative humidity (1.59% per min) compared to a high relative humidity (0.40% per min).[30]

Temperature and humidity may influence the shape and magnitude of SARS-CoV-2 airborne trajectory by altering the size distribution and evaporation process. Expelled droplets quickly lose water through evaporation. Higher temperature provides more heat source for evaporation.[31] Whilst, the evaporation process becomes much slower with increasing humidity as the humid air has less potential to absorb water vapor. Therefore, in high-temperature and low-humidity environment, large droplets can be converted to numerous small droplets. It was evident from several research that the number of aerosol particles increases in high-temperature and low-humidity environment.[32] In general, larger droplets follow a ballistic trajectory regardless of flow in the gas phase, compared with the aerosols that are buoyant to a diverse degree within a turbulent gas cloud.[33] Smaller droplets are capable of traveling further and may trigger a higher likelihood of deposition in human airways hence higher likelihood and increase risk of infection.[34]

However, although there were numerous studies on the effect of temperature and humidity on COVID-19 spread, the evidence is conflicting and unable to offer a comprehensive and full picture on how temperature and humidity may drive the spread of COVID-19.[31] This is probably due to the considerable heterogeneities among data sources and study population, difference in the socio-economic status, study period, and methodology, among others.[31]

Cost of Housing and COVID-19

According to County Health Rankings Model, another feature of poor housing conditions is high cost burden, defined as more than 50 percent of the household income spent towards housing cost.[14] Households experiencing severe cost burden have to compromise other aspects of living and might face difficulty to afford and meet other basic needs such as education, health care and medication, healthy foods, and health insurance.[14] Prior studies have shown associations between high housing costs and delays in seeking healthcare.

Household Indirect Transmission Via Fomites

Indirect transmission via contaminated surfaces and objects i.e. fomites may also play a role in the transmission of COVID-19. Infected individuals can contaminate surfaces and objects by expelling respiratory particles onto the surfaces when coughing, speaking, and breathing. Infected individuals can also create fomites by shedding onto their hands and then touching a surface. These aerosolized droplets may settle and persist on the surfaces for extended periods. Several research on the survival of SARS-CoV-2 on a variety of porous and non-porous surfaces have found that viable virus was not able to be detected within minutes to hours on porous surfaces, but were able to be detected for days to weeks on non-porous surfaces. [28,29,35–38]

During the ongoing pandemic, there are emerging evidence showing presence of SARS-CoV-2 on high-touch surfaces in different community environments including in playgrounds,[39] supermarkets,[40] public transport vehicles,[41] and workplaces.[42] Evidence on household surfaces contamination with SARS-CoV-2 is also available, although limited. A study on

samples collected from a household with two confirmed COVID-19 cases (one adult and one child) found that a month after symptom subsidence, 46 percent of the surfaces had detectable levels of SARS-CoV-2 even though cleaning appears to have attenuated the signal on many surfaces.[43]

Ample research has been conducted to identify the risks of infection with SARS-CoV-2 by contaminated surfaces. Several systematic reviews were also conducted on those. Based on those studies, it can be concluded that transmission via fomites is unlikely or only has low probability.[44,45] The existence of virus on surfaces does not prevail the risks of infection by the virus. Moreover, there was lack of information on the infectious dose of SARS-CoV-2 on the surfaces to be transmitted in order to cause infection.[45,46] There was not enough evidence to support the transmission to be solely via fomites as it is difficult to disentangle the relative contributions of inhaled droplets and contaminated surfaces because people who have come into contact with potentially infectious surfaces have generally also been in close contact with infected individuals.

Amongst the articles indicated risk of SARS-CoV-2 contaminated surfaces, only one was found performed in household. This study was conducted in March 2020 in the German district of Heinsberg in North Rhine-Westphalia among 21 households under quarantine conditions with at least one person who tested positive for COVID-19. All individuals living in these households participated in the study and provided throat swabs for analysis. Positive surface swabs and wastewater samples obtained using qRT-PCR were further cultured to analyse for viral infectivity.[47] No statistically significant correlation was found between positive environmental samples and the extent of the spread of infection between household members. No infectious virus could be propagated under cell culture conditions. This study conclude low likelihood of transmission via surfaces.[47]

Concern regarding role of contact with contaminated surfaces affecting people in shared living spaces had brought two organizations, Public Health Ontario and National Collaborating Centres for Environmental Health (NCCEH) Canada, to collaborate in gathering evidence regarding COVID-19 outbreak in multi-unit residential buildings.[48] Multi-unit residential buildings are distinct from other congregate living situations such as dormitories, shelters, camps, etc in that occupants have their own bathroom and kitchen. From the review done, it was concluded that although a number of multi-unit residential building outbreaks have been reported in the media, the scarcity of evidence suggests that such events are rare and do not appear to have contributed significantly to the pandemic. Moreover, although theoretically residents in multi-unit residential buildings have lesser and more limited interactions, there were still interactions in common areas such as the elevators, stairways, and laundry rooms that are difficult to avoid.[48]

CONCLUSION

Based on the evidence to date, transmission of SARS-CoV-2 has been indicated to be mostly airborne via droplets or aerosols through close contact with infected individuals. Contaminated surfaces are not a primary mode of transmission of SARS-CoV-2. Similarly, in a housing and indoor environment, evidence strongly suggests transmission from contaminated surfaces does not contribute substantially to new COVID-19 infections. Housing factors mainly associated with the spread of COVID-19 are crowding, temperature, humidity and other factors associated with poor housing condition. These demonstrate that existing recommendations to prevent COVID-19 transmission including physical distancing, avoidance of crowded indoor spaces, and adequate ventilation remain effective. Cleaning and disinfection can reduce the risk of fomite transmission. Based on this review, it can be suggested that in managing the pandemic, public health measures particularly addressing the unique needs of individuals living in poor housing conditions may improve the health outcomes for this group. It is important to be able to recognize the population more susceptible, to effectively allocate resources for the prevention and control of COVID-19, and also future disease outbreaks. Opportunity to learn the right lessons from COVID-19 crisis, this review hopes to highlight the importance and to lay the foundations for a long-term environmental and housing resilience against pandemic and infectious diseases. Adequate preventive measures and specific standards for indoor environmental quality control might be required, based on a precautionary approach. Further research and evaluation may be required, and involvement of policy is essential, as housing is becoming more important in view of recent urbanization, demographic, and climate changes. Housing is a public health issue, and the costs of inaction are high.

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