March 24, 2021

National Collaborating Centre for Environmental Health

Centre de collaboration nationale en santé environnementale

Contextualizing the risks of indirect COVID-19 transmission in multi-unit residential buildings

Prepared by
Angela Eykelbosh

Introduction

Since the beginning of the COVID-19 pandemic, multi-unit residential buildings (MURBs) have been of particular concern to both public health practitioners and MURB occupants. MURBs are distinct from other settings in that occupants have their own bathroom and kitchen and (theoretically) can limit their interactions more effectively than in other congregate living situations (dormitories, shelters, camps, etc). However, some interaction in common areas such as the elevators, stairways, and laundry rooms are difficult to avoid. Accordingly, homeowners' associations and property managers have adapted public health guidance to MURBs. Examples include enhanced cleaning and disinfection of high-touch surfaces, limiting the number of people in the elevators and laundry rooms, and closing amenities like recreation rooms,[1] as well as implementing mask mandates and imposing limits on private gatherings as ordered by provincial governments.

To date, these measures appear to have been largely effective in preventing MURB outbreaks, in that public health has not encountered issues in this setting to the same degree as in congregate living or long-term care facilities. Transmission via close contact, most often between members of the same household, remains the most common means through which COVID-19 is spread.[2] However, over time, there have been a number of reports in the media and academic literature of MURB outbreaks in which transmission may have occurred without close contact, suggesting a potential indirect or environmental route of transmission.

The objective of this review was to scan the literature for MURB outbreaks that may have involved indirect or environmental transmission, and to examine how transmission routes were investigated and what was found. This document is intended to help public health practitioners: 1) improve their understanding of how building systems may (or may not) contribute to transmission of SARS-CoV-2; 2) learn about the environmental or other analyses to complement a thorough epidemiological investigation if indirect transmission is suspected; and 3) communicate effectively about the relative risks of indirect transmission in a MURB setting.

Literature search methodology

For the purposes of this review, a "MURB outbreak" is an event in which SARS-CoV-2 appears to have spread among occupants without close contact, which is defined as 15 minutes (in a 24-hour period) of physical contact or interaction within a two-metre radius without personal protective equipment.[3] Transmission without close contact may also be referred to as environmental transmission or indirect transmission.

The search was not limited to residential buildings. Quarantine hotels were considered because the purpose of these is to isolate occupants from each other and there is (presumably) very little interaction between occupants and staff. Hotels, student residences, and assisted living arrangements were excluded because although occupants have their own facilities, they are not restricted to their apartments or may be brought together by recreational amenities, social programming, care workers, etc.

Two organizations (Public Health Ontario and NCCEH) collaborated in gathering evidence for this rapid review. Briefly, the review focused on MURB outbreaks due to SARS-CoV-2 (January 2020 to March 2021; however, complementary literature (e.g., other coronavirus MURB outbreaks) were sought within a period spanning 1946 to February 2021. Only English-language documents were included. Full details of the literature search are available upon request.

Documented MURB outbreaks and strength of the evidence

This literature search identified only four published MURB outbreaks with suspected indirect SARS-CoV-2 transmission (Table 1). Of these, only one event, covered by both Kang et al.[4] and Lin et al.[5], provided fair evidence to rule out person-to-person transmission and support the proposed indirect route of transmission. The evidence for the remaining three events was weak, as neither the proposed route of exposure could be supported, nor could other routes be ruled out. Three of the studies occurred in Guangzhou, China, which is host to both the Guangzhou Center for Disease Control and Prevention and the Guangdong Provincial Center for Disease Control and Prevention. This is significant because it reflects the fact that proximity to expertise is often a critical factor in whether an event can be investigated in detail.

A number of MURB outbreaks have been reported in the media (Table 2). However, these reports do not provide sufficient detail to understand whether transmission has occurred because of some failing related to the building, or whether it was to be expected given interactions or direct contact among occupants, either inside or outside the building (i.e., residents also attend the same workplace or place of worship). Incidents reported in the media will not be discussed further in this document.

Suspected causes of MURB outbreaks

Enclosed spaces and high-touch surfaces. The most commonly suspected causes of the MURB outbreaks in Tables 1 and 2 are aerosol transmission in enclosed shared spaces and fomite transmission from high-touch surfaces. Unfortunately, these two factors are often united, e.g., elevators, laundry rooms, and stairways with frequently touched surfaces and controls. However, transmission in shared spaces can be difficult to investigate because people are unlikely to remember their movements in minute detail. In addition, common areas are regularly cleaned, especially if an outbreak is declared, such that evidence of the virus will have been removed. One strategy may be to swab "no-touch" surfaces (e.g., elevator walls rather than buttons), which would capture deposited aerosols, but may not be cleaned.[6]

Indicators that an elevator in particular may be been involved are as follows: 1) shared elevator use among cases, masked or unmasked; 2) all cases clustered to floors/portions of a building served by the same elevator (pressed the same buttons or via respiratory particles); or 3) cases distributed randomly but increasing in frequency higher up in the building (transmission via respiratory particles more likely when occupants ride longer with each other). Dbouk and Drikakis provide a useful animation demonstrating how quickly droplets from a mild cough can disperse throughout the elevator cabin, meaning that riding together unmasked would result in some degree of exposure.[7]

From the outbreaks noted in Table 1, two studies have attributed MURB outbreaks to transmission within elevators. Liu et al.[8] investigated a cluster of 71 cases initially discovered within a hospital in April 2020; the outbreak was then traced backward to a MURB.[8] Genome sequencing revealed that the strain involved was one not known to be circulating in China. However, the building was also home to a woman who had recently returned from the US in March. Although she had quarantined alone and tested negative twice during her quarantine, subsequent antibody testing revealed that she had been infected with SARS-CoV-2. The only indirect connection between her and the first member of the larger cluster was that they typically used the same elevator. The time and date of the presumed exposure was not determined and it is unclear whether it was possible to obtain a sample from the traveller to confirm via sequencing that she was indeed the first case.

In the second study, Xie et al.[9] identified a link between the two infected households based on elevator use. On one specific occasion, the index case from the first infected household entered the elevator and then blew his nose into his hands. He then pressed the button for his floor. After leaving the elevator, another person who lived on the same floor entered the elevator within two minutes, touched the same button and then directly afterward picked his teeth with a toothpick. No one else used the elevator during that two-minutes interval. How the authors arrived at this detailed timeline is unclear, but they may have relied upon elevator security footage. Because only 24 of 40 households in the building were tested, other sources of exposure in the building (or the community) could not be ruled out. Nor did the authors address the possibility that respiratory particles from the nose-blowing action were not in fact the means by which the next occupant was infected.

Faulty ventilation systems. Ventilation refers to the intentional exchange of stale air for (presumably) cleaner air, which may be achieved through passive means (natural ventilation) or by the use of fans and blowers that force air through ducts (mechanical ventilation or HVAC). Under normal operations, heating, ventilation and air conditioning (HVAC) systems, are intended to promote the health and comfort of occupants by exchanging stale indoor air for fresh outdoor air, without causing noticeable drafts, moisture buildup, or thermal discomfort. Although HVAC systems are designed to a comfort standard, they can also provide a health benefit by reducing the concentrations of indoor pollutants, including bioaerosols.[10] For example, recent work showed that dormitories served by mechanical ventilation providing 100% outdoor air experienced far fewer acute respiratory infections than occupants of dormitories without mechanical ventilation (passive infiltration only).[11]

During the pandemic, however, HVAC systems have been considered as a potential source of contamination, rather than a way to mitigate transmission risk.[12] There are two key concerns around HVAC systems. The first is the use of re-circulated air, which is a necessary feature of some HVAC systems, as continuously heating/cooling 100% outdoor air can be cost prohibitive or simply beyond design specifications. The concern is that stale air carrying a viral aerosol could be collected from one room and delivered to other rooms connected to the same air handling unit, spreading the virus if not removed through filtration or some other air cleaning device. To date, there is no evidence of HVAC systems facilitating transmission in this way. There have been instances in which SARS-CoV-2 virus has been detected in filters and in ducts,[13-15] which is exactly where one would expect virus to end up after having been drawn out of the room. However, there is (currently) no evidence of transmission occurring across different rooms or zones of a building through the HVAC ductwork.

The second concern regards the number of air changes required to prevent disease transmission. Although too few air changes and not enough fresh air may be insufficient to clear the air in a single room, too many air changes may either speed the distribution/mixing of respiratory particles in a single room, or increase their presence in connecting rooms, at least over the short term.[16] Indeed, the literature now shows several examples in which lack of fresh air, drafty air flow caused by devices, or some combination thereof have led to what appears to be SARS-CoV-2 aerosol transmission among people sharing the same room.[17-20]

But can HVAC systems facilitate transmission in a MURB? MURBs are designed such that air does not intentionally flow between units; this is necessary to control odours as well as smoke in case of a fire. Thus, a properly functioning HVAC system is a key tool in preventing transmission, rather than a potential route of cross-contamination. However, it is not a given that a building's HVAC system will be functioning properly. Not only do HVAC systems require regular maintenance, but it is widely acknowledged that a large portion of Canada's older MURB building stock, which is reliant on a system known as corridor pressurization, may be drastically underventilated.[21] Without sufficient air flow to and through individual units, the potential for issues related to unintentional air flows and contaminant transfer increases (next section).

Apart from MURBs, there are a limited number of instances in which HVAC systems may have contributed to other outbreaks. Chirico et al.[22] looked at 14 such incidents, all in Asia, in which aerosol transmission of SARS-CoV-1, MERS, or SARS-CoV-2 appeared to have occurred in hospitals, workplaces, restaurants, or other community settings. Of these, the authors identified six that appeared to be substantiated by evidence. It is also important to note that where "ventilation" was implicated, the issue was typically unbalanced or drafty HVAC air flow that carried the virus to other people sharing **the same room,** and not through the HVAC ductwork to other zones.[23,24] Others did not involve an HVAC system at all, but rather strongly directional air flow created by stand-alone air conditioners with no fresh air intake.[17,18] Thus, although HVAC systems may play a limited role in outbreaks outside of a MURB setting, this role remains poorly understood and is likely still infrequent.

Air leakage or unintentional air flows. The ability to contain respiratory particles or any pollutant to a MURB unit is dependent upon air flowing predictably from cleaner to progressively more dirty space, typically driven by an HVAC system. However, there are other forces at work in a MURB that may cause air to flow unpredictably and to "leak" into other units.[21,25,26] The first natural force is the **stack or chimney effect**, which occurs when warm air rises through the interior of the building, causing air to be drawn in through the envelope in the lower parts of the building and pushing air out of the upper floors. The second is the **wind**, which when it blows against a building can create a positive pressure on the windward side and a negative pressure on the leeward side, causing horizontal flow through the interior of the building and turbulent flows up and down the outside of the buildings.[27]

A growing body of literature has described how wind, indoor/outdoor temperatures, and buoyancy or the stack effect might contribute to disease transmission by connecting the air volumes shared by occupants of different units. This work, primarily based on tracer gas studies and modelling, shows the myriad ways through which air might exit one unit and re-enter another through exterior windows or other apertures, either vertically[27] or horizontally.[28] In addition to the risk of spreading a contagion, this leakiness has implications for the transfer of other pollutants (e.g., secondhand smoke) as well as effects on thermal comfort and energy efficiency.[21] Mechanical ventilation systems, if they are present, attempt to overcome these natural forces by using fans and ducting to deliver air where needed. However, actual "state of ventilation" at any given moment is the sum total of these mechanical and natural forces and can change on an hourly basis.[25]

There are a number of indicators that may signal that transmission may be related to unintentional air flows: 1) all cases clustered together on the same floor; 2) index case on the windward side of the building and clustering of cases on the leeward side; or 3) cases distributed vertically on one side of the building and the windows of affected units habitually left open (vertical cascading due to the stack effect).[27]

This search revealed only one study in which it appears that a natural ventilation shaft (not part of an HVAC system) was subject to an unexpected reversal of air flow that may have led to transmission in a MURB. Hwang et al.[29] investigated an outbreak in which all of the 10 cases were clustered closely to each other in two adjacent columns, with two cases in one column and five cases in the other. In each column, the units were connected either horizontally through shared walls or vertically through a ventilation shaft opening into the bathroom of each unit. The bathrooms did not have exhaust fans, meaning air flow in the ventilation shaft was passive. The ventilation shaft does not appear to have been connected to a toilet. The authors postulated that virus-laden particles travelled out of one bathroom and into others driven by the naturally occurring stack effect. In addition, very hot outdoor conditions could have also caused a reverse stack effect (downward flow) to affect units below.

Although it is striking that the seven affected households were contained within two vertical columns of apartments, connected vertically through a bathroom ventilation stack, the study did very little to confirm their hypotheses beyond mapping the cases (e.g., air flow analyses or genome sequencing to link the cases). Additional analyses would have helped to solidify the conclusion that indirect transmission occurred via the ventilation shafts, especially given that the residents exposure outside of the building was unknown. Even so, this event serves as an excellent example of how mapping cases within the building can signal the need to expand upon the basic epidemiological investigation with complementary environmental analyses.

Faulty plumbing stacks. Since the discovery of SARS-CoV-2 in anal swabs and fecal samples,[30] and limited air sampling data from a mobile hospital toilet,[31] there has been concern that fecal-to-respiratory transmission could occur under conditions where fecal materials are aerosolized. Although most of this concern has focused on public washrooms and the generation of "toilet plumes,"[32] the other potential route of fecal transmission is contaminated air flowing inappropriately through the plumbing that connects units. The key indicator of such an event would be that all affected households (or more specifically bathrooms) are connected vertically through the plumbing stack.

A "plumbing stack" refers to the interconnected drainage and ventilation pipes that run vertically down the interior of the building. Configurations may vary; a typical configuration involves one or two "soil" or "drain" stacks that collect blackwater and/or greywater, respectively, which are then cross-connected to an air-filled ventilation stack or "vent stack." The purpose of the vent stack is to exhaust odours, and to also equalize pressure between the plumbing and the outdoor environment so that the soil and drain stacks can flow freely and noiselessly. Although plumbing stacks vertically connect all the units built over top of one another, the stacks and associated plumbing are designed to ensure that gas/odours cannot flow backwards into the individual units (e.g., through water-filled drain traps or other mechanisms). However, cross-contamination is possible in cases where the plumbing has been altered or if drain traps are allowed to dry out.

The most famous case of this is the Amoy Gardens SARS-CoV-1 outbreak (Hong Kong, 2003) in which aerosolized fecal matter was drawn through modified plumbing (assisted by an overpowered exhaust fan) and then expelled from the unit and carried on the wind to infect others in a nearby housing tower.[33] In total, 321 people were infected and 42 died. It should be noted that this particular incident required a number of factors to come together, and the exact mechanism remains contested,[34] but it was an important example of how a respiratory agent can opportunistically transmit via a fecal-respiratory route, originating from the plumbing.

During the current COVID-19 pandemic, Kang et al.[4] and Lin et al.[5] used a combination of air flow analyses, meteorological analysis, tracer gas studies, and CFD modelling to separately examine the same outbreak in a 29-floor block of a large MURB in Guangzhou, China. Together, the two studies indicated that virus deposited into the toilet was aerosolized into the soil stack (due to agitation while flushing) and was then borne upward through the soil stack or through cross connections into the ventilation stack. The viral aerosol was then drawn into the connected upper-floor washrooms through unsealed drain traps, which survey data suggested were typically left dry. Movement through drain traps was facilitated by both the negative pressure in the bathrooms created by wind effects, as well as impeded egress of air through an inappropriately modified ventilation stack opening at the top of the building. Although the studies did not isolate viable virus in aerosol form moving through the pipes (which is extremely unlikely after infected cases have been removed), the published studies provide fair evidence that air was able to move between bathrooms. Sequencing of the SARS-CoV-2 *S* gene indicated that all three affected units were infected with the same strain.

The evidence appears to suggest that SARS-CoV-2 could spread via plumbing stacks given a combination of favourable conditions. But how likely is this to occur? Shi et al.[35] used data from the Amoy Gardens outbreak and data from the current pandemic to perform a quantitative microbial risk assessment of transmission from fecal aerosols. In their model, Shi et al. consider two exposures: using the same bathroom as an infected person who has just flushed the toilet or being exposed to fecal aerosol from another apartment via a flaw in the plumbing stacks. The model revealed that the risk of developing COVID-19 from a single day of exposure under either condition was extremely low: 1.11×10^{-10} for exposure to a toilet plume and 3.52×10^{-11} for exposure due to faulty plumbing. However, their model only considered exposure over a single day, among other issues with estimating exposures to fecal aerosols.

Strategies to investigate indirect transmission

The studies included in this review used a number of strategies and environmental analyses to investigate indirect routes of transmission. However, these analyses **do not replace** the necessary epidemiological investigation. Rather, they may be useful if or when the epidemiological investigation has been thorough, but gaps or other anomalies in the chain of transmission remain.

Mapping affected households. Physical connections between affected households can help to understand whether the epidemiological investigation should be expanded to include indirect or environmental transmission. Mapping affected households with respect to the physical infrastructure, such as plumbing stacks, air ducts, or adjacent open windows, as well as their position in the landscape (vertical height, wind direction, incident heat), can provide important information regarding potential routes of transmission.

However, understanding how units are connected to each other can be difficult without access to building plans and the expertise to interpret them. Expert reviewers for this paper suggested bringing in a building systems expert to interpret the schematics and to visually inspect the building and flag potential issues. Issues might include modifications to the original design, the presence of obvious flaws or apertures that might allow air leakage, or a general state of disrepair. This type of "first pass" inspection can be helpful to know whether more detailed analyses of the building systems are required.

Epidemiological investigation. One of the key concerns with outbreaks attributed to indirect transmission is that the epidemiological investigation was simply insufficient to identify the more likely person-to-person transmission, especially given the frequency of asymptomatic individuals infected with SARS-CoV-2. Although detailing the steps of an outbreak investigation[36] is beyond the scope of this document, an expert reviewer suggested the following best practices:

- Make every effort to find the first case in the chain of transmission, which may not be the index case;
- Make every effort to find all cases to date (both suspected and laboratory-confirmed), and carefully identify dates of onset and symptoms during the first three days of illness;
- Identify likely cases of person-to-person transmission, including family members, roommates, and those with extensive social interactions;
- Spend equal effort to identify all non-cases by creating a complete building census and testing widely;
- Note that patterns and/or routes of transmission may change over the course of an outbreak. This can be scrutinized by first breaking cases into sub-clusters or blocks (as a default, two-week blocks of cases) and then searching for connections to cases in the preceding block via shared activities, social networks, and building characteristics. Develop hypotheses to best fit transmission during that block of time;
- Use surface swabbing for viral RNA to confirm key transmission points, being aware that it can be difficult to detect a signal due to the passage of time, too many other hands having touched the surface, and/or cleaning before sampling can occur.

Video surveillance was used by both Lin et al.[5] and Kang et al.[4] to examine with whom cases interacted and for how long while using the elevator for the same outbreak. Although members of the first infected household rode the elevator with another person on three occasions (while wearing a mask), none of these people became ill. Even when cases rode the elevator without a mask, researchers were able to ascertain that no one using the elevator within the next 30 minutes had contracted the disease. Because residents used a security swipe card to command the elevator (i.e., no button pressing), it appears that neither common surfaces nor transmission via respiratory particles in the elevator played a role in this particular outbreak. It should be noted that these types of physical surveillance activities are time-consuming to review and may also raise privacy concerns.

Environmental sampling. Outbreak investigations have frequently made use of surface swabbing[37] and air sampling,[38] both to investigate the route of transmission and to ascertain whether there is a risk to other occupants. However, environmental sampling may provide only limited insight into the outbreak, for two reasons. First, the presence of viral RNA in the air or on surfaces does not necessarily mean that another person was infected, as transmission may have occurred in other (or multiple) ways. Second, the presence of the virus may be difficult to detect.

Dumont-Lelonde et al.[6] collected one aerosol and two surface samples from the rooms of 31 COVID-19 patients in a number of long-term care facilities. Although sampling occurred over four hours and at only a two-metre distance from the infected patient, none of the air samples contained a detectable amount SARS-CoV-2 RNA. The authors attributed this to either degradation during sampling and/or the general decline in viral RNA in the respiratory tract as the disease progresses. Importantly, however, about a third of the surface samples were positive for viral RNA, including "no-touch" surfaces (e.g., door frames and high shelves) that were out of the ballistic range of droplets. This indicates that a short-lived aerosol had been generated, but perhaps not at a rate high enough to be detectable through a 4-hour sampling period. Swabbing no-touch surfaces may in fact be a better indicator that respiratory particles were present at some point in time rather than attempting air sampling after the fact.

Surface sampling may also fail to detect virus due to factors like the passage of time, the number of other hands that have subsequently touched the surface, and frequent cleaning. Xie et al.[9] did extensive air and surface sampling in the elevator and two households involved in an outbreak. Air sampling detected no viral RNA, which was to be expected given that those infected had already been hospitalized three to six days prior. However, only one of 31 high-touch surfaces tested positive (front door handle of an affected unit) as all the remaining surfaces had been repeatedly cleaned. Experiences like this show that air and surface sampling may provide limited insight into an outbreak.

A notable exception to this is described in Kang et al.[4], who performed surface sampling in the bathroom of an apartment that had been unoccupied since roughly November 2019 (pre-outbreak and perhaps pre-pandemic). The working hypothesis was that plumbing stacks had provided a route for fecal aerosols from a lower floor apartment to rise up and infect two other apartments 10 floors above; if this were true, SARS-CoV-2 RNA might also be present in other units connected to the same stack. In fact, a combined swab of the shower switch, wash basin and faucet in the connected 16th floor bathroom revealed viral RNA, supporting their plumbing stack theory. This assumes that the unit was truly unoccupied and that there were no other means that contaminated air could have been drawn inside (e.g., bathroom windows were closed).

Air flow analyses. Two studies examined whether air was able to move in and out of vertically connected units through the plumbing stack. Lin et al.[5] used a relatively inexpensive thermal anemometer, which is typically used to measure air speed in ventilation ducts, to measure air speed just above the bathtub and floor drains in upstairs units. The authors found that flushing the toilet in the "source" apartment simultaneously increased air speed over bathroom drains in upstairs suites, which had been drained to allow air flow through. Lin et al.[5] followed this with multiple tracer gas experiments. In the first, chloroform and carbon tetrachloride[a] were poured into the floor drain in the "source" apartment; gas samples were then collected in two units above (but not below) the source apartment 30 and 60 minutes later. Intrusion was most severe in one bathroom that had a dried drain trap. In the same outbreak, Kang et al.[4] injected ethane gas into the toilet of the "source" apartment and demonstrated that the gas was detectable in the bathrooms both above and below the index case's home.

Further investigation by Lin et al.[5] found that the ventilation stack had been inappropriately modified in the top-floor apartment. The pipe had been reduced in diameter and re-routed through a 90° angle, which would impede air flowing up and out of the stack. A second set of tracer gas experiments was conducted in an unmodified stack and found that no tracer gas was detectable in the upstairs apartments after 30 or 60 minutes. Taken together, these two studies of an outbreak in a Guangzhou MURB provide fair evidence that air was able to flow from one bathroom to another via the plumbing stacks. In the absence of evidence demonstrating actual viral aerosols travelling the same path (impossible to collect after the fact and inadvisable to re-create), genome sequencing linking all three households suggests that this did indeed occur.

For further useful information on air leakage analysis in MURBs, please see Lozinksy and Touchie.[21] Resources for controlling air leakage are provided by the Canada Mortgage and Housing Corporation.[26]

Computational fluid dynamics is a science that seeks to model or predict the movement of fluids (in this case, a gas bearing virus-laden aerosols) in an enclosed space based on the boundary conditions created by various surfaces and in accordance with the laws of thermodynamics. Although CFD modelling may be considered a somewhat resource-intensive endeavour in terms of computing power and sourcing the appropriate expertise, it can be extremely useful to test hypotheses regarding flows from A to B. Furthermore, the ability to visualize those flows is extremely valuable for communicating risk and for devising appropriate interventions. Kang et al.[4] used CFD modelling to estimate the pressure within bathrooms due to wind effects, finding that the affected suites were at negative pressure and were likely to have drawn in air through the drain trap. This information and the accompanying visual were a useful means to unite the various data sources in support of their proposed route of transmission.

Contextualizing the risk of MURB outbreaks and appropriate risk mitigation measures

This review suggests that plumbing stacks, as well as air flow between units driven by natural forces such as the stack effect and the wind, may pose a risk of indirect transmission in a MURB. However, given the vast numbers of people (and COVID-19 cases) that are housed in MURBs, the scarcity of documented incidents suggests that such events are rare. More such events have probably occurred, and either have not yet been published or were not fully investigated. Even so, MURB outbreaks due to indirect transmission do not appear to have contributed significantly to the pandemic.

Indirect transmission in MURBs is rare, but concern around this issue is high, especially given the spread of SARS-CoV-2 variants of concern.[39] Although the risk of indirect transmission is low, the following precautionary measures should be considered as general measures to support occupant health.

[a] Given that these substances are toxic and malodourous, they should not be used if other units on the stack are still occupied.

Reinforce public health measures. The most important means to prevent transmission within MURBs is to limit the most common cause of transmission (close contact) by preventing gatherings and limiting occupancy of shared spaces. Managers must also maintain enhanced cleaning programs and continue engaging occupants on other standard public health measures, like hand hygiene and mask use. Due to "pandemic fatigue," it may be necessary to periodically refresh communications strategies to sustain occupant engagement. The World Health Organization has created resources to address this serious challenge.[40]

Ensure that building systems are working as intended. A properly maintain HVAC system is critical for supplying fresh air and removing stale or contaminated air. In older buildings dependent on corridor pressurization, HVAC is also critical for maintaining air flow and pressure differentials such that contaminated air from a suite does not leak into the corridor. Similarly, plumbing stacks need regular cleaning to ensure that wastewater can flow and that neither wastewater nor air can inadvertently backflow into bathroom or kitchen fixtures. The World Health Organization[41] and ASHRAE[42] have provided detailed technical resources for pandemic ventilation in MURBs; the same level of resources are not available for plumbing stacks.

Encourage residents to open windows. Opening windows to increase natural ventilation and reduce the risk of transmission within households has been a key public health recommendation since the beginning of the pandemic.[43] In high-occupancy settings, simply opening a window can greatly increase air exchange and reduce the presence of respiratory particles, leading to an overall decrease in transmission risk.[44,45] However, as suggested by two outbreaks here, air pushing through the building envelope can affect interior pressures and may result in contaminated air flow between units. This may be exacerbated by one or more units opening windows. Nevertheless, because household transmission remains a much more common cause of COVID-19, **window opening should be encouraged as much as possible**.

Conclusions

Public health orders related to quarantine and self-isolation have assumed that these practices can be carried out safely in condos and apartment buildings, and in the vast majority of cases this is true. Although several MURB outbreaks been published, these incidents appear to be rare given the vast number of people housed in MURBs. The studies reviewed here suggested that exposure via shared elevators and passive air flows through plumbing stacks could have led to SARS-CoV-2 transmission, but assessment of these routes was cursory (in most cases) and potential transmission from the surrounding community poorly assessed. Although a number of environmental analyses were employed, these analyses served to test hypothesized routes (i.e., what might have happened) rather than to confirm how transmission happened in fact. Nevertheless, these highly unusual cases are useful to increase mindfulness regarding the complex but often invisible building systems that play such a critical role in a healthy indoor environment. The data suggest that continuing standard public health measures paired with good building maintenance will help to keep MURB occupants safe in their homes.

Acknowledgements

The author would like to acknowledge the expert contributions of Tom Kosatsky (BC Centre for Disease Control), JinHee Kim, Vince Spilchuk, Sue Keller-Olaman, and James Johnson of Public Health Ontario, Diana Bark (Public Health and Preventive Medicine Resident, UBC), and Michele Wiens and Juliette O'Keeffe from the NCCEH.

References

1. Eykelbosh A. COVID-19 Precautions for multiunit residential buildings. Vancouver, BC: National Collaborating Centre for Environmental Health; 2020 Mar 31. Available from: https://ncceh.ca/documents/guide/covid-19-precautions-multi-unit-residential-buildings.
2. British Columbia Centre for Disease Control. COVID-19 Monthly Update: November 12th, 2020. Vancouver, BC: BCCDC; 2021 [updated Jan 5]; Available from: https://news.gov.bc.ca/files/COVID19_Monthly_Update_Nov_2020.pdf.
3. Public Health Agency of Canada. Updated: Public health management of cases and contacts associated with COVID-19. Ottawa, ON: PHAC; 2020 Dec 23. Available from: https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection/health-professionals/interim-guidance-cases-contacts.html.
4. Kang M, Wei J, Yuan J, Guo J, Zhang Y, Hang J, et al. Probable evidence of fecal aerosol transmission of SARS-CoV-2 in a high-rise building. Ann Intern Med. 2020. Available from: https://doi.org/10.7326/M20-0928.
5. Lin G, Zhang S, Zhong Y, Zhang L, Ai S, Li K, et al. Community evidence of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) transmission through air. Atmos Environ. 2021 Feb;246:118083. Available from: https://www.sciencedirect.com/science/article/pii/S1352231020308153.
6. Dumont-Leblond N, Veillette M, Bhérer L, Boissoneault K, Mubareka S, Yip L, et al. Positive no-touch surfaces and undetectable SARS-CoV-2 aerosols in long-term care facilities: an attempt to understand the contributing factors and the importance of timing in air sampling campaigns. Am J Infect Control. 2021 Feb. Available from: https://doi.org/10.1016/j.ajic.2021.02.004.
7. Dbouk T, Drikakis D. On airborne virus transmission in elevators and confined spaces. Phys Fluids. 2021;33(1):011905. Available from: https://aip.scitation.org/doi/abs/10.1063/5.0038180.
8. Liu J, Huang J, Xiang D. Large SARS-CoV-2 outbreak caused by asymptomatic traveler, China. Emerg Infect Dis. 2020 Sep;26(9). Available from: https://www.ncbi.nlm.nih.gov/pubmed/32603652.
9. Xie C, Zhao H, Li K, Zhang Z, Lu X, Peng H, et al. The evidence of indirect transmission of SARS-CoV-2 reported in Guangzhou, China. BMC Public Health. 2020 2020/08/05;20(1):1202. Available from: https://doi.org/10.1186/s12889-020-09296-y.
10. Luongo JC, Fennelly KP, Keen JA, Zhai ZJ, Jones BW, Miller SL. Role of mechanical ventilation in the airborne transmission of infectious agents in buildings. Indoor Air. 2016;26(5):666-78. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/ina.12267.
11. Zhu S, Jenkins S, Addo K, Heidarinejad M, Romo SA, Layne A, et al. Ventilation and laboratory confirmed acute respiratory infection (ARI) rates in college residence halls in College Park, Maryland. Environ Int. 2020 2020/04/01/;137:105537. Available from: https://www.sciencedirect.com/science/article/pii/S0160412019341108.
12. Leal J, Gagnon H. Has there been documented transmission of SARS-CoV-2 virus (or similar viruses) through Heating, Ventilation, and Air Conditioning (HVAC) systems in hospitals or nonhospital settings? Edmonton, AB: Alberta Health Services; 2020 Jun. Available from: https://www.hsdl.org/?abstract&did=841326.
13. de Man P, Paltansing S, Ong DSY, Vaessen N, van Nielen G, Koeleman JGM. Outbreak of COVID-19 in a nursing home associated with aerosol transmission as a result of inadequate ventilation. Clin Infect Dis. 2020 Aug 28. Available from: https://www.ncbi.nlm.nih.gov/pubmed/32857130.
14. Nissen K, Krambrich J, Akaberi D, Hoffman T, Ling J, Lundkvist Å, et al. Long-distance airborne dispersal of SARS-CoV-2 in COVID-19 wards. Sci Rep. 2020;10(1):19589. Available from: https://www.nature.com/articles/s41598-020-76442-2.
15. Horve PF, Dietz L, Fretz M, Constant DA, Wilkes A, Townes JM, et al. Identification of SARS-CoV-2 RNA in healthcare heating, ventilation, and air conditioning units. medRxiv. 2020 Jun. Available from: https://www.medrxiv.org/content/medrxiv/early/2020/06/28/2020.06.26.20141085.full.pdf.
16. Pease LF, Wang N, Salsbury TI, Underhill RM, Flaherty JE, Vlachokostas A, et al. Investigation of potential aerosol transmission and infectivity of SARS-CoV-2 through central ventilation systems. Build Environ. 2021 2021/01/29/:107633. Available from: https://www.sciencedirect.com/science/article/pii/S0360132321000457.

17. Kwon K-S, Park J-I, Park YJ, Jung D-M, Ryu K-W, Lee J-H. Evidence of long-distance droplet transmission of SARS-CoV-2 by direct air flow in a restaurant in Korea. J Korean Med Sci. 2020 11/;35(46). Available from: https://doi.org/10.3346/jkms.2020.35.e415.
18. Li Y, Qian H, Hang J, Chen X, Hong L, Liang P, et al. Evidence for probable aerosol transmission of SARS-CoV-2 in a poorly ventilated restaurant. medRxiv. 2020 2020-04-22:Apr. Available from: https://doi.org/10.1101/2020.04.16.20067728.
19. Shen Y, Li C, Dong H, Wang Z, Martinez L, Sun Z, et al. Community outbreak investigation of SARS-CoV-2 transmission among bus riders in Eastern China. JAMA Intern Med. 2020 Dec 1;180(12):1665-71. Available from: https://doi.org/10.1001/jamainternmed.2020.5225.
20. Brlek A, Vidovič Š, Vuzem S, Turk K, Simonović Z. Possible indirect transmission of COVID-19 at a squash court, Slovenia, March 2020: case report. Epidemiol Infect. 2020;148:e120-e. Available from: https://doi.org/10.1017/s0950268820001326.
21. Lozinsky CH, Touchie MF. Inter-zonal airflow in multi-unit residential buildings: A review of the magnitude and interaction of driving forces, measurement techniques and magnitudes, and its impact on building performance. Indoor Air. 2020;30(6):1083-108. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/ina.12712.
22. Chirico F, Sacco A, Bragazzi NL, Magnavita N. Can air-conditioning systems contribute to the spread of SARS/MERS/COVID-19 Infection? Insights from a rapid review of the literature. Int J Environ Res Public Health. 2020;17(17). Available from: https://dx.doi.org/10.3390%2Fijerph17176052.
23. Wong TW, Lee CK, Tam W, Lau JT, Yu TS, Lui SF, et al. Cluster of SARS among medical students exposed to single patient, Hong Kong. Emerg Infect Dis. 2004 Feb;10(2):269-76. Available from: https://doi.org/10.3201/eid1002.030452.
24. Li Y, Huang X, Yu IT, Wong TW, Qian H. Role of air distribution in SARS transmission during the largest nosocomial outbreak in Hong Kong. Indoor Air. 2005 Apr;15(2):83-95. Available from: https://doi.org/10.1111/j.1600-0668.2004.00317.x.
25. Ricketts L, Finch G. Airflow in high-rise multi-unit residential buildings with respect fo ventilation and IAQ. ASHRAE IAQ 2013 Proceedings: Environmental health in low energy buildings Peachtree Corners, GA: ASHRAE; 2017. Available from: https://www.rdh.com/wp-content/uploads/2017/07/ASHRAEIAQ-2013-Airflow-in-High-rise-Multi-unit-Residential-Buildings.pdf.
26. Canada Mortgage and Housing Corporation. . Ottawa O. Air leakage control for multi-unit residential buildings. Ottawa, ON: CMHC; 2017 Mar. Available from: https://www.agency.coop/media/747/download.
27. Mao J, Gao N. The airborne transmission of infection between flats in high-rise residential buildings: a review. Build Environ. 2015 2015/12/01/;94:516-31. Available from: https://www.sciencedirect.com/science/article/pii/S0360132315301359.
28. Wu Y, Tung TCW, Niu J-l. On-site measurement of tracer gas transmission between horizontal adjacent flats in residential building and cross-infection risk assessment. Build Environ. 2016 2016/04/01/;99:13-21. Available from: http://www.sciencedirect.com/science/article/pii/S0360132316300130.
29. Hwang SE, Chang JH, Oh B, Heo J. Possible aerosol transmission of COVID-19 associated with an outbreak in an apartment in Seoul, South Korea, 2020. Int J Infect Dis. 2021 2021/03/01/;104:73-6. Available from: https://www.sciencedirect.com/science/article/pii/S1201971220325583.
30. Chen Y, Chen L, Deng Q, Zhang G, Wu K, Ni L, et al. The presence of SARS-CoV-2 RNA in the feces of COVID-19 patients. J Med Virol. 2020;92(7):833-40. Available from: https://doi.org/10.1002/jmv.25825.
31. Liu Y, Ning Z, Chen Y, Guo M, Liu Y, Gali NK, et al. Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. Nature (London). 2020;582(7813):557-60. Available from: https://www.nature.com/articles/s41586-020-2271-3.
32. Nicol A-M. Public washrooms in the time of COVID-19: Facility features and user behaviours can influence safety [blog]. Vancouver, BC: National Collaborating Centre for Environmental Health; 2020 Sep 22. Available from: https://ncceh.ca/content/blog/public-washrooms-time-covid-19-facility-features-and-user-behaviours-can-influence.
33. McKinney K, Gong Y, Lewis T. Environmental transmission of SARS at Amoy Gardens. J Environ Health. 2006;68:26-30; quiz 51. Available from: https://pubmed.ncbi.nlm.nih.gov/16696450/.

34. Yu ITS, Li Y, Wong TW, Tam W, Chan AT, Lee JHW, et al. Evidence of airborne transmission of the severe acute respiratory syndrome virus. N Engl J Med. 2004;350(17):1731-9. Available from: https://www.nejm.org/doi/full/10.1056/nejmoa032867.

35. Shi K-W, Huang Y-H, Quon H, Ou-Yang Z-L, Wang C, Jiang SC. Quantifying the risk of indoor drainage system in multi-unit apartment building as a transmission route of SARS-CoV-2. Sci Total Environ. 2021 2021/03/25/;762:143056. Available from: https://www.sciencedirect.com/science/article/pii/S0048969720365864.

36. US Centers for Disease Control and Prevention. Investigating an outbreak. Principles of epidemiology in public health practice (3rd ed). Atlanta, GA: US Department of Health and Human Services; 2006. Available from: https://www.cdc.gov/csels/dsepd/ss1978/lesson6/section1.html.

37. World Health Organization. Surface sampling of coronavirus disease (COVID-19): a practical "how to" protocol for health care and public health professionals. Geneva, Switzerland: WHO Headquarters; 2020 Feb. Available from: https://apps.who.int/iris/handle/10665/331058.

38. Rahmini AR, Leili M, Azarian G, Poormohammadi A. Sampling and detection of corona viruses in air: a mini review. Sci Total Environ. 2020 2020;740. Available from: https://doi.org/10.1016/j.scitotenv.2020.140207.

39. O'Keeffe J, Freeman S, Nicol A-M. An introduction to SARS-CoV-2. Vancouver, BC: National Collaborating Centre for Environmental Health; 2020 Jul. Available from: https://ncceh.ca/documents/evidence-review/introduction-sars-cov-2.

40. World Health Organization. Pandemic fatigue. Reinvigorating the public to prevent COVID-19. Copenhagen, Denmark: WHO Regional Office for Europe; 2020. Available from: https://apps.who.int/iris/bitstream/handle/10665/335820/WHO-EURO-2020-1160-40906-55390-eng.pdf.

41. World Health Organization. Roadmap to improve and ensure good indoor ventilation in the context of COVID-19. Geneva, Switzerland: WHO Headquarters; 2021 Mar 1. Available from: https://www.who.int/publications/i/item/9789240021280.

42. ASHRAE Epidemic Task Force. Guidance for residential buildings: ASHRAE Epidemic Task Force; 2020 Oct 5. Available from: https://www.ashrae.org/file%20library/technical%20resources/covid-19/guidance-for-residential-buildings.pdf.

43. Public Health Agency of Canada. Guidance on indoor ventilation during the pandemic. Ottawa, ON: PHAC; 2021 Jan 18. Available from: https://www.canada.ca/en/public-health/services/diseases/2019-novel-coronavirus-infection/guidance-documents/guide-indoor-ventilation-covid-19-pandemic.html.

44. Bartzokas N, Grondahl M, Patanjali K, Peyton M, Saget B, Syam U. Why ventilation is a key to reopening schools safely. 2020 Feb 26. Available from: https://www.nytimes.com/interactive/2021/02/26/science/reopen-schools-safety-ventilation.html.

45. Abuhegazy M, Talaat K, Anderoglu O, Poroseva SV. Numerical investigation of aerosol transport in a classroom with relevance to COVID-19. Phys Fluids. 2020;32(10):103311. Available from: https://aip.scitation.org/doi/abs/10.1063/5.0029118.

46. Government of the Hong Kong Special Administrate District Department of Health (Centre for Health Protection). Latest progress in follow up on novel coronavirus infection in Hong Mei House, Cheung Hong Estate. Hong Kong: Government of Hong Kong; 2020 Feb 11. Available from: https://www.info.gov.hk/gia/general/202002/11/P2020021100768.htm.

47. Government of the Hong Kong Special Administrate District Department of Health (Centre for Health Protection). CHP follows up on two cases of novel coronavirus infection in Hong Mei House, Cheung Hong Estate. Hong Kong: Government of Hong Kong; 2020 Feb 11. Available from: https://www.info.gov.hk/gia/general/202002/11/P2020021100063.htm.

48. North Bay Parry Sound District Health Unit. COVID-19 outbreak at Skyline-Lancelot apartments North Bay, ON: North Bay Parry Sound District Health Unit; 2021 Mar 22. Available from: https://www.myhealthunit.ca/en/health-topics/covid-19-outbreak-at-skyline-lancelot-apartments.asp.

49. Alberta Health Services, COVID-19 Scientific Advisory Group. Topic: Have clusters of COVID-19 over time been described in condos, apartments and/or hotels? What are the most commonly hypothesized mechanisms of transmission? [Rapid evidence brief]. Edmonton, AB: Alberta Health; 2020 Jul 16. Available from: https://www.albertahealthservices.ca/assets/info/ppih/if-ppih-covid-19-sag-transmission-in-condo-or-apartment-buildings-rapid-review.pdf.

50. Quon A, Smith C. Moncton landlord confirms 6 COVID-19 cases at apartment complex. Global News New Brunswick. 2021 Jan 28. Available from: https://globalnews.ca/news/7605690/moncton-landlord-covid-19-complex/.
51. British Broadcasting Corporation (BBC). Coronavirus: Extra police enforce German tower block quarantine. BBC News. 2021 Jun 22. Available from: https://www.bbc.com/news/world-europe-53131941.
52. Galloway H. Covid-19 in Spain: Architecture of an outbreak: the Spanish apartment building hijacked by the coronavirus. El PAIS. 2021 Feb 15. Available from: https://english.elpais.com/society/2021-02-15/architecture-of-an-outbreak-the-spanish-apartment-building-hijacked-by-the-coronavirus.html.
53. Kang YJ. Lessons learned from cases of COVID-19 infection in South Korea. Disaster Med Public Health Prep. 2020 May 7:1-8. Available from: https://doi.org/10.1017/dmp.2020.141.
54. ABP News Bureau. Bengaluru cluster update Karnataka imposes restrictions on travel from Kerala check details here. ABP Live India. 2021 Feb 17. Available from: https://news.abplive.com/news/bengaluru-covid-update-karnataka-imposes-restrictions-on-travel-from-kerala-check-details-here-1444548.
55. Times Now Digital Staff. Gurugram: Condominium declared containment zone after 19 residents test Covid-19 positive in Sector 67. Times Now Digital. 2021 Feb 21. Available from: https://www.timesnownews.com/delhi/article/gurugram-condominium-declared-containment-zone-after-19-residents-test-covid-19-positive-in-sector/725848.
56. Maui Coronavirus Updates. Harbor lights COVID-19 cluster now at 97 cases. Maui Now. 2021 Jan 12. Available from: https://mauinow.com/2021/01/12/harbor-lights-covid-19-cluster-now-at-97-cases/.

Table 1. Published MURB outbreaks involving suspected indirect transmission from January 2020 to March 2021.

Study	Location (Approx. Date)	Total Cases	Details	Proposed Route of Transmission
Hwang et al.[29]	Seoul, South Korea (August 2020)	10 cases in 7 households. Tested 437 residents in 267 households in a 15-floor MURB	Epidemiological survey revealed some cases had not used the elevators and all wore masks outside their homes. Mapping revealed all cases aligned in two vertical columns on one side of the building. Unclear whether the duct was an actual natural ventilation shaft or a ventilation stack cross-connected with the drains. Surface swabbing did not detect viral RNA on ventilation grilles or drains, but unclear where samples were taken. No air sampling performed. No genomic sequencing to link cases.	**Respiratory particles travelled through a passive ventilation duct** connecting the bathrooms of affected households, located in two vertical columns on one side of the building. Unclear how virus jumped from one column to another. Transmission within the seven households assumed to be direct contact. Although the vertical distribution of affected units was striking, negative surface swabs of ventilation grills contradict proposed route, and no additional analyses conducted to verify this or exclude other routes.
Kang et al.[4]	Guangzhou, China (January to February 2020)	9 cases in 3 households out of 202 residents in 57 households) in a 29-floor MURB. 26 units unoccupied and 24 building staff	Epidemiological survey revealed no contact among affected households. Mapping revealed that the master bathrooms of all three units were aligned vertically on same plumbing stack. Elevator usage was initially suspected but ruled out using video surveillance. Extensive surface sampling in units and common areas negative, except from source bathroom and vertically adjacent unoccupied bathroom; air sampling negative. Telephone survey revealed infrequent filling of drain traps or bathtub use. Tracer gas released into source toilet revealed gas penetration through to all affected suites on upper floors, and one below; water in the drain traps moderated but did not eliminate this flow. Wind direction analysis and CFD modelling estimated pressure differences in the bathrooms vs. exterior of the building during the exposure window that would have facilitated aerosol movement.	**Fecal aerosol travelled upward through the plumbing stacks a**nd into two other households through dried drain traps, assisted by the creation of negative pressure in affected units due to the use of exhaust fans and/or being on the leeward side of the building that day. Transmission within the three households could have also included direct contact.

Lin et al.[5]	Guangzhou, China (January to February 2020)	Outbreak also covered by Kang et al.[4]	Epidemiological survey revealed no direct contact; genome sequencing linked all cases to the same strain. Mapping revealed all units on the same plumbing stack with a modified vent outlet that would impede air flow. Residents of all non-affected units were moved to a quarantine hotel. Video surveillance used to rule out concurrent elevator use. One member of the third affected household did ride the elevator 8 min after two pre-symptomatic members of the index household rode without masks, but onset of symptoms did not support infection on this date. Air flow measurements over bathroom drains revealed surge of air when source toilet was flushed; air flow supported by multiple tracer gas studies. Comparison tracer gas study in a stack with an original, non-altered outlet showed no inappropriate air flow.	**See above.**
Xie et al.[9]	Guangzhou, China (January to February 2020)	5 cases in 2 households, out of 61 residents in 40 households 14 security guards and janitors	Epidemiological survey revealed no contact among affect households. Only tested 24 households out of 40. Air and extensive surface sampling of primarily the elevators, but also common areas and homes of infected. Only one surface (door handle of affected unit) tested positive. Elevator had been disinfected several times before samples could be taken.	**Fomite transmission** occurred in the elevator button when one user blew his nose into his hand, touched an elevator button, and left; another person living on his floor then entered the elevator, touched the same button, and picked his teeth. Unclear how time-specific information on elevator use was obtained. Aerosol transmission while in the elevator was not ruled out. Many people within the building appear to not have been included in the investigation, so cannot rule out other sources of exposure.
Liu et al.[8]	Heilongjiang Province, China (March to April 2020)	72 cases beginning in a MURB and spreading to 2 hospitals	Epidemiological survey revealed no contact between assumed index case and larger cluster, except a (presumed?) shared elevator ride. Time and date of shared elevator ride not confirmed. No environmental analyses. Genome sequencing among larger cluster revealed strain not currently circulating in China (but was in US). Unclear if proposed index case provided a sample for genome sequencing to confirm linkage to larger outbreak.	**Fomite or respiratory particle transmission (shared elevator)** Asymptomatic person recently returned from US believed to have transmitted the virus during an elevator ride to one other building occupant via respiratory particles. Remaining transmissions occurred through direct contact.

Table 2. Selection of suspected MURB outbreaks reported in the media from January 2020 to March 2021.

Source	Building	Cases	Proposed Route of Transmission and Other Details
Government of Hong Kong	Hong Mei House, Hong Kong	2 cases in vertically aligned units, 10 floors apart	Scarce details but noted that a plumbing vent had been inappropriately modified.[46,47] Public advised to keep drain traps filled and close toilet lids while flushing.
North Bay Parry Sound District Health[48]	Skyline Lancelot Apartments, North Bay, Ontario	42 cases, 3 deaths (ongoing)	No information on transmission route. 15 of the cases were the "South African" variant of concern (B.1.351).
Alberta Health Services[49]	Verve, Calgary, AB	58 cases	Droplet and fomite transmission in the elevators was suspected, as cases were somewhat clustered on higher floors on one side of the building. However, the role of HVAC systems and plumbing stacks were also considered.[49]
Media report[50]	Lorentz Drive Apartments, Moncton, NB	6 (ongoing)	No information on transmission route. Property managers advised to increase environmental cleaning and limit access to shared areas to 1 person at a time.
Media report[51]	Gottingen, Germany	120 cases	Attributed to overcrowded apartments, but not clear what caused spread among apartment, or whether transmission could have happened outside the building and been brought home.
Media report[52]	Apartment building in Bilbao, Spain	33 cases, 6 deaths	Attributed to shared elevators.
Kang 2020[53]	Apartment building in Gangdong-gu, South Korea	2 cases	Attributed to shared elevator and no mask use during personal interaction not meeting the definition of "close contact".
Media report[54]	Bengaluru, India	103 cases	Group of residents attended a social function in the complex clubhouse.
Media report[55]	Gurugram, India	19 cases	Some residents attended a party outside of the apartment complex; however, spread may have continued within complex due to lack of physical distancing.
Media report[56]	Harbour Lights Complex, Kahului, USA	97 cases	Some residents participated in a singing event; spread appears to have continued inside and outside of the building.

March 24, 2021

ISBN: 978-1-988234-57-1

To provide feedback on this document, please visit www.ncceh.ca/en/document_feedback

This document can be cited as: Eykelbosh, A. Contextualizing the risks of indirect COVID-19 transmission in multi-unit residential buildings. Vancouver, BC: National Collaborating Centre for Environmental Health. 2021 March.

 Production of this document has been made possible through a financial contribution from the Public Health Agency of Canada through the National Collaborating Centre for Environmental Health.

National Collaborating Centre for Environmental Health
Centre de collaboration nationale en santé environnementale

655 W. 12th Ave., Vancouver, BC, V5Z 4R4
contact@ncceh.ca | www.ncceh.ca