Climate change and opportunistic pathogens (OPs) in the built environment

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Introduction

Climate change is predicted to have diverse impacts on the natural and built environment, including the aquatic habitats that exist in towns and cities. Within built infrastructure, the water distribution lines, premise plumbing, pools, spas, and green infrastructure can harbour a range of opportunistic pathogens (OPs), such as *Legionella*, *Mycobacteria*, and *Pseudomonas* spp., that can cause serious infections and disease outbreaks among exposed, susceptible persons. Water in ponds, ditches, or even roadside puddles can also be reservoirs where these organisms can grow and subsequently be dispersed. In Canada, the only notifiable OP-related disease is legionellosis (including Pontiac fever and Legionnaires' disease (LD)), caused by *Legionella*. Legionellosis cases in Canada have risen from an average of 0.29 per 100,000 persons before 2010 to over 1.7 in 2018 and 2019 (Government of Canada, 2021). In Ontario, just three OPs, nontuberculous mycobacterium (NTM), *Legionella* spp., and *Pseudomonas* spp., represented 83% of hospitalizations and 97% of deaths attributable to a known waterborne pathogen (Greco et al., 2020). In the United States, the estimated cost of treating diseases caused by these OPs range from around $1.5 to $2.4 billion per year, and NTM-related infections are increasing (Donohue et al., 2015; Falkinham, 2020; Proctor et al., 2022) as are cases of legionellosis in many other countries (Cassell et al., 2021; Fischer et al., 2022; Fukushima et al., 2021). This may be further exacerbated by climate change (Health Canada, 2022). Climate change may affect the survival and propagation of OPs in the built environment and affect routes of transmission and patterns of exposure in numerous ways. The key drivers of change for growth and transmission of OPs in the built environment thus need further examination. This paper reports on the findings of a rapid review of the literature on how climate change could influence the spread of OPs in urban centres.

Characteristics and epidemiology of OPs

Various terms are used to describe waterborne pathogens that colonize building water systems and cause infection among exposed susceptible persons. These are sometimes referred to as OPs, opportunistic premise plumbing pathogens, or drinking water–associated pathogens that cause infection (Falkinham et al., 2015a; Hayward et al., 2022; Proctor et al., 2022). In this paper, the term "OP" will be used to refer to these microorganisms that are naturally occurring in soils, surface waters, and groundwater but thrive in the built environment in distribution and premise plumbing systems (Schwake et al., 2021). A brief description of three primary OPs (*Legionella* spp., *Mycobacterium* spp., and *Pseudomonas* spp.) and the infections they cause is provided in Table 1. Common characteristics of OPs include a preference for warm water (e.g., 25–40 °C), some resistance to elevated temperatures (e.g., ~50–60 °C) and disinfection, and the ability to form or join biofilms within pipes and plumbing fixtures (Falkinham et al., 2015b; Hayward et al., 2022). Biofilms, which are an assemblage of microbial cells, polysaccharides, minerals, nutrients, debris, and silt, allow OPs to colonize plumbing and shelter themselves from disinfection (Donlan, 2002). OPs can also live within free-living amoeba, which lend OPs mobility while shielding them from disinfection (Atanasova et al., 2018). Some OPs can enter a viable but non-culturable state when growth conditions are sub-optimal, allowing microbes to survive harsh conditions and evade detection (Falkinham et al., 2015b; Hayward et al., 2022). OPs differ from other types of waterborne pathogens, such enteric bacteria like *E. coli*, which are removed by water treatment and typically do not re-emerge (Falkinham, 2020). In contrast, OPs can increase in concentration as water travels from its source to point of use (POU), as conditions within pipework, such as temperature, presence of biofilms, and reduced competition with enteric bacteria, can favour survival and growth.

OPs are more likely to affect people with risk factors such as older age, immunodeficiency, cancer, respiratory conditions, smoking, and diabetes (Falkinham, 2020). Socioeconomic factors including race, neighbourhood poverty, and some occupations (e.g., outside construction, cleaning, or roadside workers) are associated with elevated rates of legionellosis, and this disparity seems to be worsening (Barskey et al., 2022; Farnham et al., 2014).

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 DOI: 10.5864/d2022-016 Published on 13 October 2022

Table 1: Characteristics of selected opportunistic pathogens (OPs) of concern in Canada.

***Legionella* spp.**
Description: Gram-negative bacteria, found in natural water systems and soils, have been detected in most large building water systems and some 10%–30% of home water systems in the United States. *Legionella* bacteria can be present in water storage containers, pipes, or outlets. **Optimal growing conditions:** Preference for warm water (e.g., 25–45 °C), high water age, low disinfectant residual, and often associated with biofilms or free-living amoeba (FLA). **Routes of transmission:** Inhalation or accidental aspiration of aerosolized contaminated water droplets into the lungs from faucets, showerhead, water misters, decorative fountains, hot tubs, cooling towers, etc. **Outcome of infection:** Legionellosis, includes Legionnaires' disease (LD), a severe pneumonia with a fatality rate of about 10%, and Pontiac fever, a milder flu-like illness. *L. pneumophila* is the cause of most cases of LD. **Groups most at risk:** Smokers, over-50s, men, immune-compromised persons, and those with conditions like chronic obstructive pulmonary disease, coronary artery disease, dementia, diabetes, kidney disease, and neurological diseases.
***Pseudomonas* spp.**
Description: Gram-negative bacteria that can form or join biofilms and colonize plumbing. Found in building water system at point of use areas (e.g., faucets, drains, and showerheads) more often than distribution systems, and can colonize humidifiers, respiratory equipment, swimming pools, hot tubs, and water baths. **Optimal growing conditions:** Tolerate a range of temperatures (4–42 °C), with an optimum around 37 °C, and reduced virulence below 30 °C; optimal pH around 7.2 and tolerate low dissolved oxygen, low nutrient, and stagnant waters. Grow well in poorly disinfected systems, but also resist disinfectants and can survive in FLA. **Routes of transmission:** Direct ear and skin contact in swimming pools, hot tubs, and whirlpools; inhalation of aerosols dispersed from faucets, showerhead, etc.; indirect transfer from contaminated devices or fomites. More commonly found in plumbing fixtures than in distribution systems. **Outcome of infection:** Most infections (80%) associated with *P. aeruginosa* and *P. maltophila* range from minor eye, skin, and ear conditions (e.g., swimmer's ear), to bacteremia in immune-compromised individuals or other susceptible patients. A major cause of healthcare-acquired pneumonia, wound infections, and urinary tract infections, and a cause of morbidity and mortality for cystic fibrosis patients. **Groups most at risk:** Children with cystic fibrosis, hospitalized patients at risk of hospital-acquired pneumonia, newborns, burn patients, patients with invasive devices, and those with underlying pulmonary disease.
Nontuberculous mycobacterium (NTM)
Description: NTM are a group of more than 190 known species of OP found in natural waters and soil, and building water systems. Includes *Mycobacterium avium* complex, a group of related bacteria that includes both *M. avium* and *M. intracellulare*. **Optimal growing conditions:** Preference for warm waters, high organic carbon levels, and plastic pipe material. Can survive and replicate in biofilms and protozoa including FLA. *M. avium* can tolerate extremes of low pH, elevated temperature (50 °C), low nutrients, and micro-aerobic conditions (e.g., 6%–12% oxygen). **Routes of transmission:** Detected in tap, shower, and fountain water, exposure can occur from inhalation of aerosolized water during showering, bathing, drinking, hand washing, and dishwashing; direct contact with soil (gardening), and food. Most *M. avium* infections are community acquired. **Outcome of infection:** Various pulmonary and extrapulmonary diseases including chronic pulmonary infection, soft tissue or wound infections. *M. avium* can cause bacteremia in HIV-infected individuals, and cervical lymphadenitis in young children. **Groups most at risk:** Immunocompromised individuals such as HIV+/AIDS patients, cystic fibrosis patients, and elderly females.

References: Aw et al., 2022; BaoYing et al., 2022; Barskey et al., 2022; Bedard et al., 2016; Blanc et al., 2021; Brandsema et al., 2014; Cooley et al., 2020; Donohue et al., 2015; Falkinham et al., 2015a; Farnham et al., 2014; Fukushima et al., 2021; Hamilton et al., 2017; Leslie et al., 2021; Norton et al., 2020; Psoter et al., 2013; Thomson et al., 2020.

Exposure to OPs in the built environment is usually associated with premise plumbing (e.g., direct contact and inhalation of contaminated aerosols from taps, showerheads, flushed toilets) and cooling towers that release aerosols. Other environmental exposures can occur, such as inhalation of contaminated aerosols released from hot tubs, decorative water features, or wastewater treatment plants (Vermeulen et al., 2021; Wallet et al., 2022). While most legionellosis outbreaks are associated with cooling towers, the majority of cases are sporadic (Fisman et al., 2005; Passer et al., 2020). Most cases of *M. avium* infection are community acquired, and exposure to *Pseudomonas* in community facilities like pools or spas can be important sources of infection. Urban settings have an elevated risk of LD compared to non-urban settings (Passer et al., 2020), possibly due to more cooling towers and other sources of contaminated aerosols, and more people who can be exposed (e.g., drivers, pedestrians, outside workers) (Han, 2021).

Effects of a changing climate on OP growth and transmission

A changing climate is characterized by longer and more intense periods of elevated temperature and changing patterns of precipitation and storm events. Further examination of how broader environmental determinants of OP growth and transmission could change due to climate change is needed.

Increasing ambient temperature

Warming is expected to enhance survival and propagation of OPs in the natural and built environment (Blanc et al., 2021; Walker, 2018). Seasonal increases in legionellosis observed in the late summer to early autumn in the northern hemisphere may start earlier and last longer due to climate change (Alarcon Falconi et al., 2018; Fischer et al., 2022; Fukushima et al., 2021; Park et al., 2019). The association between warmer weather and incidence of legionellosis is well documented, and increased legionellosis cases may lag a period of elevated temperatures by several weeks (Beauté et al., 2016; Brandsema et al., 2014; Fisman et al., 2005; Han, 2019; Passer et al., 2020; Simmering et al., 2017). Warming has also been found to benefit NTM survival and growth (Blanc et al., 2021).

Temperature, however, does not correlate with elevated cases of legionellosis in all climates, particularly in hot, dry climates with low relative humidity (RH) as *Legionella* is sensitive to drying conditions (e.g., <50% RH) and UV inactivation (Beauté et al., 2016; Fisman et al., 2005; Han, 2019; Simmering et al., 2017). Humidity may enhance survival and transport of NTM in aerosols, which remain suspended longer (Blanc et al., 2021), and high RH has been observed to enhance survival of aerosolized *Legionella* (Prussin et al., 2017). Seasonal trends of legionellosis cases are more prominent in areas that experience more humid summers than in the drier regions (Barskey et al., 2022), and a positive association between elevated RH and incidence of legionellosis has also been found in several studies (Fisman et al., 2005; Gleason et al., 2016; Passer et al., 2020; Villanueva & Schepanski, 2019).

Rising ground temperatures may lead to elevated temperatures in water distribution pipes (Agudelo-Vera et al., 2020). Ambient soil temperature in urban centres can be warmer than in non-urban areas due to underground heat sources (e.g., cables, subways, underground parking) and heat-absorbing land cover like pavements, which could be made worse by climate change. The extent of warming would depend on pipe depth, size, and material, as well as flow velocity and residence time of water within the pipes (Agudelo-Vera et al., 2020), but climate warming could make it more difficult to maintain cool water temperatures (e.g., <20 °C) in the distribution system. This could lead to improved conditions for OPs' growth, formation of biofilms, and lower disinfectant residual (Blanc et al., 2021; Calero Preciado et al., 2021; Walker, 2018).

Warming within the premise plumbing could also be exacerbated by climate change. Temperature is one of the most important variables in the composition of plumbing microbiomes and is positively associated with densities of OP in pipes, taps, and showerheads (Dai et al., 2018; Lu et al., 2017). Maintaining water temperature below 25 °C or above 55 °C is often recommended for OP control in premise plumbing, but maintaining cold-water temperatures may become more difficult as buildings themselves become harder to cool.

Precipitation and storm events

Heavy precipitation, flooding, and storms could introduce contamination, such as nutrients and organic carbon, into source water and soils, improving conditions for OP growth, making source water harder to treat and changing patterns of dispersal and generation of environmental aerosols (Blanc et al., 2021; Gleason et al., 2016; Simmering et al., 2017). Rainfall shows a strong association with cases of legionellosis (Beauté et al., 2016; Braeye et al., 2020; Fisman et al., 2005; Garcia-Vidal et al., 2013; Gleason et al., 2016; Hicks et al., 2007; Mitsui et al., 2021; Passer et al., 2020). As with temperature, legionellosis cases lag several days to two weeks behind a precipitation event (Beauté et al., 2016; Braeye et al., 2020; Fisman et al., 2005; Passer et al., 2020). NTM infections have also been observed to rise following elevated rainfall in the preceding months; however, due to the long incubation time possible for NTM, a firm correlation is difficult to identify (Thomson et al., 2020). Collectively the literature suggest that warm, wet, and humid conditions increase risks of legionellosis and potentially other OP-related infections (Karagiannis et al., 2009; Simmering et al., 2017).

Storm events and wind may affect the survival, growth, and distribution of OPs. US states with high occurrence of hurricanes have higher prevalence of NTM lung disease, possibly due to increased aerosolization of NTM (Walker, 2018). Storm events can also transport windblown debris, which can contaminate cooling towers with organic matter that depletes disinfectant residuals, reduces dissolved oxygen, and allows for propagation of OPs (Brigmon et al., 2020). Wind can also facilitate dispersal of bioaerosols from more distant sources over large areas. Flooding events driven by increased rainfall have also been found to be associated with elevated legionellosis cases, which may be due to exposures to OP contaminated mud or aerosolized dust during clean up and remediation (European Center for Disease Prevention and Control (ECDC), 2021; Mitsui et al., 2021; Oda et al., 2019). Flooding can increase turbidity and nutrient content and decrease oxygen in receiving waters, which could increase NTM in surface waters and shallow groundwater, and generally enhance growing conditions for OPs while making water more difficult to treat (Blanc et al., 2021; Mapili et al., 2022; Zhang & Lu, 2021).

Effects of changing demand for cooling on OP growth and transmission

As climate change makes it harder to maintain cool temperatures within buildings, increased cooling demand is also leading to wider use of air conditioners, fountains, water misters, and green infrastructure intended to cool urban heat islands (e.g., green roofs and walls), which could in turn increase opportunities for exposure to OPs if not appropriately managed.

Air conditioning and cooling towers

Cooling towers used in evaporative cooling systems (e.g., air conditioning) are prone to colonization by *Legionella* bacteria and can produce aerosols that are dispersed from buildings over a wide area. They have been found to be a primary cause of legionellosis outbreaks (Crook et al., 2020; Prussin et al., 2017; Wallet et al., 2022). Warming and other environmental factors may favour colonization of cooling towers if not adequately maintained (O'Keeffe et al., 2020). This, coupled with more towers to address cooling demands, could lead to more legionellosis outbreaks, especially in densely populated urban centres.

Cooling by water

The use of misters that aerosolize water in public spaces like parks or public venues is on the rise. These systems can be colonized by OPs including *L. pneumophila* and *P. aeruginosa,* which can subsequently be aerosolized, with models indicating that *L. pneumophila* can stay airborne for around 3 min after dispersion, whereas *P. aeruginosa* can remain airborne for much longer (e.g., >45 min) (Masaka et al., 2021). Cooling stations using misters could become new sources of exposure. As the public seeks water-related recreation to keep cool during increasingly warm summers, recreational facilities could also be increasingly important sources of exposure. *Legionella* spp. and *P. aeruginosa* can be present in inadequately maintained hot tubs (Brousseau et al., 2012), and direct contact with water in swimming pools can be a source of *Pseudomonas* infection. Reports of outbreaks of *M. abscessus*, which causes hand and foot lesions, are rare, but increased use of facilities such as wading pools could also increase exposure to such emerging OPs (Carter et al., 2019).

Green infrastructure for urban cooling

The introduction of green infrastructure, such as living walls or green walls, is becoming more common in urban indoor and outdoor spaces to improve air quality and provide urban cooling and aesthetic benefits. These systems require a water distribution system to sustain the plants, which could serve as a reservoir and point source for OPs. There is limited evidence that these systems increase ambient exposures to OPs, particularly where low water temperatures are maintained and drip systems, rather than pressurized water systems are used (Fleck et al., 2020). Further study could assist in characterizing the growth and aerosolization of OPs in these systems as their use increases.

Effects of changing patterns of water consumption on OP growth and transmission

Production and distribution of potable water is a major source of energy consumption. In Ontario, municipal drinking water treatment and pumping accounts for around a fifth of municipal energy use (Environmental Commissioner of Ontario, 2017). Reducing energy consumption to combat climate change should therefore include water efficiency measures. Water scarcity during warm, dry weather is also driving a move towards water efficiency, water reuse, and rainwater harvesting. Changes in how communities use water can affect its microbial quality, and may affect opportunities for exposure to OPs.

Water age and water-efficient devices

Water-efficient behaviours, low-flow fixtures, and water-efficient devices reduce water demand from distribution systems or premise plumbing, increasing the amount of time water spends in the pipe, otherwise known as the "water age" (Agudelo-Vera et al., 2020; Blanc et al., 2021; Leslie et al., 2021). Higher water age is associated with reduced disinfectant residual, higher corrosion and scaling, decreased dissolved oxygen, increased organic carbon, elevated disinfection by-products, growth of biofilms, and presence of OPs (Cullom et al., 2020; Dai et al., 2018; Hong et al., 2012; Leslie et al., 2021; Logan-Jackson & Rose, 2021; Zhang & Lu, 2021). Intermittent use can temporarily increase water age, causing OP and biofilm growth, which can be remobilized by subsequent periods of heavier use, increasing exposure risks (Bedard et al., 2016; Leslie et al., 2021). Water-efficient devices, such as electronic faucets, have been linked to *P. aeruginosa* outbreaks in healthcare settings (Bedard et al., 2016). This may be associated with intermittent use, low flow, low pressure, and lack of temperature control, which can prevent hot water flushing. Other devices such as low-flow showerheads reduce water consumption using water-atomizing technology, which produces smaller water droplets. This could increase generation of aerosols and inhalable particles, but more research is needed to identify if this significantly enhances infection risk (Niculita-Hirzel et al., 2021, 2022).

Rainwater harvesting

Along with a drive for water efficiency, water scarcity and watering restrictions during summers are driving uptake of rainwater harvesting. Rainwater can be of variable quality, and detection of various OPs in roof-harvested rainwater, including *Legionella* spp., *Mycobacteria* spp., and *Pseudomonas*, has been reported widely in the literature (Blanc et al., 2021; Clements et al., 2019; Garner et al., 2018; Hamilton et al., 2017, 2019; Ley et al., 2020). Risks may vary by OP, weather, cleanliness of collection surfaces, storage containers, and type of water use (Blanc et al., 2021; Hamilton et al., 2017; Zhang et al., 2021b). Exposure to OPs in aerosolized rainwater could occur if used in cooling towers, spray irrigation, toilet flushing, or fire suppression (Garner et al., 2018). Many Canadian provincial and municipal jurisdictions have produced guidance on rainwater harvesting (e.g., Alberta Health, 2021), which should be updated and expanded as rainwater harvesting increases.

Mitigating the risks of OPs in the built environment

Climate change will likely drive a net increase in concentrations of OPs in the built environment and opportunities for exposure due to more favourable water conditions, changing cooling demands, and changing patterns of water use. Addressing these issues requires a review of the existing control measures to identify if, and how, these may be adapted.

Distribution systems

Controlling OPs in distribution systems has long relied on secondary disinfection using chloramine or chlorine to maintain a disinfectant residual (monochloramine or free chlorine) in distributed water and premise plumbing. The literature is extensive on the effectiveness of chloramine versus chlorine for control of *Legionella*, *Mycobacterium*, and *Pseudomonas* (Bedard et al., 2016; Donohue et al., 2015; Falkinham et al., 2015a; Garner et al., 2018; Lu et al., 2017; Masaka et al., 2021; Pfaller et al., 2022; Proctor et al., 2022; Tolofari et al., 2022). Overall, maintaining a disinfectant residual keeps OP concentrations low, compared with systems with no residual (Waak et al., 2018). *Pseudomonas* and *Mycobacterium avium* complex may be more resistant to residual disinfectants than *Legionella* spp. (Proctor et al., 2022) but effectiveness can vary by system characteristics such the type and condition of pipes (Hong et al., 2012), or the presence of nitrifying bacteria (Hong et al., 2012; Zhang et al., 2021a).

Climate change may make it more difficult to maintain disinfectant residuals in distributed water, as increased microbial growth, presence of organic carbon, and warming of water speed the decay of residuals (Blanc et al., 2021). However, higher dosing of disinfectants alone cannot be the solution, due to the potential formation of disinfection by-products (DBPs), including trihalomethane, haloacetic acid, and nitrogenous DBPs, which are known to have toxic or carcinogenic effects (Zhang & Lu, 2021). Warming could make balancing disinfectant dosing and prevention of DBP formation more difficult. Other controls may be needed such as upstream treatment to remove organic compounds that react with disinfectants to form DBPs, or better temperature controls to decrease loss of residual disinfection, and prevent growth of OPs (Agudelo-Vera et al., 2020).

Premise plumbing

Water management plans (WMP) can assist in controlling OPs in premise plumbing by identifying areas at risk for OP-colonization and for susceptible people to be exposed. This is where environmental public health professionals could work across disciplines (e.g., with building operators, engineers) to identify and reduce risks. Building operators may need to revise WMP more frequently in the context climate change to identify and address emerging risks. This may include increased use of thermal controls or POU treatments to reduce OPs or prevent colonization. Maintaining hot water temperature (e.g., to ≥ 55 °C), and periodic hot water flushing (e.g., ≥ 70 °C for a period of 30–60 min) could be used more frequently to reduce OP concentrations and prevent recolonization (Bedard et al., 2016). Ensuring faucets and showerheads are routinely cleaned (e.g., with a bleach solution) could also reduce opportunities for colonization at POU. While POU treatments such as UV treatment (Norton et al., 2020) or POU filters (Hayward et al., 2022) do not address the root causes of OP growth, they could further reduce exposure for susceptible persons, with micro or ultrafiltration membranes (e.g., <0.22 μm) being more effective than granular activated carbon filters (Norton et al., 2020). In the United Kingdom, there is a legal duty for landlords of residential property to assess the risk from exposure to *Legionella* to ensure tenant safety. Similar measures could be considered for residential rented properties in other jurisdictions, with guidance for landlords on how to address identified risks.

Design controls could seek to reduce water age by appropriately sizing pipes and storage systems, and regularly flushing systems during periods of low use. The growth of OPs and formation of biofilms can be influenced by the pipe materials and hydraulic conditions, the quality of the water (e.g., presence of nutrients or organic content), the type and concentration of disinfectant, and water temperature, which can affect chemical absorption, disinfectant decay, microbial growth, and competition (Calero Preciado et al., 2021). Understanding the effect of pipe materials on OP growth and transmission could also inform pipe choice in new buildings (Bedard et al., 2016; Cullom et al., 2020; Proctor et al., 2017; Prussin et al., 2017; Song et al., 2021).

At a municipal level, the use of cooling tower registries can improve knowledge of potential sources of exposure to OP in the built environment, encourage good maintenance practices, and facilitate inspections and monitoring programmes. This can reduce cooling tower associated outbreaks and assist with outbreak investigations. Further consideration of other important sources of exposure could be considered for inclusion in such registries (e.g., green walls or misting stations) if found to pose a public health risk in urban settings. Canadian jurisdictions that currently have cooling tower registries include the cities of Hamilton, Ontario, and Vancouver, British Columbia; the provinces of Quebec and New Brunswick; and buildings managed by Public Works and Government Services Canada, with Vancouver also including decorative water features in their registry.

Conclusions

Many interacting elements can affect the presence, proliferation, and likelihood of exposure to OPs in water systems, including climate warming, precipitation, humidity, increased air conditioning and need for cooling, and water efficiency measures. More study is needed to characterize the epidemiology of sporadic cases of OP-related illnesses to understand how this may be influenced by climate change. Being aware of emerging sources of exposure, such as harvested water systems, floodwaters and soils, and climatic conditions that cause periodic spikes in cases (e.g., warm, wet, and humid conditions), could improve epidemiological investigations and inform the design of control measures.

Upstream measures to protect source water and maintain high quality water within distribution networks can reduce downstream risks. Downstream measures to address risks face trade-offs in balancing water treatment objectives with other public safety concerns (e.g., scalding, DBPs, addressing cooling demands), and sustainability (water and energy conservation) (Cullom et al., 2020; Leslie et al., 2021). Some groups will be more at risk due to underlying conditions that increase infection risks or socioeconomic factors that increase exposures (Barskey et al., 2022; Farnham et al., 2014). Neighbourhood factors such as older homes with premise plumbing that is more conducive to OP growth or poorly insulated properties that are disproportionately affected by warming could require greater attention. Actions to prevent rising cases of OP-related infections driven by climate change could thus be directed towards the most at-risk buildings and persons. This could include targeting retrofit measures, raising awareness among at-risk groups (e.g., those with underlying health conditions, certain occupations, and neighbourhoods) of sources of exposure to OPs, and ways to reduce risks (Proctor et al., 2022). Reducing occurrence of OP-related infections will require periodic review and re-evaluation of control measures as we learn more about the effects of climate change on the built environment.

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