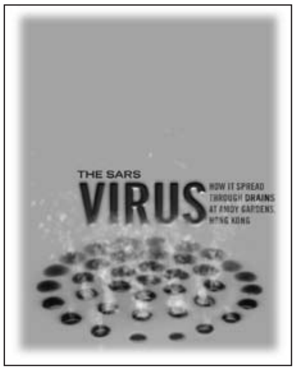

Environmental Transmission of SARS at Amoy Gardens

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Abstract

Recent investigations into the March 2003 outbreak of SARS in Hong Kong have concluded that environmental factors played an important role in the transmission of the disease. These studies have focused on a particular outbreak event, the rapid spread of SARS throughout Amoy Gardens, a large, private apartment complex. They have demonstrated that, unlike a typical viral outbreak that is spread through person-to-person contact, the SARS virus in this case was spread primarily through the air. High concentrations of viral aerosols in building plumbing were drawn into apartment bathrooms through floor drains. The initial exposures occurred in these bathrooms. The virus-laden air was then transported by prevailing winds to adjacent buildings at Amoy Gardens, where additional exposures occurred. This article reviews the results of the investigations and provides recommendations for maintenance and other measures that building owners can take to help prevent environmental transmission of SARS and other flulike viruses in their buildings.

Background

Severe acute respiratory syndrome, or SARS, is a highly contagious respiratory illness that can cause severe illness and death. Symptoms of SARS include fever, headache, fatigue, dry cough, and muscle aches. Gastrointestinal symptoms, such as nausea and diarrhea, are also common. Most SARS patients develop pneumonia, and up to 20 percent of patients require mechanical ventilation (Lee et al., 2003). SARS is caused by a coronavirus (CoV) similar to one of the coronavirus types that cause the common cold (Tsang et al., 2003). The SARS CoV is not an influenza virus, but like influenza viruses, it originally occurred in animals and spread to humans. Both kinds of virus are present in the mucus and feces of infected people, and they share the ability to persist in the environment (de Jong et al., 2005). The influenza virus can persist for hours in dried mucus (Community and Hospital Infection Control Association—Canada, 2004), while the SARS CoV can persist on surfaces for a day or longer and in feces from infected people for as long as four days (World Health Organization [WHO], 2003). Some studies indicate that other types of virus (such as adenoviruses and noroviruses) persist longer in an infectious state (International Association of Plumbing and Mechanical Officials, 2003).

Between November 2002 and July 2003, a SARS epidemic caused 8,098 infections and 774 deaths worldwide. Hong Kong was the hardest-hit area, with the highest illness rate (1,755 cases in a population of 6.7 million) and a fatality rate of 17 percent (299 deaths). The infection in Hong Kong was believed to be the source of the spread of the disease to many other countries (Yu et al., 2004).

Amoy Gardens Outbreak

In March 2003, a SARS outbreak occurred among residents of the Amoy Gardens complex in Kowloon Bay. The first, or index, case of the outbreak occurred in a 33-year-old man who lived in Shenzhen, China, and was a frequent visitor to his brother's apartment, Unit 7 on Floor 16 of Block E at Amoy Gardens. He developed SARS symptoms on March 14 and visited his brother's apartment on March 14 and 19. On both occasions he had diarrhea and used the toilet. His brother and sister-in-law subsequently developed SARS (Hong Kong Special Administrative Region Department of Health, 2003).

The epidemic at Amoy Gardens started on March 21, 2003, and for most residents the onset of symptoms occurred over a three-day period between March 24 and 26 (Yu et al., 2004). By April 15, there were 321 SARS cases at Amoy Gardens and 99 cases in Block E alone. The Amoy Gardens SARS cases accounted for 18 percent of all reported cases in Hong Kong (Hong Kong Special Administrative Region Department of Health, 2003). The epidemiological data curve for the Amoy Gardens cases was consistent with that for an outbreak with a common source (Yu et al., 2004).

FIGURE 1

Amoy Gardens Complex, Kowloon Bay, Hong Kong

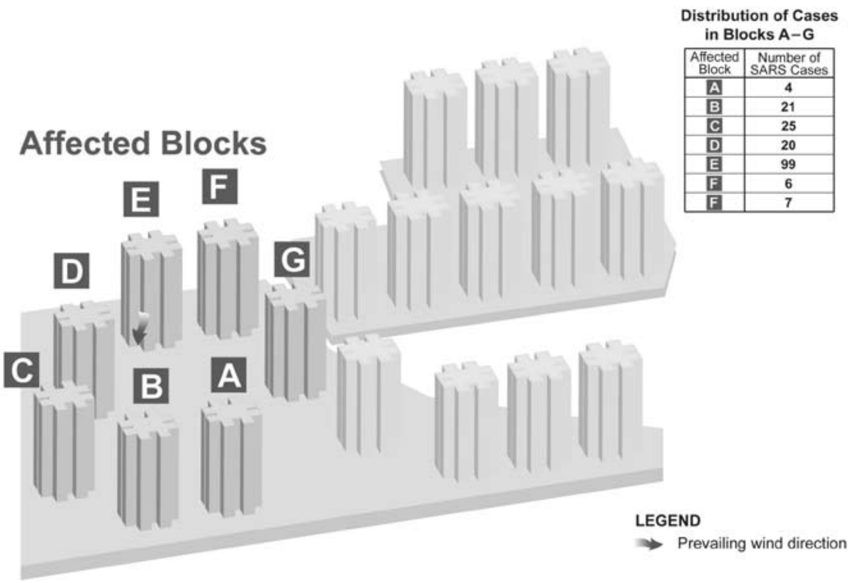


FIGURE 2

Typical Sanitary Plumbing Configuration

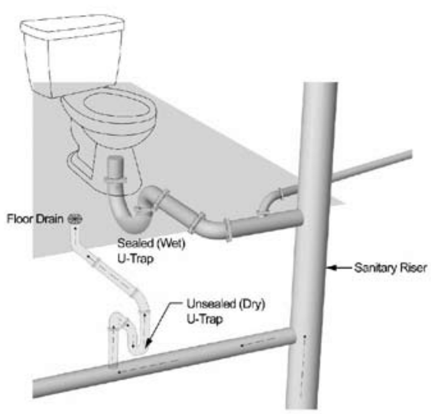


FIGURE 3

Typical U-Trap

Configuration of Amoy Gardens

Amoy Gardens is a private residential apartment complex with approximately 15,000 residents. The complex consists of 19 apartment towers, or blocks (Figure 1). Each block is a 33-story tower with eight apartments (of approximately 515 square feet each) on each floor. Recent studies suggest that the plumbing and ventilation systems at Amoy Gardens interacted to transmit the SARS CoV (Tilgner et al., 2003).

Sanitary plumbing for the towers consists of vertical drainage pipes (called sanitary risers, or stacks) connecting to bathrooms on every floor. The risers connect to sanitary fixtures (e.g., toilets, sinks, bathtubs, and floor drains, as illustrated in Figure 2), and each fixture is fitted with a U-shaped water trap (Figure 3). These traps (called U-traps or P-traps) are commonly used in building plumbing throughout the world to seal the connection between the fixture and the riser. They are designed to prevent sewer gases, insects, and rodents from entering the living space. They must be filled with water to function properly, however. Many traps in Block E were not sealed and provided a direct opening to the risers.

In interviews with officials from the Hong Kong Special Administrative Region Health Department, Amoy Gardens residents indicated that they often smelled sewer gas in bathrooms. Health department officials quickly identified bathroom floor drains as the problem. Water flows frequently through toilet, sink, and bathtub drains, and the traps for those fixtures remain filled and sealed. Residents at Amoy Gardens told health department officials that they cleaned bathroom floors by mopping, however. Because mop cleaning does not generate water flow, bathroom floor drains were left dry and unsealed. In addition, WHO found that some residents had removed traps and others had connected their own fixtures (such as washing machines) to the sanitary riser without installing trap seals (Tilgner, Flick, Grolla, & Feldman, 2003).

Backflow from sanitary risers into indoor spaces can occur because air inside the pipe rises as water flows down. Rates of backflow increase under conditions of negative pressure (i.e., when the pressure in the indoor space is less than that in the pipe). This pressure difference can be naturally occurring or, as in the case of Amoy Gardens, can be mechanically induced by building ventilation systems. Amoy residents had installed window-mounted exhaust fans in most bathrooms. The type and size of exhaust fan was not, however, dictated by building management. The bathrooms were small (less than 50 square feet each) and, according to WHO, many residents had installed high-powered fans with capacities 6 to 10 times higher than the capacity that would be required for such a small space (Tilgner et al., 2003).

A powerful fan installed in a small space creates significant negative pressure. With doors and windows closed, the fan draws air (called "make-up air") from any available source. The source of make-up air in this case was the sanitary riser connecting through the floor drains. The window-mounted fans created large pressure differentials that resulted in significant backflows into Block E bathrooms (Figure 4). The WHO environmental team verified, through odor detection and smoke tests, that sewer gas and aerosolized droplets were being drawn into the bathrooms from the plumbing system, with sewer gas velocity and droplet volume in direct proportion to fan power. In some bathrooms, air velocity inside the floor drain pipe approached 300 feet per minute, which,

FIGURE 4

Typical Bathroom Configuration, Amoy Gardens

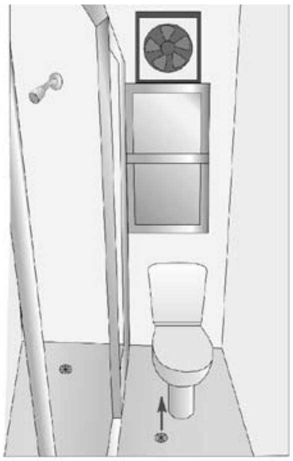
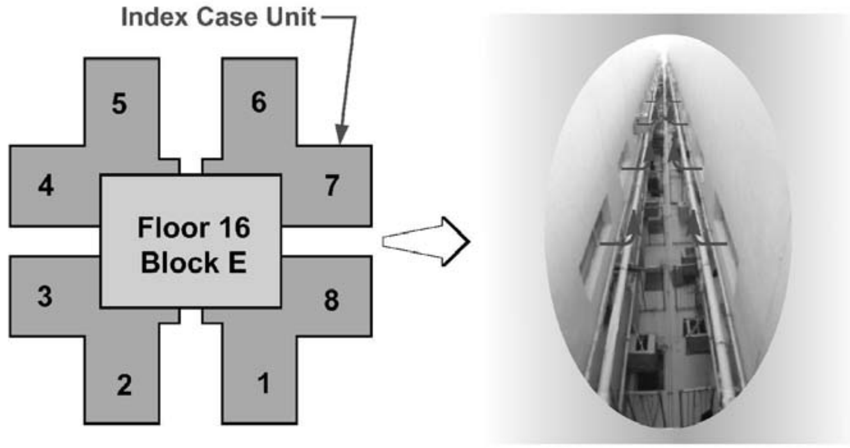


FIGURE 5

Index Case Unit and Open Airway



according to WHO, was "sufficiently energetic to deliver large quantities of droplets into the washroom from infected stool passing in the waste pipe (Tilgner et al., 2003).

Environmental Transmission

High concentrations of SARS CoV were found in the feces and urine of the person with the index case. This person "shed" the virus through feces that were suspended in air, or aerosolized, by hydraulic action and filled the sanitary riser in Block E. Results of testing with a mockup of the Amoy Gardens piping system indicated that the hydraulic action caused by flushing toilets generated huge quantities of aerosols in sanitary risers (Yu et al., 2004).

Significant initial exposures occurred in March 2003 in Block E bathrooms. The infection spread to other units in Block E by air movement between apartment units. Indeed, more than half the other patients with SARS (99 patients) lived in Block E. Yu and co-authors have confirmed through air modeling that the exhaust fans propelled virus-laden air into an outside air shaft, where it was carried upward by natural air currents and into other Block E apartments through open windows (Figure 5). The aerosols traveled upward on warm, humid air in the air shaft and entered apartments above and bordering the air shaft. After the plume reached the top of Block E, it was spread downstream to apartments in nearby buildings (blocks B, C, and D) by a predominant northeasterly wind. The warm, moist outside-air currents carried droplets into open windows in other Amoy Gardens towers downwind of Block E, resulting in significant exposures and additional infections (Yu et al., 2004).

Conclusion

The Amoy Gardens outbreak infected 321 people and caused 42 deaths. It was characterized by extensive and rapid transmission of disease. Disease transmission during epidemics typically occurs across very short distances (i.e., 3 feet or less). In the Amoy Gardens outbreak, evidence suggests that virus-laden droplets traveled hundreds of feet through the air to cause human infection. Recent studies suggest that other emerging infectious diseases, including H5N1 influenza, have the potential for environmental transmission. These results have significant public health implications for control and prevention. Public health officials, in particular, should be mindful of these newly identified hazards and should be prepared to increase awareness among building owners and managers in the event of an outbreak.

Recommendations

Modern buildings are constructed with state-of-the-art ventilation and plumbing systems designed to maximize hygiene in interior spaces. Standard maintenance procedures for these systems will go a long way toward controlling infectious droplets, regardless of building type or infectious source. As recent findings show, however, building owners must ensure that these systems are installed properly and operate effectively over time.

For instance, while bathroom floor drains are not typically found in residential buildings in the United States, they are ubiquitous in public and commercial buildings, including hospitals and nursing homes, K–12 schools, and multistory commercial office buildings. Newer building exhaust systems typically maintain a slight negative pressure in bathrooms, which can result in trap seal evaporation and, as we have seen, in the introduction of contaminated aerosols into indoor spaces (Ballanco, 2003).

Owners of public and commercial buildings are encouraged to visually inspect to ensure that exhaust systems are appropriately sized and do not create excessive negative pressures (the American Society of American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE] publishes ventilation design criteria for built spaces of nearly every type and use). Maintenance staff should be alert to tenant installations. Newly installed fixtures such as washing machines or dishwashers can overload drain lines and cause backflow in sanitary stacks. In addition, maintenance staff should regularly inspect plumbing systems to ensure that floor drains, sinks, bathtubs, and other sanitary fixtures are fitted with U-traps and that the traps are sealed. Finally, maintenance staff should endeavor to respond immediately to plumbing complaints from building

TABLE 1

Good Maintenance Practices

Inspect	floor drains weekly to ensure that traps are sealed
Check	for cracks or stains in drain pipes and fittings
Inspect	bathroom fans to ensure that they are properly sized
Be alert	to sewer gas, unusual noises, or bubbles in pipes and toilets
Check	for unauthorized tenant installations (e.g., washing machines)
Tighten	loose pipe brackets and connections
Respond	promptly to plumbing complaints

TABLE 2

Water Safety Program

Category of Activity	Activities
Inspect	Inspect floor drains weekly to ensure that traps are sealed.
	Check for cracks or stains in drain pipes and fittings.
	Inspect bathroom fans to ensure that they are properly sized.
	Be alert to sewer gas, unusual noises, or bubbles in pipes and toilets.
	Check for unauthorized tenant installations (e.g., washing machines).
	Inspect bathroom exhaust vents for proximity to intakes and windows.
Maintain	Ensure that all plumbing traps remain sealed.
	Respond immediately to pipe leaks, unusual noises, or smells.
	Seal all openings to sanitary piping.
	Tighten loose pipe brackets and connections.
	Disinfect floor drains with diluted bleach solution.
	Ensure that HVAC fresh air intakes are sufficiently far from exhaust vents.
	Install deep-seal traps or trap seal primer valves.
Inform	Provide awareness training to maintenance staff.
	Develop written materials to increase awareness of building occupants.
	Develop policies to prevent unauthorized installations.
	Install signs warning against placing obstructions in drains and toilets.

occupants. Table 1 lists the most important maintenance practices building owners should implement in every commercial and public office building.

Local environmental health officials should also consider integrating a building infrastructure component into their infectious-disease-outbreak planning process. This component could include informational materials to raise awareness of building-related risks and to provide recommendations to owners and managers. In addition, in the event of a confirmed local outbreak, environmental health officials should consider recommending that owners of buildings at particular risk, especially multistory hospitals and nursing homes, develop and implement a water safety program.

Water Safety Program

A well-designed water safety program can be a simple and effective way to prevent the spread of infectious agents through plumbing and ventilation systems. The program should describe the hazards specific to building systems and specify the controls necessary to prevent them (Kohn, Collins, Cleveland, Harte, Eklund, & Malvitz, 2003). It should designate specific responsibilities, such as monitoring and management, to ensure the integrity of sanitary systems in the building; timely responses to eliminate hazards when they are identified; and risk communication:

- Designate a person (such as the managing agent) who is responsible for water safety.
- Conduct weekly inspections of plumbing systems for leaks. Weekly inspections should also confirm that all plumbing traps are wet.
- Complete weekly maintenance of floor drains by pouring half a liter of water into each floor drain followed by a teaspoon of household bleach.
- Respond immediately to complaints by building occupants. Inspect and repair when any of the following issues are identified:
  — sewer gas or odors,
  — unusual noises from drainage piping,
  — cracks or stains in drainage piping and sanitary fittings,
  — loose pipe brackets,
  — pipe leaks or blockage, or
  — bubbles in sinks or toilets.
- Conduct an annual review of bathroom ventilation systems (noting fan-size-to-space requirements and proximity of outlets vents to vent intakes and windows). Replace vulnerable traps, such as those connected to floor drains that are likely to fail through evaporation, with deep-seal traps (consisting of a 4-inch, rather than a 2-inch seal), or install trap seal primer valves that can detect and prime dry traps.
- Develop a risk communication plan that includes an awareness-training course for maintenance staff. Prepare frequently-asked-questions (FAQ) pamphlets and fact sheets for building occupants for distribution in the event of an outbreak. These written materials would advise occupants to notify maintenance staff of sewer gas odors, pipe leaks, bubbles in toilets, and so forth. The risk communication plan would include policies to prevent unauthorized installations such

as bathroom exhaust fans, dishwashers, or washing machines. It should also include signage warning occupants not to place obstructing objects (such as paper towels) into toilets or drains.

Finally, the water safety plan should include provisions to document all risk reduction efforts, including inspection results, maintenance activities, and equipment changes (Freije & Barbaree, 1996).

Table 2 lists the main elements in a typical Water Safety Plan that would be implemented for buildings at particular risk or for all commercial and public buildings during a major outbreak event.

Long-Term Strategies

Environmental health officials also should consider long-term preventive measures. Among these measures should be a renewed focus on building design by engineers and architects.

Modern buildings codes grew largely out of the need for consistent sanitation requirements in built structures. For example, 19th- and early 20th-century New York City schools were constructed with C- and H-shaped floor plans, large built-in ventilation shafts, and operable transoms in the corridors to encourage cross-ventilation (Holden, Weisz, & Woodner, 1997). Floor drains were installed to facilitate cleaning of bathroom wall and floor surfaces. As the incident discussed in this paper shows, however, some of these same features can enhance contaminant flow.

Environmental health officials should consider reaching out to their building department colleagues to encourage a review of local building codes. Recommended changes to building codes should add minimum-depth requirements for floor drain traps, specify maximum ventilation rates in rooms connected to sanitary stacks, and specify minimum distances between potential sources (e.g., vent stacks and exhaust fans) and sensitive receptors (e.g., windows and fresh-air inlets).

With the looming threat of H5N1, environmental health officials should be aware of—and have strategies to address—the risks of environmental transmission. A combination of increased awareness and straightforward prevention by building owners and managers can effectively minimize the risks represented by these newly identified potential sources of disease.

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