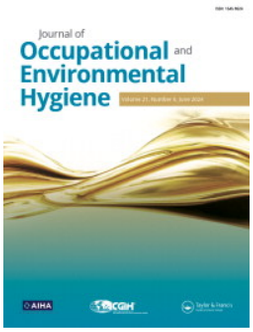

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REPORT

Low-cost interventions to improve ventilation in long-term care facilities

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ABSTRACT

Residents of long-term care facilities are particularly vulnerable to communicable diseases. Low-cost interventions to increase air exchange rates (AERs) may be useful in reducing the transmission of airborne communicable diseases between long-term care residents and staff. In this study, carbon dioxide gas was used as a tracer to evaluate the AER associated with the implementation of low-cost ventilation interventions. Under baseline conditions with the room's door closed, the mean AER was 0.67 ACH; while baseline conditions with the door open had a significantly higher mean AER of 3.87 ACH ($p < 0.001$). Subsequently opening a window with the door open increased mean AER by 1.49 ACH ($p = 0.012$) and adding a fan in the window further increased mean AER by 1.87 ACH ($p < 0.001$). Regression analyses indicated that the flow rate of air entering through the window, both passively and through the use of a fan, was significantly associated with an increase in AER ($p < 0.001$). These results indicate that low-cost interventions that pull outside air into resident rooms were effective in improving the air exchange rates in these facilities. While implementation of these interventions is dependent on facility rules and isolation requirements of residents with airborne communicable diseases, these interventions remain viable options for long-term care facilities to improve resident room ventilation without requiring costly ventilation system upgrades.

KEYWORDS

Air exchange rate; airborne communicable diseases; indoor air quality; occupational hygiene

Introduction

Long-term care facilities in the United States provide full-time assistance for those who are no longer able to live safely on their own, offering living accommodations, personal care, and meals, and may also provide nursing and medical care (National Institute on Aging 2017). The United States has about 65,600 long-term care facilities, of which 15,600 are nursing facilities and 28,900 are assisted living and residential communities (Harris-Kojetin et al. 2019). Washington State currently has 540 assisted living facilities and 209 licensed skilled nursing facilities (Washington State Nurses Association 2020). As of 2022, there are approximately 1,160,000 residents in these nursing facilities across the country and approximately 12,500 residents in Washington State (Kaiser Family Foundation 2022). The facilities in the state are regulated and licensed by the Washington State Department of Social and Health Services (Washington State Department of Social and Health Service, 2022).

To date, long-term care facilities in Washington experienced 4,080 COVID-19 outbreaks and accounted for 3% (54,148 cases) of the total cases in Washington (Washington State Department of Health 2022), but experienced 4,294 deaths due to COVID-19, accounting for 30% of the state total (Washington State Department of Health 2022). This disproportionality is attributable to the vulnerability of long-term care residents to communicable diseases, as these residents are typically elderly and often have underlying health conditions that put them at risk of infection (Lansbury et al. 2017; McMichael et al. 2020) and compromise recovery. Therefore, there is a need to reduce transmission of COVID-19 and other airborne communicable diseases in long-term care facilities.

Residents in long-term care facilities can spend up to 95% of their time indoors (Almeida-Silva et al. 2014). As SARS-CoV-2, the virus that causes COVID-

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19 is transmissible as an aerosol through the air, residents can be exposed to airborne SARS-CoV-2 and other contaminants for extended periods (CDC 2021; Linde et al. 2022). Per the US Environmental Protection Agency (EPA) (US EPA 2014), improving ventilation is a basic strategy to improve indoor air quality. In the context of the COVID-19 pandemic, ventilation is particularly important to mitigate airborne transmission (CDC 2021). The air exchange rate (AER) refers to the rate at which outdoor air replaces indoor air (Guo et al. 2008; US EPA 2019). Increasing the AER can better remove contaminants from indoor spaces and dilute contaminants that remain, reducing contaminant buildup and reducing the dose of contaminants that residents have (Morawska et al. 2020). However, this is only effective if ventilation systems can deliver sufficient amounts of clean air and achieve adequate mixing of clean and contaminated air, such that there are no areas of stagnant or undiluted air in the room.

The Washington State standard for ventilation systems in newly built nursing homes, which references the ASHRAE standard for healthcare facilities (Washington State Legislature 2008; ANSI/ASHRAE/ASHE 2017), requires that resident rooms have a minimum AER of outdoor air of 2 ACH (air changes/hour), and a minimum total AER (outdoor and filtered/cleaned air) of 4 ACH. Recirculation of air is permitted in Washington, and this standard does not apply to nursing homes constructed before the introduction of the standard in 2008. Therefore, residents in older nursing homes may be at higher risk of exposure to SARS-CoV-2.

Increasing the AER by improving mechanical ventilation systems will result in increased energy costs and may require substantial capital expenditures. Limited research has evaluated low-cost methods of increasing the AER in long-term care facilities; however, ventilation strategies in schools may apply to long-term care facilities due to the similar nature of buildings (long halls with multiple rooms). A study (Guo et al. 2008) that examined the effects of opening windows, adding fans, and turning on air conditioning found that the highest AER (7.92 ACH) was achieved by opening windows and keeping fans and air conditioning on. This study found that keeping windows open was an effective way to increase the AER, as all trials with windows closed yielded rates of less than 1 ACH (Guo et al. 2008). This is consistent with research in hospitals that found that opening windows and doors can increase the AER (Escombe et al. 2007). Other research has found that in rooms with COVID-19-positive patients, increasing the AER further (to 12 ACH or greater) can dilute the concentration of SARS-CoV-2 to the point where it is undetectable (Cheng et al. 2020).

This study investigated the effects of low-cost interventions, such as opening windows and doors, turning on built-in bathroom fans, and adding portable window fans on AERs in two long-term care facilities in Skagit County, Washington. The goal of this study was to identify which combination of interventions resulted in the greatest increase in air exchange rate in resident rooms. This study adds to the growing body of literature characterizing methods to reduce the transmission of SARS-CoV-2 and is one of the first to investigate the impact of low-cost interventions on AERs. Identifying simple interventions that improve AERs can reduce the risk of further COVID-19 outbreaks and other airborne contagious diseases in this vulnerable population.

Methods and data analysis

Room ventilation interventions were assessed at two long-term care facilities in Skagit County, WA: Facility 1 was located in Sedro-Wooley, WA, and Facility 2 was in Mt. Vernon, WA. In each facility, empty rooms were identified based on availability; in Facility 1, testing was conducted in two empty rooms in an unoccupied wing, and in Facility 2, testing was conducted in three empty rooms in an otherwise occupied wing.

Both buildings were single-floor facilities with multiple wings branching from a central location. As shown in Figure 1, Facility 1 has a sideways "H" shape, creating two outdoor alleys between wings. These alleys created turbulence in outdoor wind movement, causing variable directions in wind movement. One of the testing rooms in this facility had a window facing an alley, while the other testing room did not (see Figure 1). While the building had a heating, ventilation, and air conditioning (HVAC) system in the hallways, it was not operating during the time testing was conducted. There was no HVAC, including no exhaust other than bathroom exhaust fans, in resident rooms; rooms relied on windows and baseboard heating for climate control.

Facility 2 has a "+" shape, as shown in Figure 2; unlike Facility 1, there were no alleys that could affect wind movement. This facility had a functional ventilation system that provided air circulation in hallways with air exhaust vents and a ceiling supply diffuser, but there were no HVAC systems or functional

Figure 1. Aerial view of Facility 1, oriented North. Stars represent the two rooms that testing was conducted in. Source: Imagery ©Airbus, Maxar Technologies, U.S. Geological Survey, Map data ©2024.

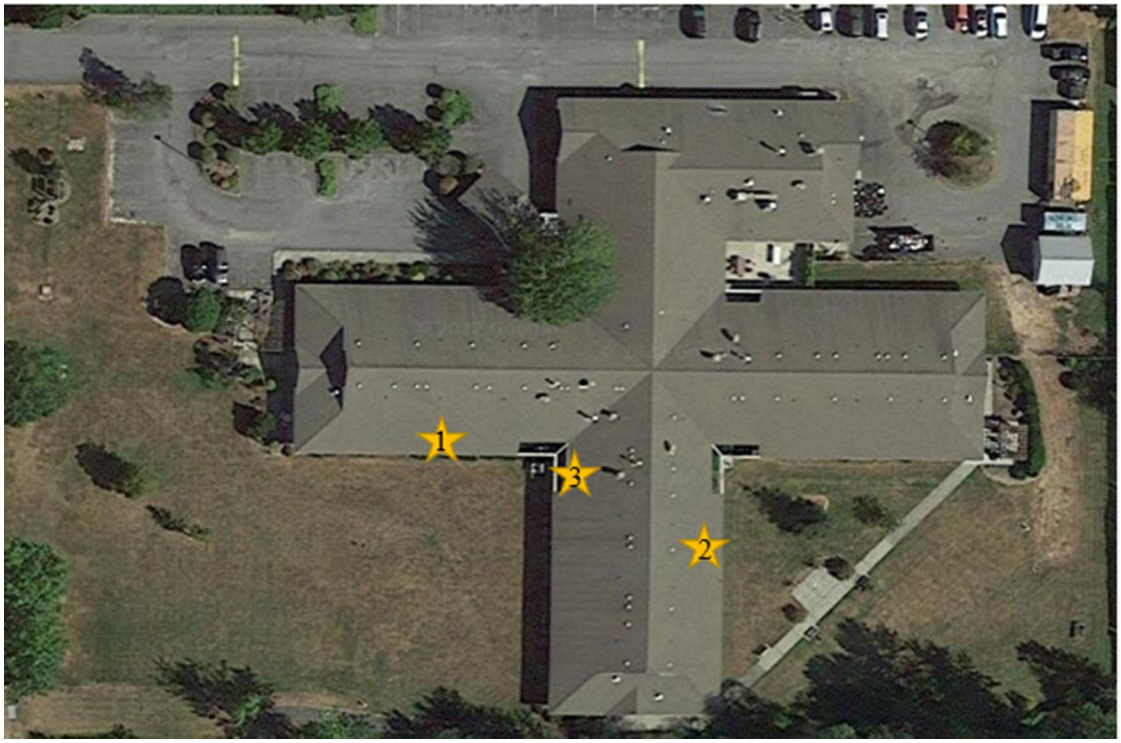

Figure 2. Aerial view of Facility 2, oriented North. Stars represent the three rooms that testing was conducted in. Source: Imagery ©Airbus, Maxar Technologies, U.S. Geological Survey, Map data ©2024.

bathroom fans in resident rooms; rooms relied on windows, infiltration from the hallway HVAC system, and baseboard heating for climate control. A mechanical air conditioning system that provided temperature regulation was not observed in the facility.

Room characterization

Before the start of testing, room characteristics including dimensions, location of the room in the building, the direction the window faces, and window and door dimensions were noted. The air flow rate of the built-in bathroom exhaust fan was measured at the start of each testing day with the main room and bathroom doors open, by placing a cardboard box with no top or bottom (creating a hood) around the fan and measuring the face velocity at nine points across the face of the box. These nine face velocity measurements were averaged and then used to calculate the bathroom fan flow rate.

Room testing

The experimental design consisted of introducing carbon dioxide (CO_2) gas, from a cylinder, into the empty resident room until the room CO_2 concentration was approximately 3,000 parts per million (ppm). Using real-time CO_2 monitors, the concentration was recorded over time and used to calculate the AER for the room (Allen et al. 2020). This was repeated with different combinations of interventions: the windows open and closed, the door open and closed, and a fan (Bionaire Whole House Window Fan, model BWF0552E) inserted in the window with cardboard placed to block any areas not covered by the fan. The door between the bathroom and room was left open, and the bathroom fan (where functioning) was left on during all trials.

At the start of each testing day, one CO_2 monitor (TSI Q-Trak Indoor Air Quality Monitor Model 7575) was set up on a tripod at a height of 1 m in the center of the room, and a second monitor was set up at the same height near the window. The second monitor was a TSI VelociCalc Model 9565 for the first two testing days, and then a TSI Q-Trak XP Indoor Air Quality Monitor Model 7585 for the remaining test days. These monitors were calibrated weekly using 5,000 ppm CO_2 calibration gas in the field laboratory and compared to each other at the start of each testing day to ensure that their CO_2 concentration readings were not notably different (less than 5 ppm differences were considered to be acceptable variance). Both monitors were set to record average CO_2 concentration and room temperature at 1-min intervals. CO_2 was introduced from a cylinder (99.5% CO_2) placed in the center of the room but angled away from the monitors. Two box fans were placed in the room as CO_2 was introduced to assist with air mixing; these box fans were switched off once CO_2 concentrations in the room stabilized. Once the room concentration of CO_2 reached approximately 3,000 ppm in the center of the room and the reading on the monitor had stabilized, the room was exited to ensure that exhalation did not impact CO_2 concentration readings, the start time and CO_2 concentration (at the center of the room) noted, and the monitors logged data with no people in the room. The concentration was monitored from outside the room by the research team, through the window. Once the room concentration had reduced to approximately 37% of the starting concentration (Allen et al. 2020), the trial was ended and the time and final CO_2 concentration was noted. In some cases where trials took more than an hour, the trial ended earlier. In Facility 1, between 8 and 14 replicate measurements were conducted for each scenario per room. In Facility 2, between 10 and 12 replicate measurements were conducted for each scenario across the three rooms, as room availability for testing was more limited than in Facility 1.

Six scenarios were assessed at each facility:

- Door open, window closed, no fan in window.
- Door open, window opened 8 inches, no fan in window.
- Door open, window opened 8 inches, fan with 8-inch width placed in gap, blowing air into room.
- Door closed, window closed, no fan in window.
- Door closed, window opened 8 inches, no fan in window.
- Door closed, window opened 8 inches, fan with 8-inch width placed in gap, blowing air into room.

In scenarios where the window was open without the use of a fan, air velocity measurements (60 s average) were taken at the start of the trial at three locations: the window face inside of the room (measuring air velocity entering the room through the window), near the window outside the building (measuring air velocity reaching the window); and outside the building away from the building walls (measuring outside air velocity). At this time, the direction of air movement at the room door (only if the door was open), the window, and outside the building were also noted using a Vosentech MicroFogger 3 Lite (Vosentech 2023). For the scenarios with the fan in the window,

cardboard was used to seal the window opening around the fan to prevent recirculation at the window. The same fan was used on the high-speed setting in all trials and had a flow rate of approximately 560 cfm, measured in situ. The pressure differential of the rooms was measured at the doorway (only in trials with the door closed, as it was measured under the door) using a Fluke 922 Airflow Meter (Fluke 2023) at the start of trials.

Data analysis

Data were downloaded from both CO_2 monitors and sorted by testing date and trial number. The start and end points of each trial in the dataset were identified and noted; the start points being when the CO_2 concentration began to decay, and the end points being when the room was entered to end the trial. For each trial, the AER was calculated by log-transforming the trial's decay curve and calculating the slope of the subsequent line, which represents the AER (Charlesworth 1988). Correlation coefficients (R^2) were determined from the fit of the data to the curve; these calculations were done in Microsoft Excel.

The data were then compiled from all testing dates into one file for further descriptive and inferential statistical analysis using R statistical software. Other data collected during the trials, such as room size, outside wind speed and direction, and the window face direction were added to the same file. Approximate outdoor temperature was compiled from the closest Weather Underground (Weather Underground 2023) station: for Facility 1, the North Burlington Station was used, and for Facility 2, the Mount Vernon Station was used. These outdoor temperature data were compared to the indoor temperature data from the monitors to determine the temperature difference between inside and outside the buildings.

The data were first analyzed using descriptive analyses (mean, range, and standard deviation) of the AER stratified by the various scenarios that were tested (door open/closed, window open/closed, fan on/off). The AER of different scenarios were compared to each other using an analysis of variance (ANOVA) to determine whether there were any significant differences between the mean AERs.

The volumetric flow rate of air entering through the open window was estimated by taking the product of the mean air velocity and window area, with a code of "0" entered into the database for trials when the window was closed, and the flow rate of the fan if the fan was in the window. To account for outdoor wind conditions, another variable representing the outdoor wind speed was created, coded to be "0" if the window was closed or if the fan was in the window, and coded as the outdoor wind speed if the window was open without the fan.

A linear regression model was developed for AER, including predictors for whether the door was open, the volumetric flow rate of air entering through the window, and the difference between indoor and outdoor temperatures. The model was controlled for the room and bathroom exhaust fan flow rate to adjust the model for differences in room size, door and window areas, and potential differences in the bathroom exhaust fan between facilities and rooms. Monitor location (center of the room vs. near the window) was not adjusted for, as a likelihood ratio test indicated that including the monitor location as a covariate did not yield a significantly different model fit compared to a model without monitor location as a covariate. To address any potential issues in heteroskedasticity in this linear regression model, standard errors were adjusted using residuals to estimate robust standard errors (Eicker-Huber-White standard errors) (White 1980; Long and Ervin 2000). The model was assessed for multicollinearity by calculating variance inflation factors (VIFs) for the predictors in the model; any predictor with a VIF > 5 would be dropped.

Results

Across both facilities, 177 trials were recorded. Of these, 107 trials were recorded at Facility 1, and 70 at Facility 2. Two trials at Facility 2 were excluded, as they were disrupted by a facility resident and staff member.

Table 1 summarizes the characteristics of each room tested. Rooms in Facility 1 were on average 54% larger than rooms in Facility 2 with approximately double the window area but a similar door area. The HVAC system was functioning in the hallways of Facility 2, but not in Facility 1. Neither facility had an HVAC system inside resident rooms. Pressure differential measurements (Table 1) indicated that, except for Room 1 in Facility 1 with the fan intervention (which had a slight positive pressure), rooms were not pressurized compared to the hallway outside. Air movement as observed using the MicroFogger tended to be turbulent and varying at resident room doors. At the windows, air moved predominantly into rooms at Facility 1, but was

Table 1. Room characteristics.

Room		Volume (ft^3)	Window area (ft^2)	Door area (ft^2)	Direction window faces	Location of room in building	HVAC functionality	Mean indoor temperature during testing (°F)	Mean bathroom fan flowrate (cfm)	Mean pressure differential between room and hallway
Facility 1	Room 1	2339.4	42.0	26.3	South	See Figure 1	None	76.4	42.4	None with closed or open window +0.009in H_2O with fan in window
	Room 2	3066.8	41.5	26.3	North			72.9	36.7	None
Facility 2	Room 1	1875.5	18.8	28.8	South	See Figure 2	Working in hallways, none in room	76.6	0	None
	Room 2	1634.2	22.7	25.3	East			73.4	0.07	None
	Room 3	1760.8	22.5	24.8	West			72.8	0	Not measured, micromanometer unavailable

Table 2. Mean, range, and standard deviation of air exchange rate by scenario.

	Overall (ACH)		Facility 1 (ACH)		Facility 2 (ACH)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Door open control	3.87 (3.21)	1.16–14.16	3.49 (3.52)	1.16–14.16	4.61 (2.46)	2.00–7.94
Door open, window open	6.08 (2.71)	0.91–13.50	6.19 (2.24)	0.91–13.50	5.93 (1.91)	3.14–8.86
Door open, fan in window	7.95 (2.35)	4.04–12.27	7.41 (0.99)	5.95–9.21	8.68 (3.35)	4.04–12.27
Door closed control	0.67 (0.13)	0.35–0.88	0.70 (0.08)	0.55–0.88	0.64 (0.17)	0.35–0.84
Door closed, window open	2.17 (1.26)	1.01–5.56	1.52 (0.39)	1.01–2.25	3.33 (1.45)	1.52–5.56
Door closed, fan in window	5.09 (1.69)	3.35–9.40	4.26 (1.02)	3.35–6.99	6.59 (1.65)	4.69–9.40

Table 3. Linear regression model for air exchange rate (AER), adjusted for the testing room.

	β	95% CI	p
Opening doors	3.436	2.836, 4.035	<0.001
Flow rate of air entering through window, cfm	0.007	0.006, 0.008	<0.001
Temperature difference (indoor – outdoor), °F	0.228	0.151, 0.306	<0.001

observed moving both in and out of rooms at Facility 2. Wind direction observed away from the building was typically from the west or northwest, except for two trials in which wind was observed to be moving from the east.

Descriptive statistics

Table 2 outlines the mean, range, and standard deviation of the air exchange rates by testing scenario. With the door closed and no interventions, the mean AER across both facilities was 0.67 ACH, which was the lowest mean AER of the six scenarios. Opening a door yielded a mean AER increase of 3.20 ACH ($p < 0.001$). Compared to the door closed with no interventions, opening the window yielded a mean AER increase of 1.49 ACH ($p = 0.012$), and adding a fan in the window further increased the mean AER by 2.93 ACH ($p < 0.001$). Compared to the door open with no interventions, opening the window yielded a mean AER increase of 2.21 ACH ($p = 0.003$), and adding a fan in the window further increased the mean AER by 1.87 ACH ($p = 0.008$). The door open with the window open and a fan in the window yielded the highest mean AER across both facilities of 7.95. The mean R^2 for all samples was 0.95; only one sample in Facility 2 had an R^2 lower than 0.70.

Regression models

Results from the linear regression model for AER adjusted for the testing room (Table 3) indicate that opening the resident room door was associated with an increase in mean AER by 3.44 ACH (95% CI: 2.84, 4.04). Increasing the volumetric flow rate of air entering through the window by 1 cfm significantly increased the mean AER by 0.007 ACH (95% CI: 0.006, 0.008). For every 1 °F that the indoor temperature is higher than the outdoor temperature, the mean AER significantly increased by 0.23 ACH (95% CI: 0.15, 0.31). VIFs for all predictors in the model were <5 (binary door variable's VIF = 1.42; volumetric flow rate of air entering through the window's VIF = 1.03; indoor and outdoor temperature difference's VIF = 4.11). The goodness of fit metrics for this regression model is included in Supplementary Figure S1, which indicates that all assumptions of linear regression models were met. Residuals vs. fitted values (Supplementary Figure S1A) demonstrate linearity and a quantile-quantile plot (Supplementary Figure S1B) demonstrates normality. While Supplementary Figure S1C may indicate some heteroskedasticity; standard errors were adjusted using residuals in the model to estimate robust standard errors (Eicker-Huber-White standard errors) (White 1980; Long and Ervin 2000), thereby accounting for this potential issue. Supplementary Figure S1D is a residual vs. leverage plot, which indicates that all data points are within

Cook's distance. Therefore, any potential outliers in this model are not influential points.

Discussion

To date, limited research has evaluated the effects of low-cost interventions, such as opening doors and windows, and adding a fan in the window, on air exchange rates in long-term care facilities. Given the concern of airborne transmission of many diseases, including SARS CoV-2, and the vulnerability of long-term care residents, this study provides important information by identifying combinations of low-cost interventions that can increase AERs and potentially reduce the risk of airborne contagious disease outbreaks such as COVID-19, without requiring costly ventilation system upgrades.

While Facility 2 did have an HVAC system in the hallways, both facilities had no HVAC system within resident rooms, except for the bathroom fan. However, bathroom fans in Facility 2 were not operating and the fans in Facility 1 only provided low flow rates. While switching on a bathroom fan may slightly influence the AER by pulling more air into the room, it should not be relied upon as the primary method of ventilation, as bathroom fans are typically only sized to provide ventilation for the bathroom, not the entire room. This lack of reliably existing ventilation highlights the need for impactful interventions that can be quickly implemented without significant structural changes, as any major upgrades would likely require time-consuming work to install and a large capital investment of money.

With the door and window closed, resident rooms had a mean AER of 0.67 ACH, which is low (Allen et al. 2020) and notably below the Washington State standard for air exchange rates in resident rooms (Washington State Legislature 2008; ANSI/ASHRAE/ASHE 2017). However, opening the resident room door alone without adding any other interventions significantly increased the mean AER to 3.87 ACH. This is consistent with literature that indicates the effectiveness of opening doors to improve air exchange rates by increasing natural ventilation (Escombe et al. 2007; Marr et al. 2012). Results from the regression analyses indicated that opening a door can significantly increase mean AER by more than 3 ACH; thus, when other interventions are not possible, this small study suggests that opening a door can be a basic intervention to notably improve ventilation.

Regardless of whether the door was open or closed, opening a window significantly increased the mean AER in resident rooms, and adding a fan in the window further increased the mean AER. With the door closed, opening a window was adequate to surpass the Washington State standard of 2 ACH of outdoor air (Washington State Legislature 2008; ANSI/ASHRAE/ASHE 2017); adding a fan in the window further increased the mean AER to 5.09 ACH. With the door open, mean air exchange rates were higher: 6.08 ACH with the window open, and 7.95 ACH with the fan in the window. Research has indicated that minimum targets of "good" or "excellent" air exchange rates of 4–6 ACH (Allen et al. 2020) in small rooms, even with just outdoor air ventilation, can be effective in reducing the spread of SARS CoV-2 (Allen and Ibrahim 2021). Combining all three low-cost interventions (door and window open with a fan in the window) surpasses these minimum targets and is therefore a viable option for long-term care facilities to improve resident room ventilation without needing to make costly upgrades to existing ventilation systems.

In regression analyses, the flow rate of air entering through the window was a significant predictor of AERs. Therefore, opening a window, particularly during windy conditions outside, can help increase room ventilation. However, research has indicated that air exchange rates via natural ventilation through windows are dependent on window size and the angle of wind incidence (Sacht and Lukiantchuki 2017). If the wind direction is inconsistent or turbulent, then natural ventilation solely by opening windows may be unreliable. Regression analyses indicated that increasing the flow rate of air entering through the window by 1 cfm was significantly associated with a 0.007 ACH increase in the mean AER. Given that the portable fan tested in the window had a flow rate of 560 cfm, based on the regression model, this could correspond to approximately a 3.9 ACH increase in the AER.

The difference between indoor temperature and outdoor temperature was also a significant predictor of the AER in regression analyses, such that a higher indoor temperature compared to the outdoor temperature increased the AER. Previous research has indicated that the difference in air densities due to temperature difference can promote natural ventilation (Marr et al. 2012); however, in conditions where there is a large temperature difference, residents may be less inclined to open windows (Offermann 2009).

Limitations

This study has several limitations. As testing was only conducted in five rooms across two facilities, results

may or may not be generalizable outside of these rooms or facilities. This study also used unoccupied rooms, and therefore may not be generalizable to occupied rooms. Both facilities only had a single floor, so these findings may not be generalizable to taller buildings which could have different outdoor wind and pressure dynamics. All testing was conducted in the summer in the U.S. Pacific Northwest; outside weather conditions, particularly temperature and wind conditions may have a different impact on air movement in other seasons and may preclude the opening of windows.

The regression model may have some issues with heteroskedasticity. This was addressed preemptively by adjusting standard errors to estimate robust standard errors. Similarly, our model may contain outliers, but since no data points fall outside Cook's distance, these potential outliers were not influential.

If a resident has COVID-19 or another airborne infectious disease, opening the door is not an effective intervention, as this can potentially move contaminated air into hallways and common areas. Some long-term care facilities require doors to be closed when a resident has COVID-19. In these situations, facilities should consider the two other low-cost interventions (opening a window and using a fan in the window, oriented to pull air from the room to maintain negative pressure while limiting the escape of contaminated air into the common areas), as well as additional interventions such as installing high-efficiency particulate air (HEPA) filters or portable air cleaners (US EPA 2020).

The practicality of the suggested interventions can vary depending on facility rules. Facilities may have rules and limitations on opening windows, due to the risk of elopement (an unauthorized leave from the facility) the safety risk of unauthorized entry by outsiders, or the use of fans, which may pose an injury hazard (residents may injure hands by touching the fan blade when it is operating). Therefore, the use of these low-cost interventions is highly dependent on facility rules and the residents in the facility, as well as the management of the use of these interventions by staff. Furthermore, finding fans that fit easily in windows without requiring cardboard to seal gaps can be challenging, considering the potentially different window styles and sizes in different rooms.

Outside weather conditions also have a direct impact on the practicality of these low-cost interventions, specifically opening a window and putting a fan in the window. Outdoor weather conditions have been shown to impact indoor microbial growth (Frankel et al. 2012), which puts residents at risk of biological exposure. In extreme cold or hot weather, bringing outside air into resident rooms may put residents at risk of temperature-related illnesses. Furthermore, given the prevalence of wildfire smoke in Washington State, opening windows when the outside air quality is poor is counter to improving indoor air quality, and for residents with preexisting respiratory conditions, may aggravate symptoms. Similarly, opening windows may expose residents to higher levels of seasonal allergens, which can also aggravate preexisting respiratory conditions.

Conclusions

Given that long-term care facilities are at high risk of outbreaks of airborne contagious diseases, improving ventilation is important to dilute and reduce contaminants in indoor air. Upgrades to ventilation systems can be costly; however, low-cost interventions such as opening doors and windows, and adding fans to windows to pull outside air into resident rooms are effective in improving the air exchange rates in these facilities. In this study, the standard for AERs (ANSI/ASHRAE/ASHE 2017) was only met when one or more of the low-cost interventions were implemented.

Despite the limitations of this study, this work remains important to public health, as improving ventilation in long-term care facilities through low-cost interventions is crucial in reducing the spread of SARS-CoV-2 and other airborne infectious diseases among residents who may already be medically compromised. Findings from this study can be immediately implemented by long-term care facilities and can inform policies and facility rules regarding the isolation of COVID-19-positive residents. Given that some facilities may have more than one resident in a room, increasing the air exchange rate can reduce the risk of exposure to airborne contagious diseases for both facility residents and staff, which can ultimately reduce the prevalence of outbreaks within long-term care facilities.

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Disclaimer

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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