Optimizing Ventilation Strategies for Mitigating SARS-CoV-2 Transmission in Long-Term Care Facilities: A Collaborative Study with Practical Implications

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Abstract

The COVID-19 pandemic has brought to the forefront the critical role of indoor environments and Heating, Ventilation, and Air Conditioning (HVAC) systems in viral transmission. The Edmonton General Continuing Care Centre (EGCCC) experienced significantly higher infection rates during the pandemic compared to the newer sections of the Edmonton General Hospital, raising concerns about the role of the EGCCC's HVAC system. As part of a collaborative effort between Alberta Health Services (AHS), this paper presents an in-depth analysis of the HVAC system, Indoor Air Quality (IAQ), and ventilation at the EGCCC and their potential role in the transmission of aerosolized viral particles during the COVID-19 pandemic. The study investigates the factors influencing the drastic difference in infection rate between the A/B Wings and the C-Wing of the EGCCC long-term care facilities. To achieve this, CONTAM simulations are conducted, leveraging both measured data and simulated scenarios. This research also explores the effects of introducing additional equipment to enhance air circulation in areas with stagnant air and compares the previous A/B wing HVAC system to a newly installed makeup air system, ventilation fans, bathroom door louvers, and portable air purifiers. This evaluation is meant to enhance the ventilation and indoor environmental quality to improve the safety and comfort of both residents and staff at the EGCCC and act as a reference for other facilities that are experiencing similar issues.

Introduction

This paper represents a collaborative effort between Alberta Health Services, Covenant Health's EGCCC, and the University of Alberta Mechanical Engineering Department aimed at evaluating the HVAC system at EGCCC and investigating its impact on viral transmission. Ensuring the safety and well-being of frontline workers and long-term care residents is paramount, especially amid a health crisis. Studies have highlighted the uncertainty and fear of infection experienced by healthcare workers during the pandemic, emphasizing the urgency of providing a secure working environment (Ulrich, 2022). The EGCCC, predominantly serving elderly residents, experienced vastly different infection rates during the COVID-19 pandemic compared to other sections of the Edmonton General Hospital. This discrepancy raised concerns regarding the existing HVAC system's role in the deadly COVID-19 outbreaks experienced by the facility.

In response, AHS initiated efforts to enhance ventilation and indoor environmental quality, starting with the replacement of Make-Up Air (MUA) units to regulate inlet air, increase ventilation rates, and manage humidity levels. Additionally, upgrades included replacing bathroom exhaust fans and providing portable air filtration units strategically placed to maximize their efficacy in communal areas.

The potential for aerosolized particle transmission in shared spaces necessitates a thorough assessment of airflow paths within the facility. This encompasses the analysis of airflow patterns and the identification of possible viral transmission routes, such as doors, elevator shafts, and exhaust ducts. To this end, CONTAM simulations—a tool for simulating contaminant transportation and airflow within buildings—were employed to evaluate ventilation rates and model contaminant exposure scenarios. These simulations focused on individual floors for CO_2 validation, serving as a proxy for ventilation effectiveness, and replicated conditions during the facility's COVID-19 outbreak in November 2020. Assumptions were made regarding resident movements and adherence to stringent sanitation measures, allowing the study to concentrate on the transmission of aerosolized viral particles.

By addressing these factors, this study aspires to provide insights into the optimization of HVAC systems in long-term care facilities. The aim is to reduce viral transmission risks, thereby enhancing the safety and well-being of both residents and staff (Fateme Mohamadi, 2022).

Methods

This section outlines the experimental measurements conducted at the EGCCC facility and the CONTAM simulations employed to assess the impact of HVAC upgrades on reducing viral transmission. Initially focusing on the heavily affected A/B wing, the project expanded to compare it with the less affected C-Wing of the Edmonton General Hospital.

The HVAC system in the A/B Wing comprises vents, registers, door leakages, door louvres, ceiling diffusers, hot water radiant heaters, and small air handling units on each floor. Initial measurements included abandoned components such as ceiling diffusers, suspended ceiling louvres, and wall registers. However, in later assessments, any openings that were not a bathroom exhaust fan that and that showed no airflow were excluded from measurements.

Measurements were consistently taken for bathroom exhausts, MUA registers, and open windows using ABM 200 sensors, with window positions recorded. A typical floor layout is shown in Figure 3 and is summarized in the following paragraph.

The B-Wing has two MUA units at the north and south side of the wing that feed conditioned outdoor air straight down a shaft that branches directly to a register on each of the floors that were studied. A-Wing has a single MUA unit that supplies air to the West side of the Wing. The C-Wing has outdoor conditioned air supplied by a single MUA unit and has sixteen diffusers in the common areas and has twenty-four registers spread throughout the resident rooms. All wings have the bathroom exhaust vents as the only source of forced exhaust ventilation, although there are some bathrooms in A-Wing that are missing vents. There is no re-circulated air in the MUA units for A, B or C-Wing.

Although AC units (Mitsubishi PKFY-P06NLMU-E and suspended ceiling units B9D-17/19) were installed in late spring 2023, they are not considered influential in viral particle dispersion and were excluded from CONTAM simulations. Energy reports identified windows as potential sources of air and thermal leakage, prompting attempts to measure leakage rates using ABM devices. However, all attempts to measure closed window leakage resulted in zero flow measurement values.

Three rounds of measurements were taken during each of Winter 2022-2023 (before upgrades were complete), Summer 2023 (MUA units replaced, AC units installed), Winter 2023-2024 (Ventilation fans replaced); most measurements of the bathroom exhaust fans were able to be completed each of the three rounds, however, some resident's rooms were closed during the measurement period, so some measurements were only taken once or twice. This is not a concern for accuracy since little variance was observed between measurements in each season due to the constant supply volume system. ABM Easyhood and ABM 200 (CPS, 2024) sensors were used for vents smaller than 0.30 m x 0.30m, with a hood extender utilized for larger vents. Each measurement with the ABM Easyhood waited for the volumetric flow measurement to stabilize, and then was recorded for approximately 10 seconds. The "Regular Test" mode measured volumetric flow rates of 59.5-1223.3$\frac{m^3}{h}$, while the "Low Volume Test" (11.9-84.9$\frac{m^3}{h}$) required a special adapter plate. However, discrepancies between "Low Volume" and "Regular" test results prompted additional sweeps and consultation with the manufacturer, though no resolution was reached. For consistency, the highest flow rate measurement was considered for simulations and analysis.

For some of the Summer 2023 testing, open windows were measured using the ABM 200 sensor; however, the values of airflow through the windows were highly fluctuant over the 30-second period.

This comprehensive methodology ensures accurate data collection and robust analysis, which are essential for assessing the efficacy of HVAC upgrades in mitigating viral transmission risks at EGCCC.

The TSI 5825 Micromanometer, was used to gauge the pressure disparity between two sampling ports. In this project, it was employed to assess the pressure difference across doorways within the EGCCC facility. This involves attaching rubber tubing to each port and feeding one sampling tube under the door to acquire measurements from both sides. Positioning the tube ends at the door's midpoint and ensuring their orientation is perpendicular to the airflow beneath the door facilitates static pressure measurement. Each measurement required the pressure value to stabilize to approximately ± 1.4kPa before recording the measured pressure for 10 seconds. This measurement method was used in C-Wing Winter 2023-2024 measurements of door leakages and models for estimating the pressure difference to air flow measurement were created based on analysis of velocity measurements and door pressure measurements in A/B Wing Winter 2023-2024 measurements.

The TSI 9545, serves as an air velocity meter equipped to measure air velocity, temperature, and humidity. In this project, it was deployed to assess airflow dynamics across various points: through door cracks, oversized Makeup Air (MUA) registers.

Each measurement point underwent a sampling duration of 10 seconds, with a criterion of maximum permissible fluctuation set at +/-0.03 m/s. Instances of highly variable measurements within this timeframe prompted a retake to ensure data integrity. Door leakage measurements were particularly crucial to account for airflow not captured by the ABM Easyhood (as described in the subsequent section).

Door leakage measurements were conducted by assessing the door gap at 12 points around the door's perimeter using a tape measure. The 9545 Air Velocity Meter was then employed to measure air velocity through these door gaps.

The validation measurements were completed by the AQM 102 Carbon Dioxide Monitor and Data Logger. Several locations throughout the A/B Wing hallway, dining area and lounge area were selected. Each location was measured for 1 minute and the average CO_2 measurement was recorded by hand on a floor plan. The number and gender of residents and staff and the activity during the measurements were also recorded. The Measurement ranges and errors are summarized in Table 1 (CPS, 2024) (TSI, 2024) (Dwyer Omega, 2024).

The typical error calculation used in previous works compares the absolute concentration of CO_2 measured and simulated, as shown in equation (1) below.

$$\%\,Error = \frac{c_{Measured} - c_{Simulated}}{c_{Measured}} * 100\% \qquad (1)$$

However, since most of the CO_2 is already present in the ambient air and the CONTAM models are simulating to find concentrations of CO_2 above the ambient concentrations, a modified %Error calculation relative to ambient concentrations is used in this paper and is shown in equation (2) below.

$$\%\ Error_{Above\ Ambient} = \frac{C_{Measured} - C_{Simulated}}{C_{Measured} - C_{Ambient}} * 100\% \quad (2)$$

The COVID infection testing was conducted using available, government-approved test kits. On Oct 17th 2020, residents in rooms 4B08, 4B13 and 4B20 were tested for COVID, and the results came back positive. On Oct. 20th, all residents on the 4th floor were tested for COVID and only the residents in room 4A16 had a negative test result. On Oct 21st, all residents on the 5th and 7th floors were tested for COVID and an additional 15 rooms had residents that tested positive for COVID. Regular testing began, meaning any non-infected residents were tested every 2-3 days in the A/B and C-Wings.

For the simulations CONTAM's recommended practice for representing closed windows was used. For the validation of the simulation using CO_2 measurements, if there was an open window, a "Two-way Single Opening" was created between the room and the ambient zone with dimensions of the window width (1.117m) and an opening of 0.1m.

Table 1:Summary table of devices and measurement errors.

Equipment	Measurement Range	Measurement Error
ABM Easyhood Low Volume	11.9-84.9$\frac{m^3}{h}$	$\pm 5\%\ of\ reading$
ABM Easyhood Regular	59.5-1223.3$\frac{m^3}{h}$	±5% of reading
TSI 5825	$\pm$3735 Pa	$\pm 1\%\ of\ reading \pm 1Pa$
TSI 9545	0-30 m/s	$Greater\ of$: $\pm 3\%\ of\ reading \pm 0.025\ m/s$
AQM 102	0-9999 ppm	$Greater\ of$: $\pm 3\%\ of\ reading \pm 30\ ppm$

CONTAM 3.4.04 was used to simulate the CO_2 generation and concentrations throughout the 4th, 5th and 7th floors. For this paper, each floor was simulated separately. For these simulations, the typical schedule of staff and residents is shown in Table 10. The A/B Wings have 6 Frontline staff, and office staff in the A06 and A07 rooms. Each resident room is assumed to have each bed filled with a resident and the active residents were determined based on the values of CO_2 measurements. The MET values for the residents and staff were determined based on Table 2 and Table 3.

After setting up the initial simulations, tests were conducted to determine the optimal combination of variables. These included the number of residents who were in bed versus those active during the day, and which windows were open. Our goal was to find the simulation scenario that most closely matched the measured data. The results shown in have the simulation scenario that best matched the measured data. (A. Persily, 2017). The measurement data and summaries of room volumes inputted in the CONTAM simulations are not shown in this paper due to space constraints. The CONTAM simulations did not accurately show CO_2 concentrations if the bathrooms had zero airflow. When a bathroom exhaust vent measured zero air flow, an airflow of 11.9 $\frac{m^3}{h}$ (7 CFM) was applied based on the ABM Easyhood lowest measurable value shown in Table 1. The CONTAM simulations that were representing the different ASHRAE and CSA Standards used the relevant minimum required airflows from each respective standard as inputs to the simulation.

Table 2 MET Values to CO_2 Generation Based on Age.

MET	CO_2 Generation	
	Staff (Age 40-49)	**Resident (Age 70-79)**
1.0	-	0.0031 L/s
1.4	0.0054 L/s	0.0045 L/s
1.6	-	0.0051 L/s
1.8	0.00694 L/s	-
3.5	0.0111 L/s	-
4.0	0.0127 L/s	-

Table 3: MET Values Based on Activities (ProCon, 2022).

Activity	MET Value
inactivity quiet/light	0.95
self-care eating, sitting	1.5
tai chi, qi gong, sitting, light effort	1.5
talking or singing, attending a ceremony, sitting, active participation	1.8
walking, 3.0 mph, moderate speed, not carrying anything	3.5
chambermaid, hotel housekeeper, making bed, cleaning bathroom, pushing cart	4.0

To calculate the concentration in each room, Equation (3) was used along with the ode (ordinary differential equation) function in MATLAB. Chat GPT was used to assist with coding of the exposure risk calculations (Openai, 2024).

$$v\frac{dC(t)}{dt} = q \circ I - VC(t) \quad (3)$$

where v is a column vector of zone volumes, $C(t)$ is the concentration of contamination in units of (quanta/m^3), q is the quanta production rate of infectious individuals (quanta/min), I is the number of infectious individuals and V is the ventilation matrix with units of (m^3/min) which is shown in detail in equation (4) (Alexander J. Edwards, 2023). These equations were used along with the MATLAB ode function to generate simulations of the outbreak on the 4th, 5th and 7th floors of the EGCCC based on the airflows before the upgrade, after the upgrade and assuming that the exhaust ventilation met ASHRAE Standard 170 and ASHRAE standard 241 (Openai, 2024).

$$V = \begin{bmatrix} Q_1 + \sum_k \beta_{1k} & -\beta_{21} & -\beta_{31} & \cdots & -\beta_{M1} \\ -\beta_{12} & Q_2 + \sum_k \beta_{2k} & -\beta_{32} & \cdots & -\beta_{M2} \\ -\beta_{13} & -\beta_{23} & Q_3 + \sum_k \beta_{3k} & \ddots & -\beta_{M3} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ -\beta_{1M} & -\beta_{2M} & \cdots & -\beta_{M-1,M} & Q_M + \sum_k \beta_{Mk} \end{bmatrix} \quad (4)$$

$$\frac{dE(t)}{dt} = \lambda S(t) \quad (5)$$

$$\lambda(t) = pC(t) \quad (6)$$

$$E(t) = pC(t)S(t) * t$$

$$t_{Exposure} = \frac{1}{0.01\frac{m^3}{min} * C_{steady}} \quad (7)$$

For the expected exposure calculation E is the expected number of people exposed which is defined as a person being infected but not infectious (Alexander J. Edwards, 2023). S is the number of susceptible individuals, λ is the infection rate, p is the pulmonary rate which is assumed to be $0.01\, m^3$ /min (Alexander J. Edwards, 2023). For simplicity, this paper assumes that the infected individuals stay in their beds while they are contagious and that the only people visiting their rooms are the staff taking care of them. Equation (7) was created to evaluate the expected amount of time for a single person to be exposed to the aerosolized viral particles based on the steady particle concentration and the expected pulmonary rate of people. This can be manipulated to calculate the $t_{Exposure}$ which is the time until a single susceptible person in a room is expected to become infected with a virus, given the steady state concentration in the room. To reduce the spread of an infection, having a higher $t_{Exposure}$ is beneficial.

Results

Table 4: Pre-Upgrade (Winter 2022-23)- A/B Wing ACH Compliance Summary.

Location (Floor-Wing)	% of Resident Rooms Compliant with Standards		
	ASHRAE 170	ASHRAE 241	CSA Z317.2:19
4-A/B	19%	24%	10%
5-A/B	33%	38%	14%
7 A/B	29%	38%	14%
Average A/B	27%	33%	13%

Results from the ventilation measurements on the 4th, 5th and 7th floor of the A/B Wing and C-Wing were used to compare to ASHRAE Standard 170-2017 (Ventilation of Healthcare Facilities), ASHRAE Standard 241-2023 (Control of Infectious Aerosols), and CSA Z317.2:19 Table 1.27.2 Class A Facility (100% outside air system) (Special requirements for heating, ventilation, and air-conditioning (HVAC) systems in health care facilities). For each resident room, ASHRAE Standard 170-2017 Table 7-1 Behavioural and Mental Health Facilities (patient bedroom, resident room) recommended 2 (air change per hour) ACH of outdoor air, ASHRAE Standard 241-2023 Table 5-1 Healthcare Resident Room requires 84.8m3/h/occupant (50 CFM/occupant), and CSA Z317.2:19 requires 4 ACH total and 2 ACH of outdoor air.

Table 4 shows a summary of the A/B Wing's compliance with the standards and Table 5 shows the comparison after the HVAC upgrades. C-Wing's compliance with the standards is shown in Table 6.

This data, along with the information from Table 4, Table 5, and Table 6, was used to generate Figure 1 and 2, which plot the % Infection rate as a function of % Rooms compliant with ASHRAE 241 and ASHRAE 170, respectively. Table 7 shows the percentage of infected people during the Covid-19 November 2020 outbreak (Covenant Health, 2020).

Table 5: Post-Upgrade Winter (2023-24)- A/B Wing ACH Compliance Summary.

Location (Floor-Wing)	% of Resident Rooms Compliant with Standards		
	ASHRAE 170	ASHRAE 241	CSA Z317.2:19
4-A/B	30%	33%	10%
5-A/B	10%	5%	5%
7-A/B	33%	29%	14%
Average A/B	23%	20%	9%

Table 6: C Wing (Winter 2023-24) ACH Compliance Summary.

Location (Floor-Wing)	% of Resident Rooms Compliant with Standards		
	ASHRAE 170	ASHRAE 241	CSA Z317.2:19
4-C	50%	43%	14%
5-C	86%	86%	14%
7-C	57%	50%	36%
Average C	64%	60%	21%

Table 7: % Infected during November 2020 Covid-19 Outbreak.

Wing	% Residents	% Staff	% People
4AB	100%	45%	71%
5AB	63%	23%	41%
7AB	77%	40%	57%
4C	5%	0%	2%
5C	9%	0%	4%
7C	0%	4%	2%

The results of the attempted validation are summarized in . The average absolute errors from the different validation simulations were at a minimum of 35.2 ppm, a maximum of 86.4 ppm, and an average of 56.3 ppm. The % error above ambient CO_2 concentration ranges from 34% to 239% error and has an average of 110% error of CO_2 value above the ambient concentration. One key issue with these measurements is that for the AQM 102 CO_2 logger the measurement error was at least ±30 ppm (Table 1) which could account for between 35%-85% of the error in the simulations.

The results of the MATLAB exposure simulations are summarized in Table 8, based on calculations from the Simulated room calculations from Equation (3) and the expected time until exposure shown in Equation (7).

Table 8: Simulated Expected Time Until Exposure for 4th Floor of EGCCC.

Expected Time Until Exposure for staff (minutes)				
Floor Section	**Before Upgrade**	**After Upgrade**	**ASHRAE 170**	**ASHRAE 241**
A Wing Staff	127	108	135	177
B Wing North Staff	221	220	286	227
B Wing South Staff	178	202	129	156
C Wing Staff	521	-	494	505

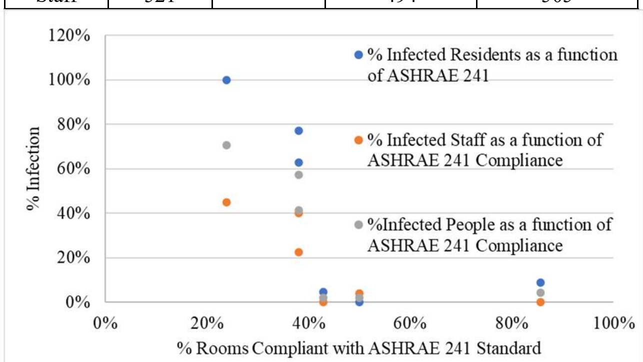

Figure 1: Infection Rate in November 2020 Outbreak as a Function of % Rooms Compliant with ASHRAE 241 Standard.

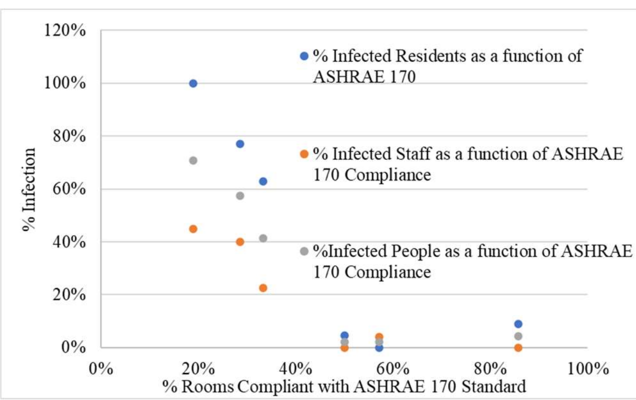

Figure 2: Infection Rate in November 2020 Outbreak as a Function of % Rooms Compliant with ASHRAE 170 Standard.

Discussion

Based on the results of the CO_2 validation summarized in , the CONTAM model and validation procedure had extreme difficulty in predicting the contribution of CO_2 of the staff and residents to the building and resulted in an average of 110% error above the ambient CO_2 Concentration of 419.7 ppm (Envrionment and Climate Change Canada, 2023) as shown in equation (2). The +/-5% error of the ABM Easyhood could be significantly contributing to the error, when the error calculation ignores the equipment error (30 ppm) the average error above ambient is reduced from 110% error to 46% error (CPS, 2024). In previous papers, high levels of error were found during CO_2 validation studies usually in the range of 10-30% and those studies specified to treat their models and conclusions as indicative of air flows and contaminant concentrations but not representative of the exact buildings. If our error is taken using the same methodology of taking it based on the absolute CO_2 concentration as shown in equation (1) we get around 12.7% error, therefore our models are a similar level of accuracy to previous publications (Kishwer Adbul Khaliq, 2024).

In Figure 3 it can be seen that a majority of the resident bathrooms are identified as either having "No Airflow On Any Floor" or "Critically low airflow" based on their exhaust ventilation rates. Under ASHRAE Standard 241, deficiencies in ventilation rates can be made up for by using portable air cleaners or other similar equipment and is being worked on by the AHS HVAC team.

Tables 4 and 5 show that the approximately 75% of the resident rooms in the A/B wing do not meet ASHRAE 170 Standard requirements for ventilation rates before the upgrade and 78% do not meet standard upgrades after the upgrade. This is largely due to an imbalance in the supply and ventilation throughout the floor, where many rooms have zero measured exhaust airflow while others have over 300% of the required exhaust air flow rate.

Table 6 shows that C-Wing had a 64% of its rooms meet the requirements for ventilation rate based on the ASHRAE 170 Standard for Ventilation of Healthcare Facilities (2 ach per resident room), and 60% of resident rooms compliant with the ASHRAE 241 standard for Control of Infectious Aerosols. Based on the low infection rate in the C-Wing this amount of airflow may be sufficient for buildings where strict hygiene procedures are followed.

Table 7 shows the results of the COVID-19 testing during the Oct-Nov 2020 Outbreak. The A/B-Wing had an average resident infection rate of 80% across floors 4, 5 and 7, while C-Wing only had 4.7% of residents infected. Since the residents are of a similar demographic between the A/B and C wings and the COVID protocols between the wings were similar, it can be assumed that it is a difference between the wings themselves. Based on the airflow measurements, we can see a significant difference in both the amount of airflow exhaust in each of the wings, as well as the balance of the exhaust throughout the wings. Figure 1 shows that as the % compliance of the room ventilation to ASHRAE Standard 241 increases, the rate of infection decreases. This suggests that in this study, for this building, once a room reaches approximately 40% of the ASHRAE Standard 241 requirement of 84.9 $\frac{m^3}{h}$ (50 CFM) per resident the probability of infection is significantly decreased. Similarly, Figure 2 shows that at around 50% of compliance with the ASHRAE Standard 170 of 2 ach, the infection rates on the floors are much lower. The issue with this conclusion is that the data points with low infection rates are all in the C-Wing, and all the high infection rates are in the A/B Wing, so it is possible there is another difference in the two wings that this study is not aware of which is causing the extreme difference in rate of infection.

Table 8 shows that for resident rooms where the residents are contagious with COVID-19, the time it takes until a single not-infected person is expected to be exposed to the virus ($t\_expected$) was 176 minutes in the A/B Wing before the HVAC upgrade and was 177 Minutes after the upgrade. This minimal change in the risk of infection is due to the fact that the HVAC upgrades did not address the low exhaust ventilation rates in a majority of the A Wing that is represented in Figure 3. Table 8 also shows that if the A and B wing exhaust ventilation system was changed to meet the high ACH required by ASHRAE 241, the time until exposure is only significantly improved in the A-Wing. In contrast, the C-Wing, which had a significantly lower infection rate during the 2020 outbreaks, had an average $t_{expected}$ was 521 minutes. C-Wing infection risk is significantly lower since the $t_{expected}$ is significantly higher, meaning that it takes significantly longer for a susceptible individual to become infected. The rooms in C-Wing on average matched the $t_{expected}$ for the ASHRAE 170 and ASHRAE 241 air change rates, however, for the 4th floor of C-Wing, the air change rates in each room varied significantly, causing the $t_{expected}$ for each room to range from 230 minutes to 1128 minutes.

The actual infection risk for staff visiting is dependent on many factors, including the Personal Protective Equipment (PPE) used, the sanitization procedure, proximity to the contagious resident, the amount of time they spend around the contagious resident, and actual airflow in the rooms. Many of these factors were not documented during the 2020 outbreak. Hence, it is not possible to estimate the probability of infection of each staff and track how they may have carried the virus to other patients. The simulations and data we have collected show a strong correlation between higher air change rates and lower infection rates throughout the EGCCC; the results also suggest that for this scenario there are diminishing returns in terms of infection risk prevention past approximately 1 ach or approximately 34 m^3/h/occupant of ventilation per person in a room at this facility where strict hygiene and PPE requirements were followed.

Originally this paper planned to investigate the effects of portable air cleaners added to the A/B wings to reduce the risk of transmission. The locations of installation of this equipment in the actual hospital are in the A/B wing dining rooms. Based on the assumption that the contagious residents are confined to their rooms and the airflow results show that there is no airflow from resident rooms to any public areas, the inclusion of this equipment did not affect the simulated results. For future work, this project will be investigating contaminant flow within each resident room and seeing if a localized air purifier could eliminate significant amounts of aerosolized viral particles in rooms with contagious residents.

Conclusion

This paper provides a detailed comparison of ventilation rates and infection risk at the Edmonton General Continuing Care Centre. This project was a collaboration between Alberta Health Services, Covenant Health, and the University of Alberta Mechanical Engineering Department which aimed to address the safety of frontline workers and long-term care residents during virus outbreaks.

The combination of experimental measurements and simulations highlights the extreme discrepancy in infection rate and ventilation rates between the C-Wing and the recently upgraded A/B wing. The results of the simulations show that there is a strong correlation between the high rates of infection in the A/B wing and the relatively low rates of ventilation in the resident rooms. This suggests that proper, balanced ventilation is critical for the reduction of infection risk. This study also shows that for this scenario of viral outbreaks in a long-term care facility that is following strict sanitation and personal protective equipment protocol, the positive effects of ventilation diminish significantly after approximately 1 ach and 34 m^3/h/occupant in this facility. Therefore the air change rates specified in ASHRAE 170 and ASHRAE 241 may not have as much impact for the cost of heating and moving fresh outdoor air as localized air purification assuming that strict hygiene and masking is followed.

In future work, this project will delve into alternative air purification solutions aimed at mitigating infection risks without necessitating substantial increases in the facility's air change rate, which could incur significant installation costs and energy consumption, thereby posing environmental concerns. Computational Fluid Dynamics (CFD) will be employed to enhance the precision of modelling aerosolized viral particle movement within rooms, facilitating optimal placement strategies for Upper-Room Ultraviolet Germicidal Irradiators and portable air filters to effectively minimize transmission risks.

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Table 9: CONTAM Validation Summary

Simulation	# of Rooms in Validation	CO_2 Simulated/ Measured Comparison		
		Average Absolute Error (ppm)	% Error Above Ambient	RMSE (ppm)
4th Floor, May 4th Breakfast	9	62.2	89%	77.53
4th Floor May 4th Sing	12	52.7	239%	54.33
4th Floor May 11th Sing	11	86.4	110%	104.2
5th Floor April 18th Lunch	4	40.2	42%	145.1
5th Floor April 18th Exercise	7	37.5	34%	43.4
7th Floor April 27th Bingo	14	35.2	66%	53.4
7th Floor April 27th Lunch	15	79.8	188%	102.5

Table 10: MET and Activity Schedules for CONTAM Simulations

Row Description	Time	Frontline Staff	Office Staff	Resident Bed	Resident Active
Location Metabolic Rate	00:00-7:00 Morning	Common 3.5 MET	Out of Building	Room 1.0 MET	Room 1.0 MET
Location Metabolic Rate	7:00-8:45 Wakeup	Resident Rooms 4 MET	Office 1.5 MET	Room 1.0 MET	Common 1.4 MET
Location Metabolic Rate	8:45-9:45 Breakfast	Common 1.5 MET	Office 1.5 MET	Room 1.4 MET	Common 1.4 MET
Location Metabolic Rate	9:45-11:00 Morning	Common 3.5 Met	Office 1.5 MET	Room 1.0 MET	Common 1.0 MET
Location Metabolic Rate	11:00-12:00 Lunch	Common 1.5 Met	Office 1.5 MET	Room 1.0 MET	Common 1.4 MET
Location Metabolic Rate	12:00-13:45 Activity	Resident Rooms 4 Met	Office 1.5 MET	Room 1.4 MET	Activity 1.6 MET
Location Metabolic Rate	13:45-15:00 Afternoon	Common 3.5 Met	Office 1.5 MET	Room 1.0 MET	Common 1.0 MET
Location Metabolic Rate	15:00-16:00 Dinner	Common 1.5 Met	Office 1.5 MET	Room 1.4 MET	Room 1.4 MET
Location Metabolic Rate	16:00-18:00 Evening	Common 3.5 Met	Out of Building	Room 1.0 MET	Common 1.0 MET
Location Metabolic Rate	18:00-19:45 To bed	Resident Room 4 Met	Out of Building	Room 1.0 MET	Common 1.4 MET
Location Metabolic Rate	19:45-24:00 Night	Common Area 3.5 Met	Out of Building	Room 1.0 MET	Common 1.0 MET

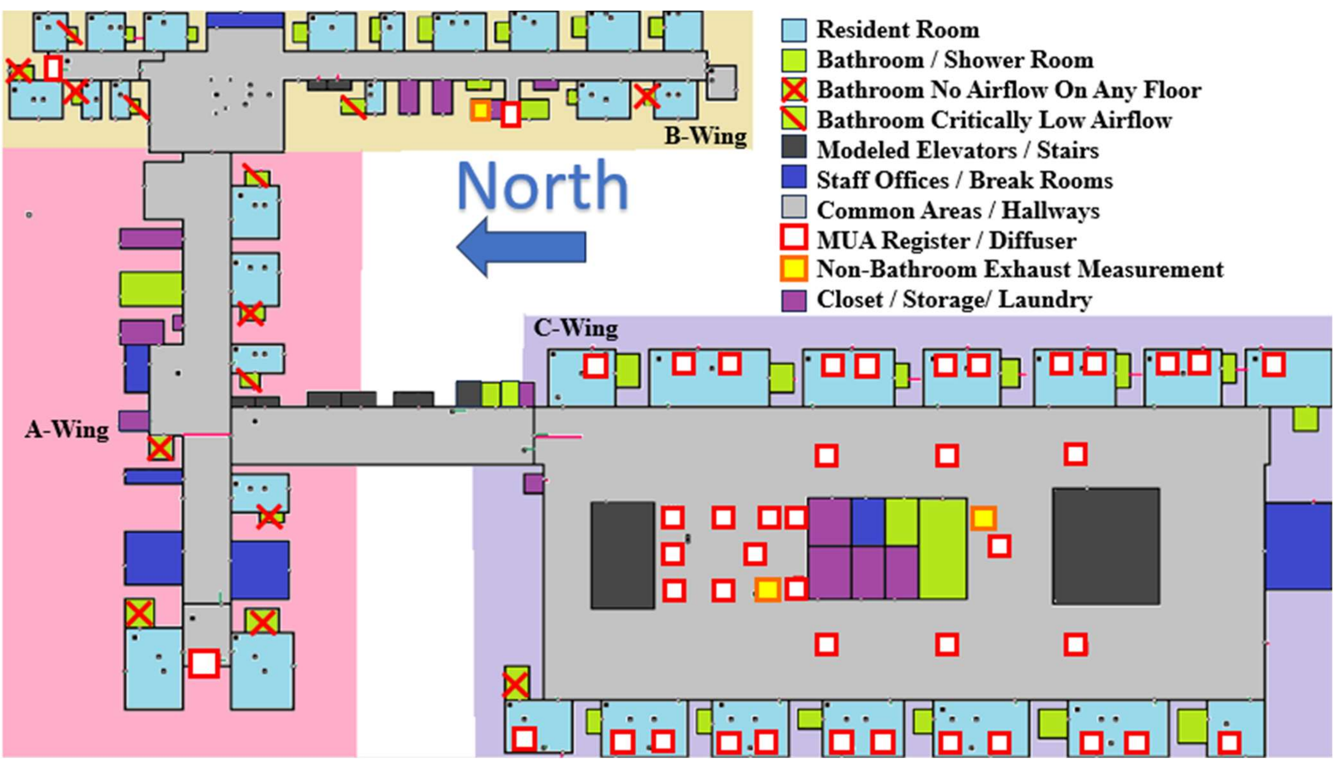

Figure 3: Typical Floor Layout for EGCCC Resident Floors 4, 5 and 7