Corridor Pressurization System Performance in Multi-Unit Residential Buildings

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ABSTRACT

Corridor pressurization based ventilation systems are pervasively used to ventilate mid- to high-rise multi-unit residential buildings in North America. This paper provides a summary of a study evaluating the performance of these systems based on an experimental program conducted at a case study building which has undergone an energy efficient building enclosure retrofit. In particular, the efficiency and effectiveness of these systems at providing ventilation air to the zones of the building will be assessed, along with the interaction between the ventilation system and the exterior environment.

The experimental program carried out at the case study building includes measurement of airflow rates provided by the make-up air unit, measurement of flow rates between zones of the building using perfluorocarbon tracer methods, and long-term monitoring of pressure differences. Exterior conditions including wind speed and direction, temperature, and relative humidity were monitored using a weather station installed on the roof of the building to allow for evaluation of the interaction between the building and the exterior environment. Pressure equalized airtightness testing was also performed on a sample of suites to measure the airtightness provided by both the exterior enclosure and interior compartmentalizing elements. The results of this extensive experimental program are presented and conclusions are drawn with regards to the interaction of the driving forces of airflow (wind, stack effect, and mechanical ventilation systems) with the physical building to create airflow patterns in mid- to high-rise multi-unit residential buildings. The performance of the corridor pressurization ventilation system is specifically evaluated including discussion of its limited potential for use moving forward due to generally poor measured performance and increasing energy efficiency and indoor air quality expectations.

Overall, this study works to improve the understanding of corridor pressurization based ventilation system performance as well as the general understanding of airflow patterns in mid- to high-rise multi-unit residential buildings. This knowledge can then be applied to the design of improved ventilation systems and compartmentalization strategies for these buildings. Effort is made to extend the conclusions of the study to meaningful recommendations for industry.

INTRODUCTION

Corridor pressurization based ventilation systems are pervasively used to ventilate mid- to high-rise multi-unit residential buildings in North America. This system uses a make-up air unit (MAU), usually located on the roof of the building, to draw fresh air in with a large fan either continuously or on a pre-set schedule. Once the air is drawn into the building, it is distributed to each floor through a large vertical duct usually located in the building core. A grille is provided

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in this duct at each floor to allow air to flow from the duct to the corridor. This flow of air into the corridor pressurizes the corridor relative to the surrounding spaces (thus giving the system its name) and this pressure is intended to force air through intentional gaps below the suite entrance doors and into the suites. Typically these ventilation systems are supplemented with intermittent occupant controlled point-source exhaust fans often located in bathrooms, kitchens, and incorporated into clothes dryers, to exhaust high concentrations of air contaminates. As well as providing ventilation air to the corridors and suites, the pressurization of the corridors relative to the surrounding suites is intended to prevent the flow of contaminates such as tobacco smoke and cooking odors from suites to the corridors and from one suite to another via the corridor. Despite its pervasive use, anecdotal accounts of poor performance and supporting research are common.

This paper provides a summary of an ongoing study of the performance of the corridor pressurization based ventilation system at 13-storey multi-unit residential building in Vancouver, BC. The building was originally constructed in 1986, has a gross floor area of approximately 5,000 m² (54,000 ft²), and has 37 residential units with an average of 125 m² (1,340 ft²) each. The residents of the building are typically 55 years or older and many spend much of their time within their suites, unlike some condominiums which are occupied for fewer hours per day. The building is ventilated by an MAU on the roof of the building using a corridor pressurization based ventilation strategy. Overall, the case study building is archetypically representative of much of the existing mid- to high-rise multi-unit residential housing stock constructed from the 1970's through 1990's across North America. In the latter half of 2013 the building underwent a significant building enclosure retrofit including over-cladding and window replacement. The potential impact of this retrofit on ventilation rates and airflow patterns is considered where appropriate.

To evaluate the performance of the ventilation system and its interaction with other drivers of airflow at this case study building, an experimental program was developed and implemented. This program includes:

- Measurements of airflow between zones using perfluorocarbon tracer (PFT) gas testing
- Measurements of airflow rates in to the MAU and airflow rates supplied to each corridor
- Measurements of exterior enclosure and interior compartmentalizing element airtightness using pressure neutralized testing techniques
- Monitoring of pressure differences between building zones

The methodology and results for each of these components of the experimental program are presented in the Experimental Program section of this paper. Conclusions are drawn at the end of the paper based on the compilation of the findings of each of the individual components of the experimental work. These conclusions are then extended to recommendations for the building industry with respect to multi-unit residential building ventilation system design. This paper provides a summary of this research work, and the complete airflow and ventilation component of this study is detailed in Ricketts 2014.

EXPERIMENTAL PROGRAM

The subsequent sections of this paper present the methodology and results for each of the components of the experimental program. First, measurements of the actual airflow (i.e. ventilation) rates are presented, and then measurements of other factors which may impact airflow rates are presented as means of explanation.

Perfluorocarbon Tracer Gas Testing

Airflow rates between zones of the case study building were measured using the perfluorocarbon tracer gas (PFT) testing method developed by Brookhaven National Laboratory. (Heiser, & Sullivan, 2002) (D'Ottavio, Senum, & Dietz, 1988) This testing used 7 distinct PFT gasses to tag the air in various suites of the case study building. Because the source release rate is known, and assuming that these gasses are well mixed with the air within a given zone, measurement of the quantity of these gasses in the air of the tagged zones can provide a measurement of the air change rates of the tagged zones as well as of the airflow rates between zones. To measure the concentration of the PFTs in the selected zones, capillary absorption tube samplers (CATS) were placed in each of the selected zones. These CATS absorb all of the PFT gasses simultaneously and when subsequently analyzed, they provide a time-averaged measurement of the concentration of each of the PFT gasses in the zone in which they were installed. For this testing, the sources and CATS were installed for a period of one week from April 10th to 17th, 2013 to capture typical occupancy patterns. For reference, the average exterior temperature during this period was 8°C and the average wind speed was 3.3 m/s.

The total air flow rates into the suites as determined by the PFT testing are provided in Figure 1.

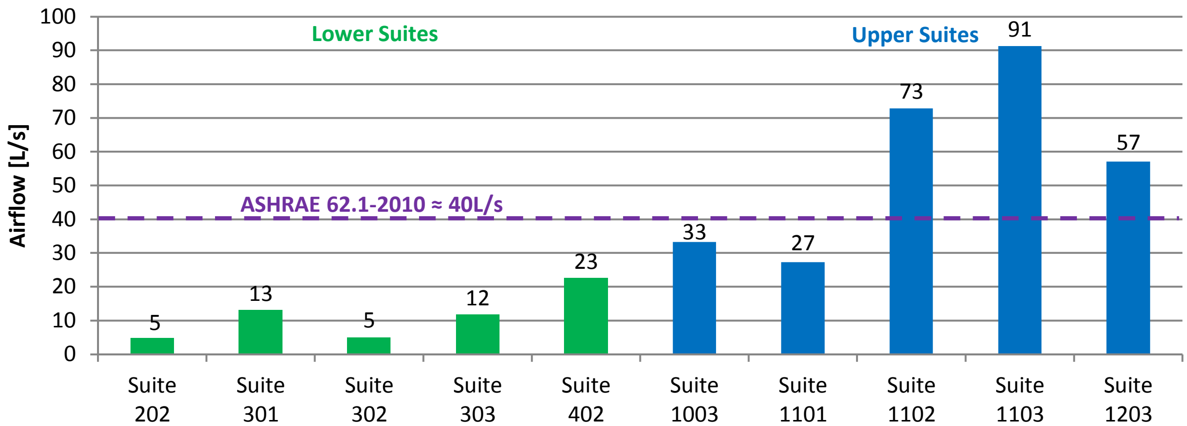

Figure 1 Chart showing the total airflow rate from all sources into each of the measured suites (to convert from L/s to cfm multiply by 2.13)

This figure indicates that there is an order of magnitude variation in the ventilation rates of the suites at the case study building. Typically, upper suites are more ventilated than lower suites, and most suites are either over- or under-ventilated compared to modern ventilation standards. (ASHRAE 62.1-2010) The cause of this variation is discussed in subsequent sections of this paper.

Figure 2 and Figure 3 illustrate the airflow rates to and from adjacent zones for six suites at the case study building as measured as part of the PFT testing.

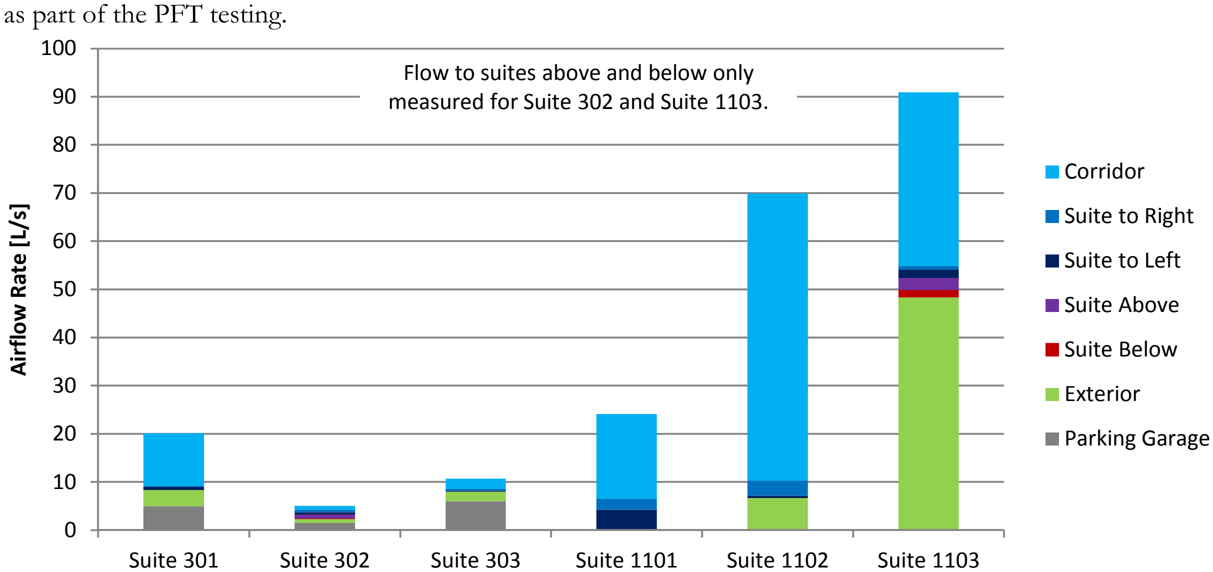

Figure 2 Chart showing source of airflow into suites for six suites at the case study building (to convert from L/s to cfm multiply by 2.13)

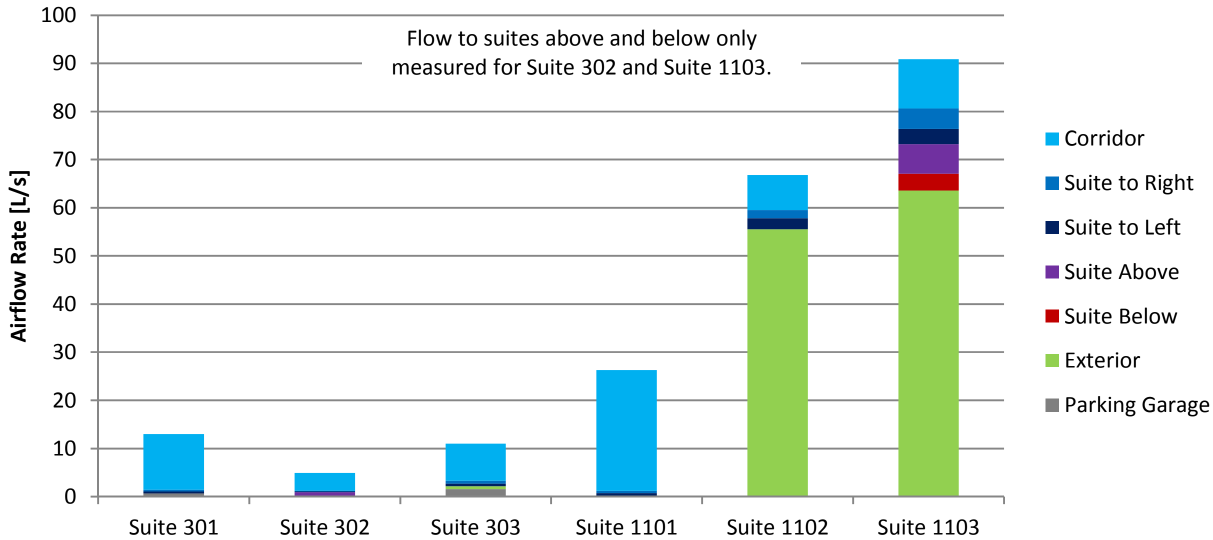

Figure 3 Chart showing airflow out of suites for six suites at the case study building (to convert from L/s to cfm multiply by 2.13)

Consistent with Figure 1, these figures also show significantly higher airflow rates into and out of the upper suites compared to the lower suites. Generally, this is due to higher airflow rates into the suite from the corridor (ventilation) and higher airflow rates out of the suites to the exterior. This finding is consistent with stack effect which would tend to cause exfiltration at the top of the building from the corridor through the suites to the exterior. This may also be caused by proximity to the make-up air unit and increased magnitude of wind on upper floors.

It is also apparent that the lower suites (Suite 301, Suite 302, and Suite 303) receive a significant proportion of the airflow into the suites from the parking garage. Parking garages often have relatively high concentrations of harmful contaminates including particulates, carbon monoxide, and various hydrocarbons from vehicle exhaust; consequently, airflow from the parking garage to occupied spaces of the building is a significant health concern.

Overall, the PFT testing at the case study building found that typically the upper suites are over-ventilated and the lower suites are under-ventilated compared to modern ventilation standards, and that there is an order of magnitude variation in the ventilation rates. These findings indicate that the corridor pressurization ventilation system at this building is not effectively or efficiently ventilating the suites. The cause of these airflow patterns is discussed in more detail in subsequent sections.

Make-Up Air Unit Airflow Measurements

The airflow patterns determined by the PFT testing may be as a result of improper operation of the MAU. To evaluate the performance of the MAU the intake airflow rate was measured using a custom made powered flow hood apparatus, and the airflow rates supplied to each corridor was measured using a balometer. The MAU flow measurement was correlated with a pitot tube pressure measurement and this pressure was monitored hourly and then converted to flow rate. Based on this monitoring, the flow rate of the MAU was found on average to be very similar to the rated flow rate of 1,560 L/s (3,300 cfm) at a static pressure of 250 Pa. Figure 4 provides the measurements of the airflow into the corridors from the MAU.

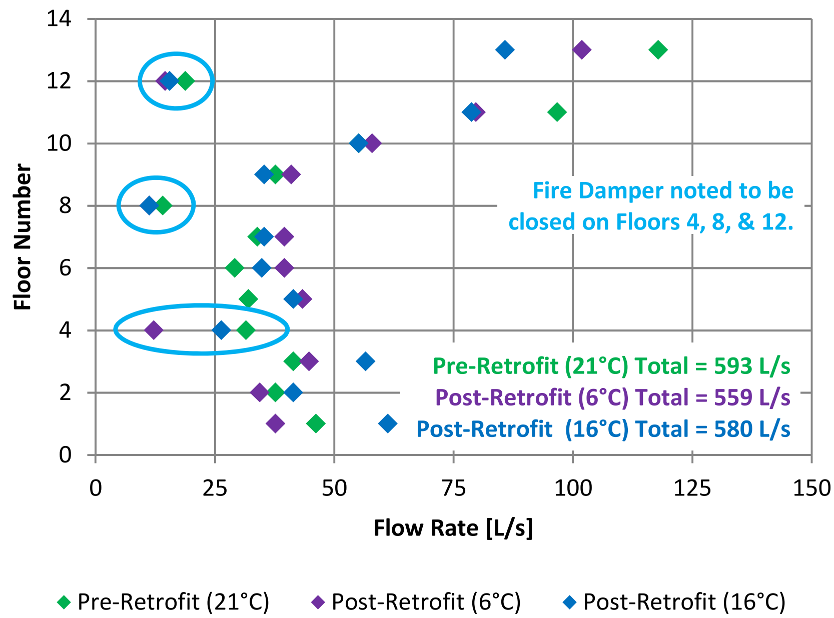

Figure 4 Graph showing measured airflow rates into each corridor through the MAU grilles (to convert from L/s to cfm multiply by 2.13)

This figure shows that the MAU is delivering significantly more ventilation air to the upper floors than to the lower floors, which is consistent with previously discussed findings indicating that the suites on upper floors are more ventilated than the suites on lower floors. Also, the total airflow provided to the corridors is only approximately 37% of the intake airflow rate, so the remaining airflow must leak out of the MAU duct prior to being supplied to the corridors. This loss of air from the duct is a significant inefficiency in the system.

Airtightness Testing

Airtightness resists airflow and it is possible that the distribution of airtightness of the exterior enclosure and of interior compartmentalizing elements is impacting the airflow patterns at the case study building. To evaluate the role of airtightness in creating the measured airflow patterns, pressure-neutralized multi-point fan depressurization/pressurization testing was performed. This technique uses multiple fans to sequentially develop and neutralize pressure differences across the exterior enclosure and interior compartmentalizing elements thereby determining the airflow resistance characteristics (i.e. the flow coefficient (C), and the flow exponent (n)) of each of the zone boundaries. This type of testing was performed on 3 corridors (Corridors 3, 9, and 11). The airflow resistances of the corridor compartmentalizing elements were determined by sequentially sealing openings to the corridors (i.e. suite entrance doors, elevator doors, stairwell doors, etc.). The average result of the 3 corridor tests is presented in Figure 5.

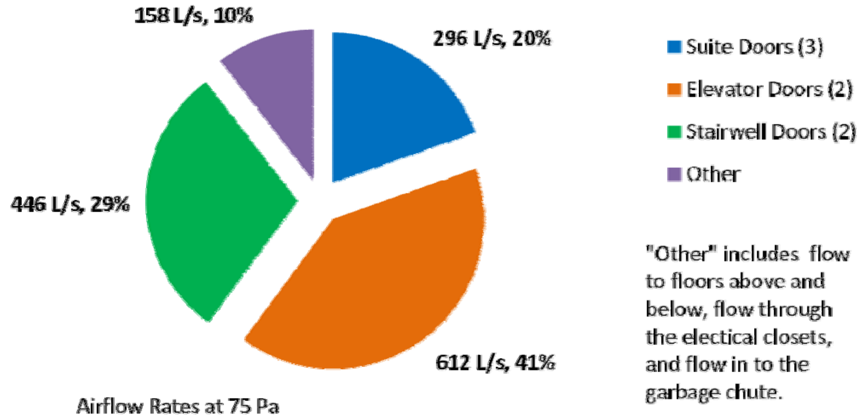

Figure 5 Chart showing the average distribution of airtightness for the three tested corridors

Figure 5 illustrates that when the corridor is equally pressurized relative to adjacent zones, only approximately 20% of the airflow paths are directly to the adjacent suites through the suite entrance door. As the pressurized corridor ventilation system relies on pressurization of the corridor to deliver ventilation air to the suites, this finding indicates a significant potential for loss of ventilation air to other adjacent spaces such as the stairwells and elevator shafts, and consequently a significant inefficiency in the system. Additionally, large flow paths to zones other than the adjacent suites make controlling pressure differences more difficult as the zones are less compartmentalized relative to each other.

Pressure Monitoring

A long-term monitoring program was implemented as part of the experimental program at the case study building. This monitoring included hourly measurements of pressure differences between various zones of the building as well as across the exterior enclosure at locations on each elevation near the top of the building and near the bottom of the building. As pressure differences drive airflows, these measured pressures provide an indication of the drivers that are creating the measured airflow patterns.

Stack effect was found to have a relatively large impact on the building pressure regime despite the relatively moderate climate of Vancouver, BC. Literature commonly discusses stack effect across the exterior enclosure, and the airtightness testing indicates that approximately half of the stack effect pressures should act across the exterior enclosure post-retrofit because the exterior enclosure and suite entrance doors have similar airtightness. However, the pressure measurements indicate that approximately 69% of stack effect acts across the boundary between the corridors and the adjacent suites. This is thought to be due to the use of operable exterior windows which, when open, provide large airflow paths relative to the airflow paths through rest of the exterior enclosure. Figure 6 shows the average pressure difference from the corridor to the adjacent suites for three upper floors and three lower floors. (Positive indicates the corridor is pressurized relative to the adjacent suites.)

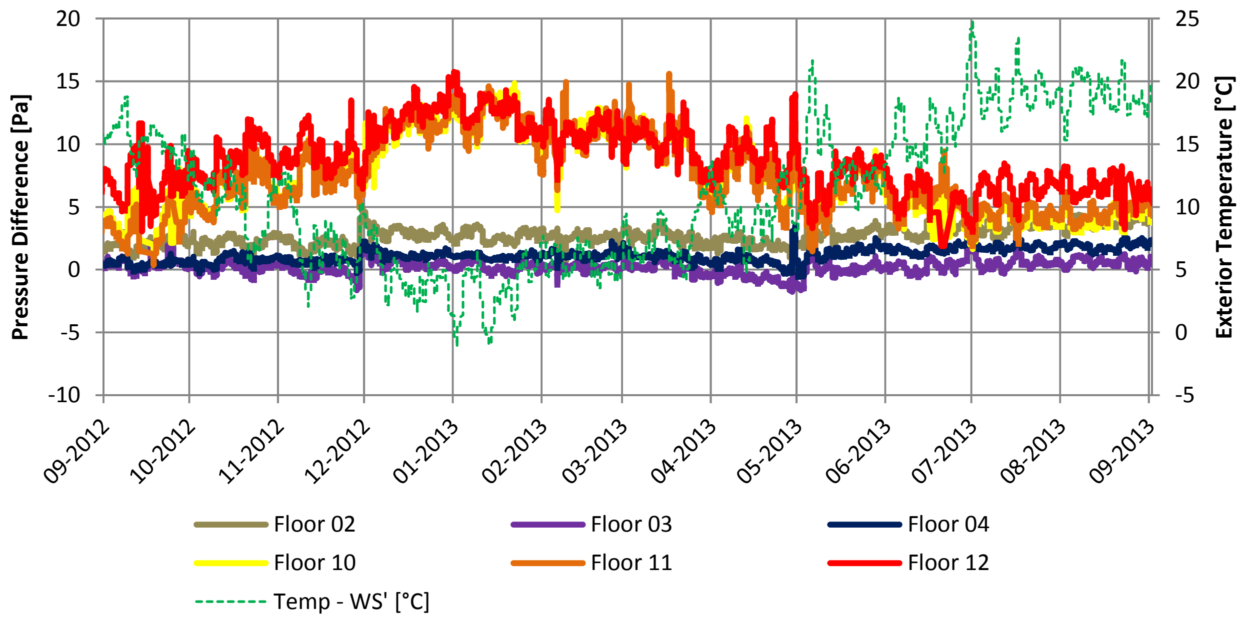

Figure 6 Graph showing the average pressure difference from the corridors to the adjacent suites for six floors at the case study building

This figure clearly illustrates that on upper floors the pressure of the corridor increases relative to the adjacent suites during colder periods of the year; while on lower floors there is little to no fluctuation. This finding is consistent with stack effect. Importantly the variation in the pressure on upper floors is approximately 10 to 15 Pa, and the MAU was determined to pressurize the corridor by approximately 5 to 10 Pa. Because these pressure differences are of similar magnitude and acting in the same location, it is likely that stack effect significantly affects ventilation rates within the case study building and is likely a major cause of the measured ventilation patterns.

Wind is another cause of pressure differences at buildings, and as one would expect, it was found to create the peak pressure difference across the building enclosure; however, typically these pressure acted for relatively short time periods. Wind also created the peak pressure differences across interior elements which could cause transfer of air contaminates between adjacent suites. Overall, pressures created by wind were found to be highly variable and difficult to predict.

CONCLUSIONS & RECOMMENDATIONS

A study was conducted at a case study building to evaluate the performance of the corridor pressurization based ventilation system. This study included measurements of airflow rates, airtightness, and pressure differences.

Overall, the pressurized corridor based ventilation system at the case study building was found to unevenly distribute ventilation air to both the corridors and suites of the building with upper zones receiving significantly higher ventilation rates than lower zones, and most suites being significantly over- or under-ventilated. This poor performance is in part likely due to significant leakage of ventilation air along the ventilation flow path both from the duct (approximately 60% leakage) and from the corridor (approximately 80% of flow paths not directly to the suites).

Effective distribution of ventilation air in the building is also significantly impacted by stack effect, and, on a shorter time-scale, by wind. These driving forces were measured to create pressure differences of similar (and frequently greater) magnitude as those created by the mechanical ventilation system. Furthermore, operable windows can significantly reduce the airtightness of the exterior enclosure such that pressures created by wind and stack effect frequently act across interior compartmentalizing elements such as suite entrance doors. In the case of stack effect, approximately 69% of the theoretical stack effect pressure difference was measured across the suite entrance doors. Given that these driving forces of airflow frequently act across interior compartmentalizing elements and are of similar magnitude to mechanically induced pressure differences, there is significant potential for overwhelming of the mechanically induced pressures and consequently for alteration of airflow rates and direction. Changes in the flow rates and direction due to stack effect and wind can lead to the under- and over-ventilation that was measured and can also cause contaminate transfer between zones.

As the elimination of operable windows and doors is not practical for residential buildings, these types of buildings should be designed to accommodate their operation. Consequently, interior compartmentalizing elements between suites and between the suites and the corridor should be relatively airtight such that the operation of windows in one suite does not significantly impact airflow and ventilation rates in other parts of the building. Additionally, floors and vertical shafts should be sealed to reduce the effective stack height and limit the development of associated pressure differences.

If suites are to be compartmentalized relative to adjacent to zones, the corridor pressurization based ventilation system is no longer a feasible option for ventilation of the suites, and the ventilation air would need to be ducted directly to each suite or supplied by in-suite systems. A significantly smaller corridor pressurization system could potentially be used to ventilate the corridors and could also help control contaminate transfer by pressurizing the corridors. This system would require significantly less airflow and be more predictable due to the compartmentalized nature of the corridors.

Overall, the case study building examined in this study is a typical multi-unit residential building, and many of the findings and conclusions are broadly applicable to multi-unit residential building ventilation system design. Based on the findings of this study, corridor pressurization based ventilation systems often do not appropriately or efficiently ventilate and control airflow in high-rise multi-unit residential buildings, and furthermore do not likely provide the potential to do so. Consequently, alternative ventilation designs should be used for these buildings and these systems would likely require compartmentalization of the suites and direct supply of ventilation air to each suite.

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NOMENCLATURE

IAQ = Indoor Air Quality
MAU = Make-up Air Unit
PFT = Perfluorocarbon Tracer

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