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Comparing air sealing techniques for suite compartmentalization in a multi-unit residential building: Aerosolized sealant vs. conventional air sealing approaches

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ABSTRACT

Recently, the use of aerosolized sealant has been proposed as an alternative to conventional (manual) air sealing approaches for suite compartmentalization in multi-unit residential buildings (MURBs). With this approach, aerosolized sealant is released into a positively pressurized zone; the resulting pressure differential across the zone partition draws the aerosolized product to the leakage paths where the particles accumulate until the leakage path is fully sealed. In theory, aerosolized sealants are more effective than conventional air sealing, as their installation does not require manual identification of leakage pathways. However, prior studies assessing the efficacy of aerosolized sealants have typically not included control groups, making it difficult to quantitatively compare aerosolized sealants against conventional techniques. This paper compares the performance of conventional air sealing approaches against aerosolized sealant (for suite compartmentalization) in a newly constructed MURB, in Toronto, Canada. Compartmentalization was assessed using unguarded, suite-level blower door tests. On average, suites sealed using aerosolized sealant were 27% tighter than those sealed using conventional approaches (q_{50} = 0.22L/s/m^2 of suite surface area (0.04cfm$_{50}$/ft^2) vs. 0.30L/s/m^2 (0.06cfm$_{50}$/ft^2), N = 5 suites per test group) – a statistically significant difference (t(8) = -2.01, p = 0.04). Guarded floor-level air leakage testing revealed that aerosolized sealant was most effective for leakage paths on vertical surfaces and had no impact on floor/ceiling airtightness. Apart from quantitative system performance, this paper discusses advantages and disadvantages of aerosolized sealants, based on lessons learned from the case study building. These results can help building designers and contractors weigh the relative benefits of using aerosolized sealants for suite compartmentalization.

1. Introduction/Background

In recent years, there has been a consistent trend of housing stock densification, particularly in urban areas. For example, in Vancouver, British Columbia, multi-unit residential buildings (MURBs) comprised only 34% of the housing stock in 1991; in 2021, this share increased to 43% [1]. During that same period, the percentage of single-family homes dropped from 50% to 28%. Similarly, in

Abbreviations: ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers; EnergyStar MFHR, EnergyStar Multi-Family High-Rise; LEED, Leadership in Energy and Environmental Design; MURB, Multi-unit residential building; ULC, Underwriters Laboratories of Canada.

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Toronto, Ontario, MURBs account for 59% of the housing stock, while single-family homes account for only 24% [2]. Coupled with the fact that humans spend, on average, 68% of their time at home [3], the design of MURBs has a huge impact on our quality of life.

MURBs present an interesting design challenge. They comprise both private zones (suites), and public zones (corridors, stairwells, elevators), separated by shared partitions. Within MURBs, uncontrolled air flow between different building zones has a large impact on a variety of building performance metrics, such as energy efficiency [4]; occupant comfort (increased sound and odour transmission [5]); and health and safety (pest transmission; pollutant/contagion transfer; and smoke/fire transmission [6]). Controlling inter-zonal air flow is critical for building performance and is accomplished via compartmentalization. Compartmentalization refers to the installation of continuous, airtight barriers between interior zones, effectively limiting inter-zonal air flow by isolating each zone from the others. From a design perspective, inter-zonal airtightness is covered by a combination of (1) prescriptive requirements in building codes, which primarily focus on maintaining the continuity of fire and acoustic separations, and (2) performance-based requirements in building standards and optional building certification programs. For new construction, LEED v4.1 for Multifamily Construction [7]; and EnergyStar Multifamily High-Rise Program (EnergyStar MFHR) [8] specify a maximum allowable suite-level air leakage rate of 1.52L/s/m^2 of suite surface area at 50Pa (0.30cfm_{50}/ft^2). ASHRAE 62.2 – 2022, "Ventilation and Acceptable Indoor Air Quality in Residential Buildings" specifies a slightly lower target of 1.00L/s/m^2 at 50Pa (0.20cfm_{50}/ft^2) [9]. The metric specified by LEED, EnergyStar and ASHRAE is an average air leakage rate, accounting for air leakage through both interior and exterior partitions, averaged over the entire suite surface area. LEED v4.1 has two additional targets, representing advanced performance: 1.17L/s/m^2 (0.23 cfm_{50}/ft^2) and 0.67L/s/m^2 (0.15cfm_{50}/ft^2) [7]. Building codes are also starting to incorporate performance-based air leakage requirements, including compliance testing for MURBs. The 2021 Edition of the International Energy Conservation Code (IECC), the national model energy code adopted by most US jurisdictions, specifies a maximum allowable air leakage rate of 1.52L/s/m^2 of dwelling unit enclosure area at 50Pa (0.30cfm_{50}/ft^2) for dwelling units in multi-family buildings [10]; however, most performance-based requirements for suite-level compartmentalization are still confined to optional building certification programs.

Despite large improvements in building envelope airtightness design practices in recent years (to help improve building energy efficiency, durability, and thermal resiliency), inter-zonal airtightness design practices have largely remained unchanged over the years. If we want to optimize building performance and ensure that our MURBs are comfortable and safe, we need reliable strategies to achieve high levels of compartmentalization.

1.1. Compartmentalization strategies in MURBs

Conventional air sealing approaches for interior partitions rely on the drywall (or interior wall finish) as the main plane of airtightness. Penetrations through the drywall finish and/or interfaces with other materials are sealed or gasketed, to form a continuous, airtight barrier. Installation of a polyethylene sheet between the interior wall finish and the back-up wall assembly has also been reported [11]. An obvious limitation of this strategy is that the air sealing is done manually. The resulting quality is contingent on the experience of the trades completing the sealing work, their diligence in finding leakage paths and the accessibility of these leakage paths. Another major limitation is that the interior sealing work is often completed at different points in construction, by different trades. This potentially leads to issues with installation and/or quality assurance [12,13]. In addition, compliance testing (if completed) is conducted at the end of construction, when suites are fully finished. Problems with air sealing completed earlier in the construction process may not be identified until the responsible trade has left site.

An alternative to conventional air sealing techniques is aerosolized sealant. To install in a suite, the aerosolized sealant is sprayed at the relevant partition(s) while the suite is positively pressurized using a blower door fan installed in the suite entrance door. Fig. 1 shows the equipment configuration and suite preparation, just prior to aerosolized sealant installation.

Under positive pressurization, the aerosolized particles are drawn towards any leakage paths in the surface finish (gaps, cracks, penetrations, etc.). The particles build up until the leakage path is fully sealed. The use of aerosolized sealants in building envelope air barrier and suite compartmentalization applications has been documented in the literature for the past 10 years [13–17]; however, similar technologies date back to the 1990's, when they were originally used for duct sealing applications [18]. Unlike conventional approaches, where air sealing is handled by multiple trades at different points in the construction process, the installation of the aerosolized sealant is handled by a single trade. From a construction sequencing and quality assurance perspective, this has many benefits. The use of aerosolized sealant has been documented in single-family home [13]; MURB [15,16]; and commercial/institutional whole-building [17] applications, with generally positive results.

All of these studies assessed suite and/or whole-building airtightness using the blower door test method. Briefly, a blower door test involves the pressurization and/or depressurization of a zone, relative to the exterior, using a calibrated fan. By pressurizing/depressurizing the zone to multiple test pressures and measuring both the pressure differentials induced by the fan, and the corresponding fan air flow rate required to maintain the pressure differential, one can determine the air leakage rate of the zone enclosure. Fig. 2 shows a schematic of the test configuration for a blower door test in a MURB suite. Two common airtightness metrics reported in the literature are air leakage rate at 50Pa, normalized by zone surface area (units of L/s/m^2 or cfm_{50}/ft^2) and air changes per hour at 50Pa (ach_{50}), which is the number of times per hour that the zone volume is fully exchanged with new air. Airtightness metrics are typically reported at a standard test pressure of 50Pa to allow for easy comparison between measurements at different buildings, and to overcome the baseline indoor-outdoor pressure differentials caused by wind and differences in indoor and outdoor air densities.

Air leakage rates tend to vary by construction type, with concrete partitions/buildings generally being more airtight than wood-frame assemblies. A recent study of 175 suite-level blower door tests from concrete-framed buildings constructed in Southern Ontario between 2007 and 2019 reported an average whole suite air leakage rate of 0.49L/s/m^2 at 50Pa (0.10cfm_{50}/ft^2) [19]. Minimum and maximum values were 0.16L/s/m^2 (0.03cfm_{50}/ft^2) and 2.51L/s/m^2 (0.49cfm_{50}/ft^2) and the mean ach_{50} for the sample was 2.02ach_{50}. In contrast, Bohac et al. reported a mean air leakage rate of 1.20L/s/m^2 at 50Pa (0.24cfm_{50}/ft^2) for a sample of suites in low-rise wood

Fig. 1. Aerosolized sealant installation apparatus.

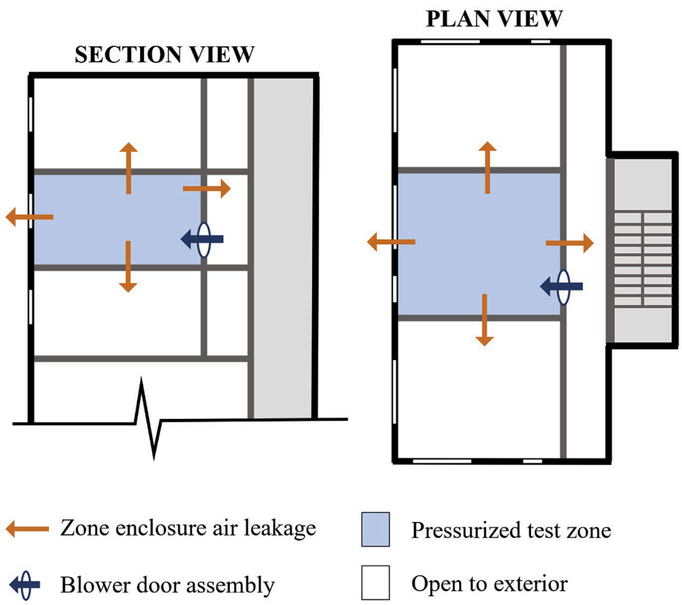

Fig. 2. Blower door test configuration for a MURB suite (pressurization test).

framed MURBs – more than twice the sample average from the concrete buildings (N = 274 suites) [20]. The mean air change rate was also higher than the concrete building sample, at 4.35ach$_{50}$ (range: 1.45 – 10.71ach$_{50}$).

Bohac and Harrington evaluated aerosolized sealant performance in residential buildings in California (N = 11 single-family homes), Minnesota (N = 15 single-family homes) and Illinois (N = 3 triplex units) [13]. Twenty-six of the 29 test buildings were compared against control groups, sealed with conventional air sealing techniques. The mean air exchange rate achieved using aerosolized sealant was 1.36ach$_{50}$ (range: 0.62 to 3.82ach$_{50}$, measured at building completion), which was, on average, 31% lower than the control group.

In MURB applications, Maxwell et al. assessed aerosolized sealant performance in three suites in a newly constructed concrete-framed building [15]. On average, the aerosolized sealant reduced whole-suite air leakage by 71% between the pre-sealed and fully finished state (0.55L/s/m^2 to 0.40L/s/m^2 at 50Pa (0.11cfm$_{50}$/ft^2 to 0.08cfm$_{50}$/ft^2)). The authors noted that the aerosolized sealant was useful for sealing difficult-to-reach or abnormally shaped penetrations, which would be difficult to seal manually. A major limitation of this study is that there was no control group, to compare the aerosolized sealant performance against conventional air sealing techniques. Bohac et al. used an aerosolized sealant to seal 18 suites in three newly constructed MURBs and nine suites in three existing MURBs (existing buildings constructed circa 1940s) [16]. For the new construction suites, sealing was completed at the rough-in drywall stage. The average pre-sealed air leakage rate was 0.80L/s/m^2 at 50Pa (0.16cfm$_{50}$/ft^2), which dropped to 0.15L/s/m^2 (0.03cfm$_{50}$/ft^2) after sealing – an 81% reduction. Across the entire sample, aerosolized sealant resulted in reductions in air leakage ranging from 67% to 94%, compared to pre-sealed conditions. Similar to Maxwell et al. [15], no control group was included in the study.

In their 2018 study, Modera and Harrington used aerosolized sealant to seal nine existing Department of Defense buildings (combination of offices and barracks) [17]. Individual rooms and/or portions of each building were tested, for a total of 16 measurements. Of the 16 measurements, 12 reported zone surface areas allowing for normalized air leakage rate calculations. The mean pre-sealed air leakage rate was 4.34L/s/m^2 at 75Pa (0.87cfm$_{75}$/ft^2), while the mean post-sealed air leakage rate was 2.20L/s/m^2 at 75Pa (0.44cfm$_{75}$/ft^2). The aerosolized sealant was responsible for a mean reduction in air leakage of 48% (range: 31%–65%).

The results from these studies demonstrate that aerosolized sealant can be effectively implemented in a range of building types – single-family homes, MURBs and/or commercial and institutional buildings – in either new construction or retrofit applications; however, there are several limitations. All but one of these studies have examined the efficacy of aerosolized sealant in isolation. Bohac and Harrington [13] was the only study to include a control group, comparing aerosolized sealant to conventional air sealing techniques. Even then, samples within the control group were broadly defined as being of the same construction type, constructed by the same builder and during the same time period as the corresponding test buildings. There could be variations in size, surface area-to-volume ratios, or leakage path types/distributions, between the test buildings and the control group counterparts, impacting comparability.

It is also important to note that many of these studies define the "pre-sealed condition" as the rough-in drywall stage. At the rough-in drywall stage, drywall boards are installed with joints mudded and taped; this stage of construction is nowhere near close to the finished levels of airtightness that can be achieved using conventional air sealing methods. Depending on when the pre-sealed condition is defined, this will greatly influence the percent reduction that is reported. By using the rough-in drywall stage as the pre-sealed condition, the percent reductions reported in these studies are not necessarily an accurate representation of aerosolized sealant air sealing capability. While this issue is eliminated in retrofit studies, where the aerosolized sealant is installed in the suite's/building's fully finished state, the effectiveness of aerosolized sealant in retrofit applications are also not necessarily a good predictor of aerosolized sealant performance for new construction. The two studies that implemented aerosolized sealant in retrofit applications [16,17] noted that the effectiveness of the aerosolized sealant was greatly contingent on the size and location of existing leakage paths, with larger and/or concealed leakage paths being difficult to seal. These site-specific conditions resulted in larger variations in percent reductions, compared to new construction applications.

1.2. Scope of study

This paper summarizes results from a field study, which compares suite-level air leakage rates from suites sealed with an aerosolized sealant against suites sealed using conventional air sealing techniques in a newly constructed MURB in Toronto, Canada. Testing was completed when suites were fully finished. The study addresses the limitations noted above, by (1) providing a matched control group that utilized conventional air sealing techniques, and (2) comparing airtightness metrics at the fully finished stage. The results from this study provide context for the *relative* effectiveness of aerosolized sealant in new construction applications, compared to conventional air sealing strategies. Lessons learned, including qualitative benefits and drawbacks, are also discussed. The results from this study will help designers and developers make informed decisions about how compartmentalization can be achieved in newly constructed MURBs.

2. Methodology

The following section summarizes the project methodology. Section 2.1 describes the test building, test suites and interior air sealing specifications for the two test groups. Sections 2.2 and 2.3 describe the air leakage test procedures.

2.1. Test building

The test building is a 16-storey, concrete-framed MURB, located in Toronto, Canada, constructed in 2022. Interior and exterior wall assemblies are summarized in Table 1. The building contains 177 suites (studio, one-bedroom, two-bedroom and three-bedroom configurations) and was designed as a market-rental building.

Two groups of five suites each were selected for testing. Group #1 suites, which were sealed using conventional air sealing techniques, were located on the 11th floor. Group #2 suites, which were sealed using the aerosolized sealant, were located on the 6th floor. All suites on the 10th and 12th floors were also finished using conventional air sealing techniques, to ensure that no interior suite surface adjacent to the Group #1 suites was sealed with aerosolized sealant. Descriptions of the conventional air sealing techniques and aerosolized sealant installation procedure are provided in Sections 2.1.1 and 2.1.2, respectively. Each group of test suites contained the same five suite layouts, as shown in Fig. 3. The test suites ranged in size from 33.9 m^2 to 73.6 m^2 (365 ft^2 to 792 ft^2). Details of the test suites, including floor and wall areas, are summarized in Table 2.

Table 1
Test building constructions.

Element	Assembly
Floors/Ceilings	Cast-in-place concrete slabs, finished with 13 mm gypsum wallboard on the ceiling
Suite-to-Suite Partition Walls (Type 1)	2 × 16 mm fire-rated gypsum wallboard; 64 mm steel studs at 200 mm o.c. w/acoustic batts in the stud space; 2 × 16 mm fire-rated gypsum wallboard
Suite-to- Suite Partition Walls (Type 2)	13 mm gypsum wallboard; cast-in-place concrete wall (varying thickness); 13 mm gypsum wallboard
Suite-to-Corridor Partition Walls	2 × 16 mm fire-rated gypsum wallboard; 92 mm steel studs at 610 mm o.c. w/acoustic batts in stud space; 16 mm fire-rated gypsum wallboard
Building Enclosure	Aluminum window wall with double-glazed insulated glazing units (fixed and operable units)

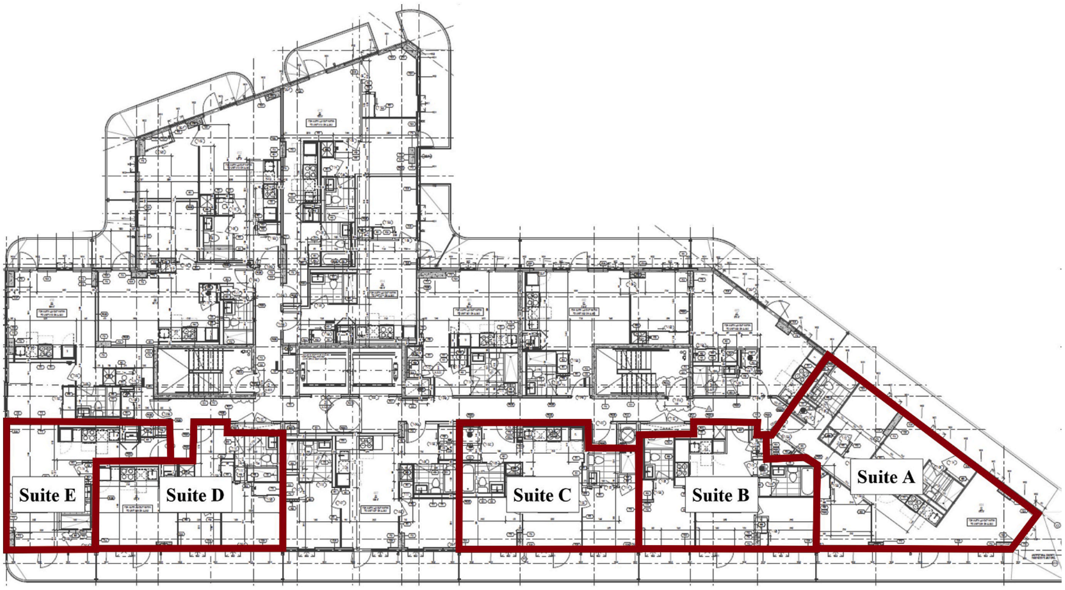

Fig. 3. Level 6 floor plan, showing Group #2 test suite locations (Group #1 used the same test suites).

Table 2
Test suite partition areas.

		Floor and Ceiling		Building Enclosure		Interior Walls (Suite-to-Suite and Suite-to-Corridor)	
Test Suite	Total Surface Area, m^2 (ft^2)	Surface Area, m^2 (ft^2)	Percent of Total Surface Area	Surface Area, m^2 (ft^2)	Percent of Total Surface Area	Surface Area, m^2 (ft^2)	Percent of Total Surface Area
A	242.7 (2,613)	147.1 (1,584)	61%	63.4 (683)	26%	32.2 (347)	13%
B	174.5 (1,879)	97.6 (1,051)	56%	22.3 (240)	13%	54.6 (588)	31%
C	185.4 (1,996)	109.0 (1,173)	59%	22.4 (241)	12%	54.0 (581)	29%
D	175.3 (1,887)	97.0 (1,044)	55%	23.3 (251)	13%	55.0 (592)	31%
E	141.4 (1,522)	67.8 (730)	48%	26.2 (282)	19%	47.4 (510)	34%

2.1.1. Conventional air sealing techniques

Conventional air sealing requirements for the test building fall under two broad categories: air sealing requirements to maintain continuity of fire separations and air sealing requirements to maintain continuity of acoustic separations.

Penetrations through all fire-rated assemblies (floors and walls) were sleeved and sealed with a flexible fire-stopping sealant. The entire fire stop assembly (including the sealant) was ULC-approved.

For all assemblies acting as acoustic separations, a continuous bead of acoustical sealant was specified at the top and bottom stud tracks, and at the top and bottom of each layer of drywall within the assembly. A continuous bead of acoustical sealant was also specified around all penetrations through acoustic separations.

2.1.2. Aerosolized sealant installation

In addition to the air sealing requirements described in Section 2.1.1, aerosolized sealant was installed in the five, Group #2 test suites (and all other suites in the building, except for those on the 10th, 11th, and 12th floors). The aerosolized sealant did not replace the conventional air sealing techniques to maintain the continuity of fire and acoustical separations. Rather, the aerosolized sealant was meant to supplement the manual sealing work.

Prior to aerosolized sealant installation, test suites were visually reviewed for large leakage paths. The aerosolized sealant can seal gaps up to 16 mm (5/8”) in width, but it is not rated to seal larger gaps. Typically, large leakage paths are sealed using spray polyurethane foam or acoustical sealant. As all test suites were in a (near) finished state prior to aerosolized sealant installation, no large leakage paths were identified/sealed in the test suites. Horizontal surfaces were covered with protective sheets. Similarly, any surfaces or leakage paths that did not need to be sealed were covered with tape or polyethylene sheets (electrical outlets, ventilation ducts, windows, etc.). In smaller suites, a spray nozzle was placed in the living area; in larger suites, spray nozzles were placed in both the living area and bedrooms. In both cases, all spray nozzles were placed such that there was at least 2.4 m (8 ft) from the tip of the nozzle to the nearest wall, in the direction of the nozzle spray, to ensure the sealant was fully aerosolized prior to encountering a hard surface (to avoid the risk of clumping).

Suites were pressurized using a Model 3 fan and blower door assembly, manufactured by The Energy Conservatory (equipment specifications summarized in Table 3). Suite pressure was monitored using a custom hardware and software package developed by the aerosolized sealant manufacturer. The fan and manometer were connected to a laptop operating the proprietary software, which allowed for automated control of the fan. Suites were pressurized to 50Pa. The aerosolized sealant was sprayed at a continuous rate until the change in air leakage over time approached zero. Fig. 4 shows a screenshot of the suite air leakage at 50Pa over the application period for a sample suite in the test building. The whole-suite air leakage rate in the sample suite steadily decreased over a 2-h period, from an initial whole-suite air leakage rate of 233cfm$_{50}$ (110L/s) to a final air leakage rate of 74cfm$_{50}$ (22L/s). The peaks in the air leakage profile represent points in the application process when sealant installation was suspended to allow the installation crew to visually inspect the suite, to ensure that the process was proceeding normally.

Temperature and relative humidity were monitored in the suite during installation. The optimal application temperature is 22 °C (72 °F), with a minimum of 20 °C (68 °F). At the time of aerosolized sealant installation, the test building’s heating system was not operational; when required, portable propane heaters were used to condition the building corridors, to ensure the proper temperature range in the suite was maintained.

On average, aerosolized sealant installation took 3 h per suite – including suite surface preparation, sealant installation, and suite clean-up. The aerosolized sealant contractor used a four-person crew, which allowed them to work on several suites/tasks concurrently (e.g., different crew members could be preparing, sealing, and cleaning in different suites). The contractor typically worked after regular business hours, to minimize disruption to other work crews and reduce the schedule impact.

Normally, the aerosolized sealant is installed at the rough-in drywall stage, to minimize the amount of surface protection that needs to be installed. Due to construction sequencing issues at the test building, timing of aerosolized sealant installation varied, with most suite sealing taking place when final interior finishing was in progress. This increased suite surface preparation and cleaning tasks by 15 – 30 min.

Table 3
Equipment specifications.

	Calibrated Range	Accuracy
Model 3 Fan (TEC)	5 – 2973 L/s[a]	±4% (5 – 54 L/s) ±3% (54 L/s – 2973 L/s)
DG-1000 Digital Manometer (TEC)[b]	±2,500Pa	0.9% of reading or 0.12Pa (whichever is larger)

[a] The fan is outfitted with multiple flow rings, which throttle the air flow. Each flow ring has its own calibrated range, with each range overlapping slightly. The full range of all flow rings is reported here.
[b] The DG-1000 manometer was field-calibrated in December 2021, in accordance with TEC guidelines.

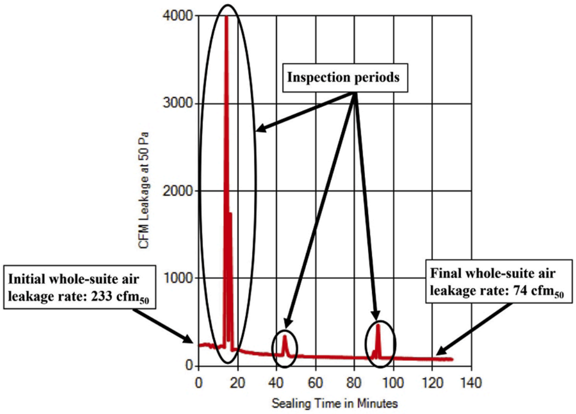

Fig. 4. Screenshot of suite air leakage (cfm$_{50}$) over time for a sample suite.

2.2. Suite-level air leakage testing

Unguarded, suite-level air leakage testing for the ten test suites was conducted in general accordance with CAN/CGSB-149.10 – 2019, "*Determination of the airtightness of building envelopes by the fan depressurization method*" [21]. The blower door assembly was installed in the suite entrance door of each test suite. Intentional ventilation openings in the test suite (kitchen and bathroom exhaust ducts) were sealed from the inside, and exterior windows and doors were closed and locked. The exterior doors and windows in the adjacent suites – including suites above, below and to each side of the test suite – were propped open during testing, to ensure that all interior and exterior surfaces of the test suite were exposed to ambient conditions. The test suite was depressurized relative to the exterior at 5Pa increments between 15 and 50Pa. Pre- and post-test baseline pressures were recorded to account for baseline weather conditions. Suite-level testing was completed on May 17 and 19, 2022. Tests were completed using equipment manufactured by The Energy Conservatory (TEC). Equipment specifications are summarized in Table 3.

2.3. Guarded floor-level air leakage testing

Guarded floor-level testing was completed on the 6th and 11th floors, to measure the difference in air leakage rates for the floor/ceiling assemblies between the two air sealing techniques. Floor-level testing was completed in general accordance with ASTM E3158 – 2019, "*Standard Test Method for Measuring the Air Leakage Rate of a Large or Multizone Building*", using the multi-point test approach for the Building Envelope configuration [22]. To isolate air leakage through the floor and ceiling assemblies, two rounds of tests were completed for each floor: Test #1 (the unguarded test) measured air leakage through the test floor building envelope and the test floor and ceiling assemblies. This required the floors above and below the test floor to be open to the exterior, to ensure that all test zone boundaries were exposed to ambient conditions. For Test #2 (the guarded test), the floors above and below the test floor were depressurized in tandem with the test floor, neutralizing any air leakage through the floor and ceiling assemblies. The difference between Tests #1 and #2 represents the air leakage rate for the floor/ceiling assemblies.

3. Results

This section summarizes the results from the suite-level and guarded floor-level testing. The results are compared against measurements from recently published studies for similar building types. The advantages and disadvantages of aerosolized sealants are discussed, as well as study limitations.

3.1. Suite-level testing

The mean air leakage rates for the two test groups were 0.30L/s/m^2 at 50Pa (conventional air sealing techniques) and 0.22L/s/m^2 (aerosolized sealant) (0.06cfm$_{50}$/ft^2 and 0.04cfm$_{50}$/ft^2, respectively). On average, the suites sealed using the aerosolized sealant were 27% tighter, compared to those sealed using conventional approaches. This percent improvement is consistent with Bohac et al., the only other study to utilize a control group. Bohac et al. reported an average improvement in airtightness of 31% between wood-frame single-family homes (and one triplex) sealed with aerosolized sealant compared to comparable dwellings sealed using conventional approaches [13].

Descriptive statistics for the suite-level tests are summarized in Table 4. A two-sample *t*-test was used to compare the sample means. Despite the small sample sizes, a statistically significant difference was detected between the two groups ($t(8) = -2.01$, $p = 0.04$).

Fig. 5 illustrates the suite-level results from the test building for the two air sealing conditions, compared against measurements from seven buildings of similar construction type, constructed in Southern Ontario between 2007 and 2019 [19]. All buildings were concrete-framed with a combination of concrete and steel stud interior partition walls, clad with window wall – consistent with the test building construction.

Within the context of the test building, the aerosolized sealant was effective at reducing suite-level air leakage rates, compared to the conventional air sealing techniques, by an average of 27%. When compared against the larger sample of measurements from buildings with similar construction assemblies and vintages, both the conventional air sealing and aerosolized sealant test groups are on the lower end of the air leakage spectrum.

Table 4
Descriptive statistics for suite-level test results.

	Conventional Air Sealing (N = 5 suites)	Aerosolized Sealant (N = 5 suites)
q_{50}, L/s/m^2 (cfm$_{50}$/ft^2)		
Minimum	0.24 (0.05)	0.16 (0.03)
Mean	0.30 (0.06)	0.22 (0.04)
Maximum	0.39 (0.08)	0.34 (0.07)
Standard Deviation	0.05 (0.01)	0.07 (0.01)
ach$_{50}$, hr^{-1}		
Minimum	1.17	0.80
Mean	1.65	1.20
Maximum	2.38	1.79
Standard Deviation	0.41	0.40

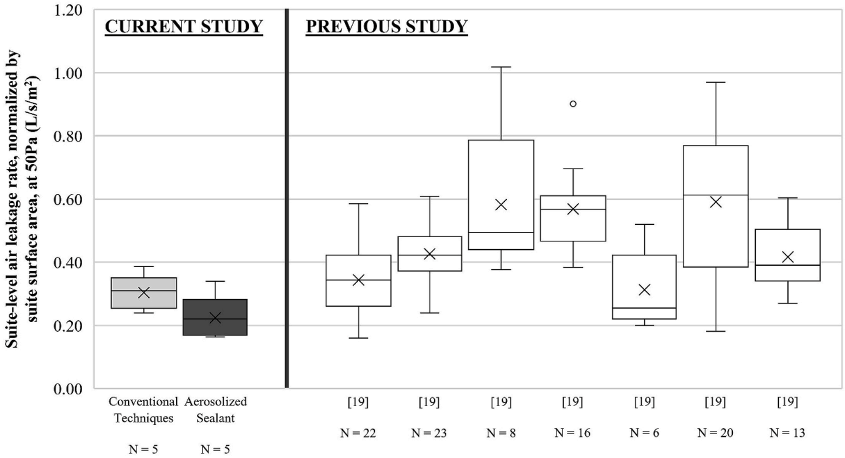

Fig. 5. Box-whisker plots of the suite-level air leakage rates, normalized by suite surface area, at 50Pa (L/s/m^2), compared against previously published measurements.

The average flow exponent, *n*, for the conventional air sealed suites was 0.60, compared to 0.63 for the aerosolized sealant suites. The flow exponent, which can range from 0.50 to 1.0, characterizes the size of the leakage pathways. A flow exponent closer to 0.50 suggests predominantly orifice flow, consistent with larger leakage pathways, while a flow exponent closer to 1.0 suggests predominantly crack flow through small, narrow leakage paths. Most flow exponents for residential buildings are between 0.60 and 0.70 [23,24], indicating a combination of orifice and crack flow. Theoretically, aerosolized sealant should be more effective at sealing small, narrow cracks that would be difficult to manually identify and seal, resulting in a lower flow exponent compared to conventional air sealing techniques. In this study, we found the opposite to be true; however, the difference in flow exponents between the two test groups was not statistically significant ($t(8) = -1.15$, $p = 0.14$). The counter-intuitive results and lack of statistical significance could be due – in part – to the small sample size, or the fact that suites were sealed later in the construction process.

As noted in Section 1, LEED v4.1 has three performance-based air leakage targets within the Enhanced Compartmentalization Credit for Multifamily new construction projects: Compartmentalization (1.52L/s/m^2, 0.30cfm$_{50}$/ft^2); Enhanced Compartmentalization (1.17L/s/m^2, 0.23cfm$_{50}$/ft^2); and Enhanced Compartmentalization – Exemplary Performance (0.67L/s/m^2, 0.15cfm$_{50}$/ft^2) [7]. Assuming that the conventional air sealing techniques were consistently implemented, the test building would be able to achieve LEED's Exemplary Performance Compartmentalization target without the use of aerosolized sealant.

3.2. Floor-level testing

After normalizing for surface area, no significant difference was found between the floor/ceiling air leakage rates for the two air sealing conditions. The 6th floor (the floor where all suites were sealed with aerosolized sealant) had an air leakage rate of 0.10L/s/m^2 at 50Pa (0.02cfm$_{50}$/ft^2), while the 11th floor had an air leakage rate of 0.09L/s/m^2 at 50Pa (0.02cfm$_{50}$/ft^2).

This result is not surprising. Previous studies that have reported air leakage rates for floor assemblies have reported consistently low values, particularly for concrete floor assemblies (e.g., 0.14L/s/m^2 (0.03cfm$_{50}$/ft^2) [19]; 0.11 – 0.62L/s/m^2 (0.02 – 0.12cfm$_{50}$/ft^2) [25]; 0.03 – 0.32L/s/m^2 (0.01 – 0.06cfm$_{50}$/ft^2)) [26]. The floor/ceiling air leakage rates measured at the test building are on the low end of this spectrum. As noted in Section 2.1.1, all penetrations through the floor slabs required a ULC-approved fire stop assembly. This was consistent for both the 6th and 11th floors.

Taking the air leakage rates for the floor/ceiling assemblies and the floor/ceiling areas for each test suite configuration, the suite-level air leakage rates can be broken down by source, i.e., air leakage occurring through the floor/ceiling assemblies vs. air leakage occurring through the interior and exterior walls. Fig. 6 shows the air leakage rates for each suite type, by air leakage source. The contribution of air leakage through the floor/ceiling assemblies is relatively minor, compared to wall air leakage (average 21% of total suite air leakage for the conventionally sealed suites). The amount of air leakage through the floor/ceiling assemblies (in L/s) remains steady between the two test groups. The aerosolized sealant is most effective at reducing air leakage paths through the interior and exterior wall assemblies, with four of the five test suite pairs showing a reduction between the conventional and aerosolized sealant conditions.

3.3. Advantages and disadvantages

Many of the advantages and disadvantages of aerosolized sealants have already been identified in previous publications. Where applicable, we compare the advantages and disadvantages cited in previous works against the findings from this study.

3.3.1. Sub-trade responsibility and quality assurance

The use of aerosolized sealants for suite compartmentalization effectively shifts responsibility to a single contractor [15]. With conventional air sealing techniques, air sealing work would be done a handful of sub-trades, depending on the element being sealed and the construction stage. While some conventional air sealing techniques cannot be eliminated with aerosolized sealants (e.g., firestopping), there is a single trade responsible for suite airtightness. This is particularly beneficial for buildings that are aiming for performance-based compartmentalization targets in optional building certification programs. Another benefit closely linked to sub-

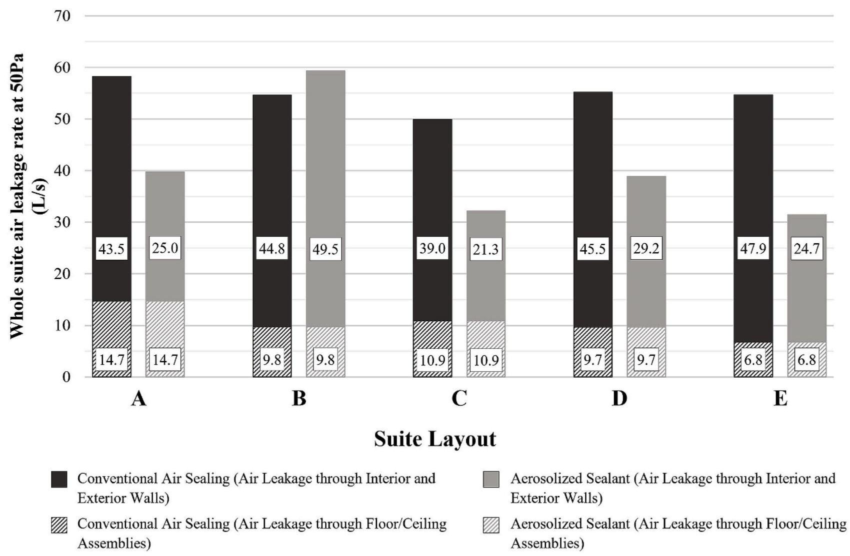

Fig. 6. Whole suite air leakage rate at 50Pa (L/s), by suite layout.

trade responsibility is that pre- and post-sealed air leakage rates are measured for every zone that is sealed. Depending on when aerosolized sealant is installed, the post-sealed value may or may not closely represent final, fully-finished suite air leakage rates; however, having that quantitative measurement (even if it is approximate) at the time of sealant installation, is helpful in identifying potential air leakage problems earlier in the construction process, instead of at the end, when compliance testing is typically completed. At the test building, the aerosolized sealant sub-trade maintained a spreadsheet with all pre- and post-sealed air leakage measurements documented on a per-suite basis. This made it easy to track progress and gave project stakeholders a preliminary estimate of suite-level airtightness.

3.3.2. Inter-suite installation consistency

In theory, aerosolized sealants should reduce the variability inherent with manual air sealing practices, which rely on individuals to identify and effectively seal all leakage paths [15]. In this study, the conventional air sealing techniques and aerosolized sealant performed comparably in this respect. The standard deviations for the two samples were $0.05L/s/m^2$ and $0.07L/s/m^2$, respectively ($0.010cfm_{50}/ft^2$ vs. $0.014cfm_{50}/ft^2$). It is possible that a larger sample size would have revealed a difference in variability between the two test groups; however, based on these measurements, aerosolized sealants and conventional air sealing techniques appeared equally consistent. The extent of installation consistency will be heavily project specific. Regardless of whether the installation consistency for a given project is real or perceived, the automated nature of the aerosolized sealant installation still provides a built-in safety factor, mitigating the risk associated with variability in worker experience/skill and on-site conditions.

3.3.3. Flexibility in installation timing

There is greater flexibility when using aerosolized sealants with respect to the timing of air sealing. Instead of specific air sealing activities being tied to an individual sub-trade, who may only be on site for a short period of time, the aerosolized sealant can be installed at any point between the rough-in drywall stage and just prior to building occupancy. Previous studies have acknowledged this benefit [13] and this was consistent with our observations at the test building, where the timing of the aerosolized sealant application varied, depending on construction sequencing. Note, there are limitations associated with installing aerosolized sealant later in the construction process. Fully finished suites require more surface protection and suite clean-up. There is also the potential for reduced effectiveness, depending on leakage path location. In existing building applications, Bohac et al. [16] noted that the effectiveness of aerosolized sealant was greatly dependent on leakage path location. Air leakage paths behind built-in elements, such as cabinets, were difficult to fully seal. In the test building, cabinet doors were closed, with joints sealed with tape, to prevent the aerosolized sealant settling on the cabinet shelves. Therefore, leakage paths obstructed by the cabinets were not captured in the aerosolized sealant application process. The aerosolized sealant contractor noted that their preference is to install as early in the construction process as possible, to avoid having to work around built-in cabinetry.

3.3.4. Potential retrofit applications

Bohac et al. [16] measured the reduction in suite-level air leakage rates associated with the installation of aerosolized sealant in nine MURB suites in three buildings constructed circa the 1940s. On average, the aerosolized sealant reduced suite-level air leakage by an average of 68% (range: 39%–89%). In a 2007 study, Bohac et al. evaluated the performance of various suite-level air sealing treatments in existing MURBs (N = 38 suites across six buildings) [27]. Using a combination of visual inspection, infrared thermography, and smoke tracers under suite pressurization/depressurization to identify leakage locations, the authors noted a median reduction of 16% in suite-level air leakage rates. Access to the leakage paths appears to be the limiting factor when considering air sealing effectiveness in retrofit applications. In both studies, the authors noted that some leakage paths could not be physically reached. Two of the suites sealed with aerosolized sealant only achieved an air leakage reduction of 39%, due to large leakage pathways behind kitchen cabinets [16]. Similarly, leakage pathways behind built-in bathtub surrounds were inaccessible in several suites sealed manually [27].

3.4. Study limitations

The main limitation of this study was the small sample size. Each test group contained five suites, which roughly equates to 2.8% of all suites in the building. Sampling schemes used for LEED and EnergyStar MFHR compliance testing roughly require a minimum of one in seven suites to be tested (~14%), to account for intra-building variability. The sample size of this study was dictated by our resources (including availability of testing personnel), as well as site availability. Testing was completed while suite finishing was in progress, just prior to building occupancy. Site access required coordination and cooperation with the developer and other trades working on the site.

Another limitation is that the test building construction assemblies are typically very airtight, regardless of interior air sealing strategy. The test building has a concrete structure and is clad in window wall. The National Building Code of Canada specifies maximum allowable air leakage rates of $0.20 L/s/m^2$ and $1.50 L/s/m^2$ at 75Pa for fixed and operable window wall components, respectively [28]. While these air leakage rates are only applicable to the window wall components and not the entire finished building envelope assembly, the airtight window wall components greatly contribute to lower suite-level air leakage rates. In addition, suite-level air leakage rates from concrete-framed buildings are consistently lower than those from other construction types [19,20,23,29,30]. Put together, the baseline suite-level air leakage rates are very low, potentially tempering any benefits we would see from aerosolized sealant application. This outcome is similar to the results reported by Maxwell et al. from a concrete building, where the average "pre-sealed" air leakage rate of the test suites was very low (mean $= 0.55 L/s/m^2$, $N = 3$ suites), even though the "pre-sealed" condition was measured at the rough-in drywall stage [15].

It is important to note that, even with the airtight building assemblies, we still observed a statistically significant improvement in suite-level airtightness with the use of the aerosolized sealant; however, the fact that all suite-level measurements in both test groups were very low may give the impression that suite compartmentalization and inter-zonal airtightness is easy to achieve in any construction type. It is possible that we would see different baseline air leakage rates – and corresponding effect from aerosolized sealant – in different construction types, e.g., wood-frame construction or building envelope assemblies with a combination of opaque and punched window elements.

4. Conclusions

Unguarded suite-level and guarded floor-level air leakage testing was completed in a newly constructed concrete MURB in Toronto, Canada, to compare the performance of aerosolized sealant and conventional air sealing techniques for suite compartmentalization. On average, suite-level air leakage rates for suites sealed with the aerosolized sealant were 27% lower than those sealed with conventional air sealing techniques. Both groups of test suites had average air leakage rates well below the performance-based targets specified by ASHRAE 62.2; LEED v4.1 for Multifamily Construction; and EnergyStar MFHR Program. The very low suite-level air leakage rates were attributed in part to the building construction, which was concrete-framed and clad in window wall, both of which generally contribute to very low suite-level air leakage rates. Guarded floor-level testing showed that airtightness improvements were concentrated at the interior and exterior wall assemblies. This study builds on previous work assessing the performance of aerosolized sealants, by comparing suites sealed with aerosolized sealant against a control group of suites sealed with conventional approaches (previous studies typically did not include a control group).

Aerosolized sealants offer several advantages over conventional air sealing techniques.

- Aerosolized sealants do not rely on manual identification of leakage paths.
- The use of aerosolized sealants shifts the bulk of the air sealing responsibility to a single trade.
- Whole suite air leakage rates are measured during installation, providing additional quality assurance during construction.
- Timing of sealant installation is more flexible.

With increasing numbers of people living in MURBs, maintaining the integrity of our indoor spaces is critical to our health and well-being. Suite compartmentalization is a key strategy for achieving those goals. The results from this study illustrate what levels of compartmentalization are achievable with different air sealing strategies within concrete-framed buildings. Future research could focus on assessing the performance of these various interior air barrier systems in different construction types (e.g. wood frame), in both new construction and existing building applications.

Author statement

Cara H. Lozinsky: Conceptualization, Methodology, Formal Analysis, Investigation, Writing – Original Draft, Writing – Review and Editing, Visualization, Project Administration.

Mariann**e F. Touchie:** Conceptualization, Methodology, Writing – Review and Editing, Supervision, Funding Acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Cara H. Lozinsky reports financial support was provided by Nerva Energy Group Inc.

Data availability

The data that has been used is confidential.

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