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Apartment Compartmentalization With an Aerosol-Based Sealing Process

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Consortium for Advanced Residential Buildings

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Apartment Compartmentalization With an Aerosol-Based Sealing Process

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The work presented in this report does not represent performance of any product relative to regulated minimum efficiency requirements.

The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

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Definitions

CFM	Cubic Feet per Minute (of airflow)
CFM50	Cubic Feet per Minute (of airflow) at 50 Pascals
CARB	Consortium for Advanced Residential Buildings
CFM50/ ft^2	Cubic Feet per Minute (of airflow) at 50 Pascals per Square Foot of Enclosure
Pa	Pascal

Executive Summary

Air sealing of building enclosures is a difficult and time-consuming process. Current methods in new construction require laborers to physically locate small (and sometimes large) holes in multiple assemblies and then manually seal each one. The innovation demonstrated under this research study was the automated air sealing and compartmentalization of buildings with an aerosolized sealant.

Aerosol sealants have been used commercially to seal ductwork for more than 15 years with much success, most notably through the Aeroseal brand name and network of contractors. The process can typically seal 80%–90% of gaps and cracks in ductwork without having to actually locate the leaks.

More recently, the technology was adapted by the Western Cooling Efficiency Center at the University of California-Davis to seal building enclosures. A sealant is injected into the building space during construction in coordination with an air leakage pressurization test, and the sealant finds its way to leaks and seals them. Results of controlled testing on lab-constructed enclosures, as well as limited field testing on single-family new construction and existing homes, have been very promising (Harrington and Modera 2014).

The U.S. Department of Energy Building America Team, Consortium for Advanced Residential Buildings, sought to demonstrate this new technology application in a new construction multifamily building in Queens, New York. The effectiveness of the sealing process was evaluated by three methods: air leakage testing of overall apartment before-and-after sealing, point-source testing of individual leaks, and pressure measurements in the walls of an apartment during sealing.

Aerosolized sealing was successful by several measures in this study. Many individual leaks that are labor intensive to address separately were well sealed by the aerosol particles. Also, many diffuse leaks that are difficult to identify and treat were sealed. The leaks most noticeably sealed were small penetrations such as electrical outlets in the unit walls. These leaks are often easy to identify during a preliminary air leakage test, but can be difficult to address because of their complicated geometry. Other leaks sealed included difficult-to-reach cracks such as the bottom edge of drywall at wall/floor joints.

The apartments were tested before sealing, then again immediately after sealing, and again once the apartments were finally finished. Results for the three apartments are shown in Table 1. In general, the leakage was reduced dramatically as a result of sealing at this early stage of construction. The aerosol process effectively achieved compartmentalization and easily surpassed the thresholds set by ASHRAE 62.2-2013 for compartmentalization of 0.2 CFM50/ft^2 of enclosure area. The aerosol process resulted in an average reduction of 71% in air leakage across three apartments and an average apartment airtightness of 0.08 CFM50/ft^2 of enclosure area. The actual sealing process took an average of less than 2 hours each. At construction completion, though, apartment 303 was noticeably leakier than it was immediately following sealing. The windows in some apartments were difficult to close tightly, not because of the sealing, but because of troublesome lock mechanisms. In one instance, however, a seal around a

pipe penetration was disrupted and effectively removed by workers installing sprinkler pipes. Some of this disruption is expected as a part of normal construction.

Table 1. Air Leakage Test Results From Three Sealed Apartments (All Values in CFM50)

Apartment	Pre-Sealing	Post-Sealing	Construction Completion	Leakage Reduction
202	659	182	183	72%
303	514	85	159	69%
402	511	166	145	72%

Generally, smaller leaks were easily sealed by the aerosol, while larger leaks took too much time to effectively seal. The aerosol process will seal gaps that are ½ in. in the smallest dimension; however, the process is intended for openings smaller than ¼ in. Smaller leaks result in higher sealing efficiency and typically better seal durability. This has certain advantages, because larger leaks are generally more accessible and addressable by conventional means; smaller leaks are less cost effective to address in the same way. The process probably cannot be adjusted to address significantly larger leaks more effectively.

Overall, the aerosol sealing process has the potential to shortcut other very labor-intensive methods for sealing apartments, including the airtight drywall approach.

1 Introduction

1.1 Compartmentalization and Air Leakage

Air sealing to control air movement is one of the most cost-effective means of reducing building energy consumption. While sealing the exterior building envelope is the primary concern, sealing interior boundaries such as shared walls and floors also provides benefits (Klocke et al. 2014; Noris et al. 2013; Lstiburek 2006). The process, called *compartmentalization*, reduces stack effect, noise, and odors; improves fire stopping, comfort, and indoor air quality; and provides a first line defense against pests.

Voluntary green building and energy-efficient building programs have had building airtightness standards for more than 20 years. More recently, building codes and widely used standards have begun to incorporate airtightness requirements. For example, the 2012 International Energy Conservation Code (R402.4) requires exterior enclosure airtightness of 3 air changes per hour at 50 Pa in climate zones 3–8. This very tight standard of construction applies only to exterior envelope leakage. ASHRAE 62.2-2013 (8.4.1.1) goes further to specifically require compartmentalization, calling for 0.2 CFM50/ft^2 of apartment enclosure area, also a very stringent threshold (ASHRAE 2013). This tightness metric is for apartment enclosure area, and includes the exterior walls, floor, ceiling, and demising walls. Achieving these tighter standards across the market in a variety of construction configurations will be difficult without a more repeatable, flexible, and cost-effective process.

The U.S. Department of Energy Building America team Consortium for Advanced Residential Buildings (CARB) has performed thousands of air leakage tests on individual apartments and has compiled extensive data on the results of this testing. Its database includes results from more than 600 apartment tests across 38 New York projects (Figure 1). All projects included in the data set were enrolled in at least one green building program with air leakage requirements. Therefore, all projects were assumed to allocate more resources to air sealing (in both labor and materials), than standard (non-green building program) new construction projects.

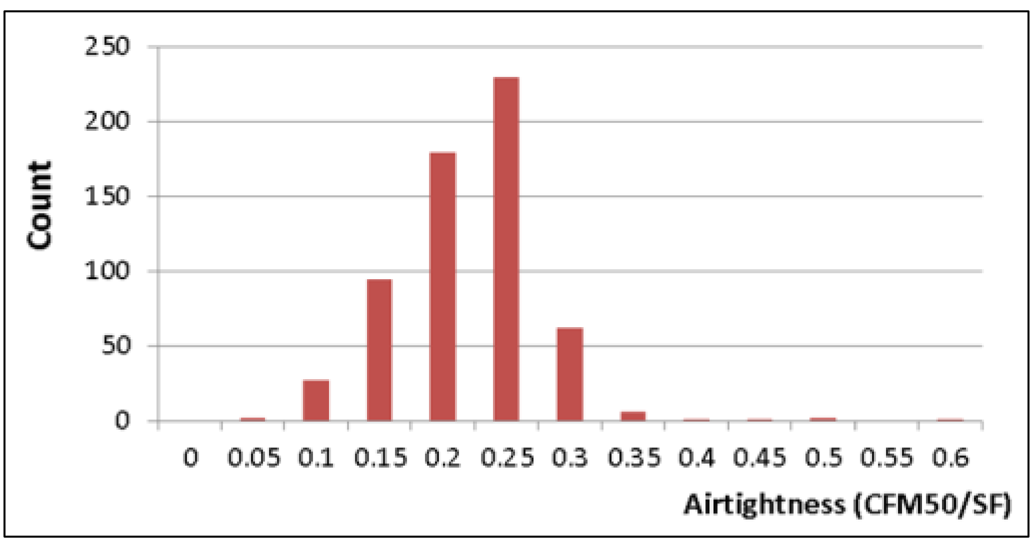


Figure 1. Airtightness results of 600+ green apartments

This air leakage testing data shows that 89% of the apartments tested met requirements for air leakage at the final testing stage for basic green building standards such as ENERGY STAR® or Leadership in Energy & Environmental Design for Homes Multifamily Mid-Rise (0.3 CFM50/ft^2 of enclosure area). However, the new ASHRAE 62.2-2013 (0.2 CFM50/ft^2 of enclosure area) standards were met by only 20% of apartments tested.

The benefits of compartmentalization are fairly well understood; however, several problems need to be addressed to achieve tighter construction in multifamily dwellings:

1. Sealing leaks between apartments is less straightforward than sealing leaks to the outside, because the number of penetrations and joints is several times greater through demising walls than through exterior walls. The leaks tend to be diffuse and widespread (see Figure 2), in contrast to exterior envelope leakage points, which are more localized.
2. An individual contractor is seldom responsible for ensuring good compartmentalization during construction. The general contractor is ultimately responsible for overseeing all subcontractors to make sure they maintain the integrity of the apartment enclosure, but coordination of trades can be a difficult task.
3. Commonly used air sealing techniques to reduce air movement between units are labor intensive and time consuming. The levels of airtightness necessary for truly high performance buildings are not practical for mass market implementation using current methods and technologies.
4. Verifying that a unit is airtight enough to meet standards is difficult until late in the construction process, when fixing problems can be expensive.

Figure 2. Leaks in multifamily units are diffuse and numerous

1.2 Aerosol Sealing of Building Enclosures

Aerosol sealing of dwelling enclosures is a new approach to sealing that promises to address many of the shortcomings of traditional approaches. This technology originated with the use of aerosol sealants to seal ductwork, most notably through the Aeroseal brand name and network of contractors. The process has been refined and modified to simultaneously measure and seal envelope leakage. A fan is used to pressurize the dwelling enclosure, then a sealant is released into the space by atomizing nozzles, which disperse particles small enough to be carried by air currents. The resulting fog of sealant particles travels to envelope air leaks, where they catch on the edges and accumulate. Eventually, enough particles build up that they seal the leaks entirely. Initial evaluations of the process indicated the potential for large reductions of building air leakage (Harrington and Modera 2014).

Improvements to the efficiency of the setup and sealing protocol of the aerosolized sealing can dramatically reduce the time required to reach a given level of airtightness and provide greater reliability. The intent is that in a couple hours, a team of aerosol sealing technicians can achieve the required level of airtightness and verify it at the drywall, prepainting stage, early in the construction process. This is far superior to traditional methods in which the air leakage test is one of the last stages of construction, when remediation is difficult and expensive. Therefore, aerosol sealing has the potential to dramatically reduce the labor and expense associated with achieving air sealing and compartmentalization.

The goal of this research effort was to evaluate the use of aerosol sealants for compartmentalization, specifically in multifamily dwellings. The viability of this approach as a market solution is predicated on the answers to the following basic questions:

- What preparations are necessary?
- How long does the process take?
- What level of sealing is possible?
- How much does the process cost?

During sealing, documenting the factors that influenced its speed and effectiveness was important. After sealing, examining the quality and locations of the seals revealed how the process could be more effectively implemented.

1.3 Background

Air sealing in new construction buildings is often required but not consistently enforced. On many projects, responsibility for air sealing rests with the individual trades. For example, if a plumber makes a hole for a pipe, he or she is often responsible to seal the hole. This is often not a reliable way to achieve continuity of the air barrier. Projects with a designated contractor responsible for air sealing, such as the installer of an aerosolized sealant, can see better results in air infiltration and compartmentalization testing because that person has a level of accountability in the construction process.

The Western Cooling Efficiency Center at the University of California-Davis has performed controlled testing on lab-constructed enclosures as well as limited field testing on single-family new construction and existing homes to demonstrate the concept of aerosol sealing. Preliminary data from those tests have been very promising, yielding at least a 50% reduction in enclosure leakage in test homes (Harrington and Modera 2014). In single-family homes, the benefit of air sealing is well documented and understood. In multifamily buildings, reducing enclosure leakage is equally important, but because the buildings can be taller, controlling stack effect becomes an important priority as well. One strategy to reduce stack effect is compartmentalization.

To illustrate the problem facing multifamily buildings, consider a poorly compartmentalized building in which air flows freely between units (Figure 3). If a resident opens a window in such a building in winter, hot air rushes out the open window, and cold air easily rushes in to replace it. By contrast, in a building in which the apartments are well sealed, the air barrier surrounding that apartment not only prevents air from escaping, it prevents air from traveling through the rest of the building to replace the lost air. Energy savings and improved comfort are obvious benefits of compartmentalization.

Figure 3. Comparison of non-compartmentalized and compartmentalized buildings

Typical methods of compartmentalization largely entail locating and sealing leaks manually. Air sealing products, including EnergyComplete Sealant by Owens Corning and the EcoSeal System by Knauf Insulation, are available in the residential new construction market targeting compartmentalization and interior air sealing. These products are manually installed, and are generally applied to framing materials before the interior gypsum is installed, creating complete seals where materials meet if applied correctly. Spray foam insulation and standard caulking can also be used to provide compartmentalization sealing through targeted application at air leakage points. The aerosolized sealing process offers a significant improvement over the current methods of air sealing because it does not require exact knowledge and treatment of every leak location.

In the current market for compartmentalization products such as the manufacturers mentioned above, projects install air sealing materials, then install and seal drywall, then perform testing to verify compliance. If units do not meet compartmentalization requirements at the time of testing, the ability to implement additional air sealing is limited and difficult, because construction has progressed beyond the point of access. Performing aerosolized sealing with real-time leakage tracking eliminates the need to perform labor-intensive searching and sealing of air leakage pathways that were missed by previous, incomplete compartmentalization efforts.

The main market barriers to entry for the aerosolized sealant method are process optimization, industry recognition and acceptance, and technician training. The next step is to streamline the mechanics of the process to allow for sealing units quickly and efficiently, and to adjust construction schedules to accommodate the process. Demonstration of the process on larger scales will be necessary to gain market acceptance. Finally, technicians will need training to run the specialized equipment and software. Another benefit of this technology is that it uses many off-the-shelf components that contractors are already familiar with, including air compressors and standard diagnostic pressurization fans.

1.4 Relevance to Building America's Goals

Few technologies specifically address compartmentalization of individual dwelling units. In some ways, compartmentalization is more difficult to achieve than sealing of the exterior building enclosure, because of the large number of penetrations between units and the comparatively early stage of industry knowledge on the subject. The potential market for this technology as a solution to interior and exterior envelope leakage is large, including single-family and multifamily new construction. Developing a large-scale, easily repeatable method for compartmentalizing individual residential units has enormous value. As a cost-effective and efficient method of sealing, it has the potential to make more aggressive levels of airtightness achievable in broad sections of the market.

1.5 Cost Effectiveness

The use of aerosol for air sealing and compartmentalization is still in the development stage; therefore, the cost of the process has not yet been established. The final product is anticipated to produce better air sealing results than are currently being realized, at a substantially lower cost. While this is ambitious, it is achievable given that the process eliminates the need for a laborer to manually locate and seal individual leaks.

Currently, multiple hours are devoted to air sealing an apartment at various stages during construction, to achieve tightness levels required to meet green building standards. This carries the costs of materials, labor, sequencing, and coordination. Commercialization of the aerosol envelope sealing process aims to refine the setup and sealing techniques so that it can be seamlessly integrated into the construction process.

An experienced team of two people using the aerosol process in the state of development studied here can likely seal three to four apartments per day to a very tight level. Materials for setup and sealing may total $100–$200 per apartment.

1.6 Tradeoffs and Other Benefits

Aerosol sealant for building enclosures is an innovative solution to the unique challenges of apartment sealing because it:

- Excels at sealing small, numerous, widespread leaks, which are least cost effective to address by other means.

- Can achieve extremely tight levels of compartmentalization called for by high performance dwellings, which can be difficult to achieve using conventional means.
- Offers an automated method of sealing that is easily replicated, measured, and verified and piggybacks on top of air leakage testing that is often already conducted.
- Can allow for precise airtightness levels to be specified in contract documents, regardless of construction type.
- Can be used at a stage of construction when it is inexpensive to fix large problems.
- Requires no direct access, visual location, or direct inspection of leaks.
- Places responsibility for tight construction on a subcontractor, which may translate to lower costs for other trades that no longer must accept liability for failing to meet airtightness standards.
- Removes the uncertainty associated with waiting until the end of construction to verify airtightness levels. This may eliminate possible schedule overruns caused by failing to meet airtightness standards at completion.
- Offers a reliable method of compartmentalization to builders that face increasingly stringent codes and standards.
- Has the potential to transform the entire multifamily building sector by making mandatory airtightness standards readily achievable.

1.7 Research Objectives

Answers to the following research questions were sought during this research study:

- How effective is the aerosol process in a block-and-plank construction apartment? Can it reach levels of airtightness recommended by common standards such as ASHRAE 62.2-2013?
- What are the effects of using this technology on the typical air barrier locations in an apartment? What does this tell us about the nature of apartment leakage and how the aerosol process affects it?
- What types of leaks are best sealed by the sealant, and can the process be altered to target certain types of leaks?
- What are the likely expenditures of time and materials for a typical apartment during this evaluation?
- Can this approach be used to simplify the construction process? Can it supplement or replace certain materials and practices?

2 The Aerosol Sealing Process

The process described here is typical for the aerosol process in its current stage of development. Sealing is conducted on one apartment at a time, but multiple apartments can be prepared at once, and the equipment can be staged to seal several apartments in series. For example, Figure 4 shows a floor plan of the building evaluated in this study. A single central apartment can be designated as a "base" from which to operate the equipment to seal nearby apartments. The apartment being sealed will be referred to in this report as the "target apartment" or "target unit."

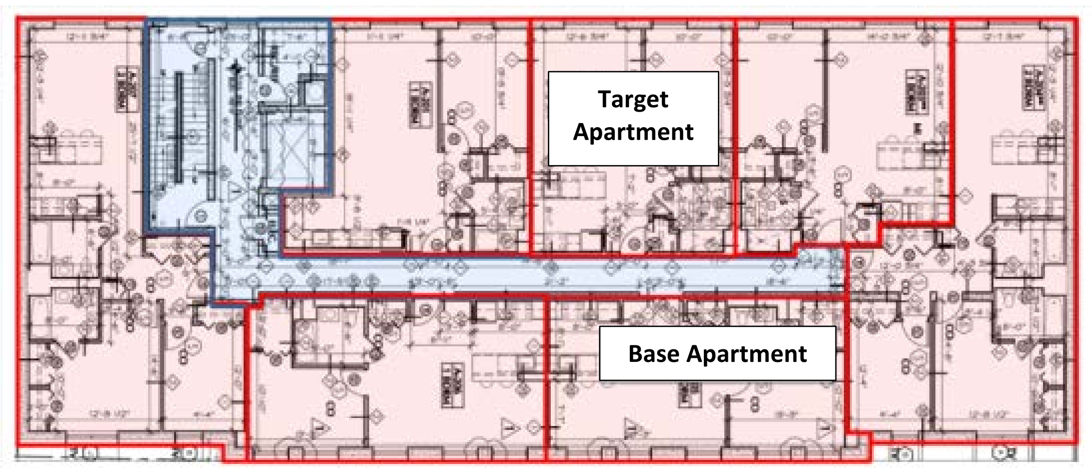


Figure 4. Typical floor plan of research building

2.1 Apartment Preparation and Equipment Setup

Preparations of the target and base units are described in the following sections, along with estimates for labor required.

2.1.1 Preparation of the Target Unit

The unit being sealed is considered the target unit. Tasks and estimates for preparation (Figure 5) include:

- Debris is swept away from the wall base to clear it so that the sealant can adhere to it (10 minutes per apartment).
- Large, easily accessible holes are stopped with low-expansion one-part polyurethane spray foam (10 minutes per apartment).
- If necessary, coverings for finishes such as tiled floors are placed to protect them from sealant that settles out of the air by gravity. Exhaust vents in this apartment were sealed with tape (20 minutes).

Figure 5. (L) Sealing large holes with foam; (R) sweeping debris for sealant access

2.1.2 Equipment Setup

The equipment that supplies the sealant material and compressed air is set up in a base unit nearby (not the target room). The air compressor requires clean air for operation, and cannot be in the same room as the sealing material. Tasks for preparation (Figure 6) include the following:

- A 5 standard cubic feet per minute reciprocating air compressor is connected to power (20 minutes).
- A peristaltic pump (used for moving sealant to the injectors in the target apartment) is set up. A scale to weigh the sealant consumed was used during this study (30 minutes).

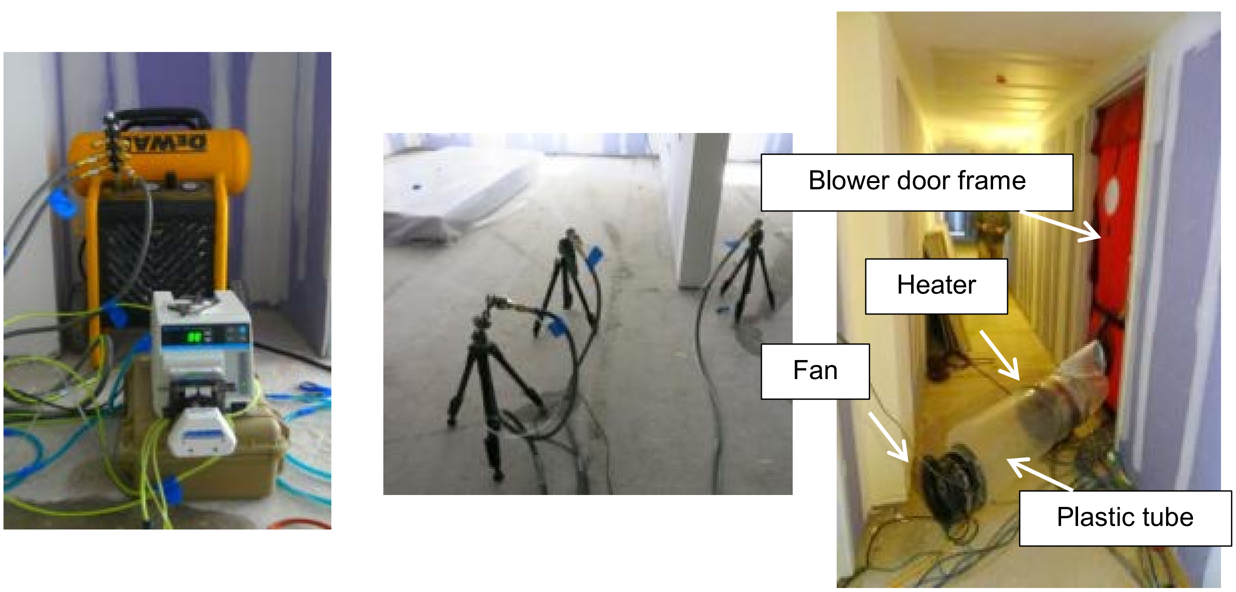


Figure 6. Equipment setup details

- In the target apartment, nozzles are set up on tripods and connected to both compressed air hoses and sealant lines (20 minutes).
- A blower door assembly is set up in the corridor door of the target apartment, and a plastic tube is attached to this. A duct heater is connected to power (220 V and 110 V) and placed in line with this tube, and a blower fan (in this case a Duct Blaster from the Energy Conservatory) is placed at the end (30 minutes).
- A computer is set up with blower door software to track the sealing rate. In this case, TECLOG 3.0 from The Energy Conservatory was used.

2.2 Sealing Process

Once the target apartment has been set up, the sealing process takes less than 2 hours. The steps in the process are as follows:

- The apartment is pressurized using the blower door to 100 Pa or as close as possible.
- The air compressor is started, sending pressurized air to the spray nozzles.
- The sealant pump delivers sealant to spray nozzles. Small droplets of sealant are injected into the air of the target apartment where they remain suspended for some time.
- As air exits the leaks in the apartment envelope, air currents carry the sealant to the leaks where it sticks to their edges. This process continues and sealant builds up to the point that it virtually blocks any air movement into the leaks.
- The operators monitor the humidity of the air in the apartment constantly, because it has a significant impact on the sealing performance. If humidity is too high, the droplets do not sufficiently evaporate for the particle to become tacky. If humidity is too low, the particle becomes too dry, which also reduces tackiness, as well as the sealant's ability to form a durable seal at a leak site. The optimal humidity range within the building during the process is still under investigation. When performing the sealing process in cold or humid climates, auxiliary heaters should be used to improve sealing rates.

3 Evaluation Approach

The effectiveness of the sealing process was evaluated in a new construction building in Queens, New York, by three methods: blower door testing of overall apartment leakage before and after; point-source testing of individual leaks; and pressure measurements in the walls of the target apartment during sealing.

3.1 Building Description

The building in this field evaluation is an insulated concrete form building (Figure 7). The floors are made with prefabricated concrete panels. The insulated concrete forms used for the walls are hollow forms of extruded polystyrene foam, which are progressively filled with concrete as they are built higher. As the concrete in the center of the forms solidifies, it makes a high-strength wall that is substantially airtight and is already insulated on the inside and outside with high R-value foam. The result is an extremely airtight and well-insulated exterior shell. Channels for services are dug through the foam, as shown in the right image of Figure 7.

Figure 7. Insulated concrete form exterior wall construction (L); typical channel through exterior wall for electrical (R)

Heating and cooling in this building are supplied by air-source heat pumps, and the main blower cabinet is placed near the ceiling of each apartment in the area near the entryway. Well-sealed supply ductwork leads from the main blower cabinet to the bedrooms and living room. There is no return ductwork; instead, there is an open ceiling plenum and a large grille for both a return air path and a means of servicing the heat pumps. An inline fan provides kitchen and exhaust ventilation in each unit, with the ductwork terminating at the exterior wall (Figure 8).

Figure 8. HVAC placement in apartment ceilings. Heat pump above entryway, no drop ceiling installed yet (L); inline fan boxed into soffit (R).

Although the open ceiling plenum soon proved to be a major weakness in the apartments' air barriers, the builders used several other techniques to reduce air leakage between units, mostly relating to the way they installed drywall. Figure 9 illustrates the general strategy of building interior partitions within the pressure envelope, where the red surfaces are continuous layers of drywall separating one unit from another and the outside, and the green shapes are interior walls or partitions that are applied within this air barrier. Thus, finding and sealing leaks become much easier. Strict fireproof construction essentially requires many of these details, but typically adherence is not perfect.

Figure 9. Layered drywall approach. Red surfaces indicate continuous drywall that forms the apartment air barrier. Green shapes indicate interior partitions.

None of these interior-erected structures is completely airtight, but each provides an additional level of resistance to airflow. In the case of the half-height wall partition between the kitchen and the living room of each apartment, the layered drywall approach, which refers to a sequential construction of drywall, kept leakage from penetrations in that partition to virtually zero. The exterior and demising walls are built first, to provide a continuous air barrier. Demising walls are then constructed so that they terminate at—but do not interrupt—the air barrier. This method is shown in Figure 9.

The left image of Figure 10 shows good drywall techniques. Even in interior partitions such as this closet, drywall extends from floor to ceiling and is taped to the ceiling. Framing for a drop ceiling is applied afterward, interior to this and within the air barrier created by the drywall partition.

The right image of Figure 10 illustrates good and bad techniques. The drop ceiling framing is layered inside the demising wall, which places the drop ceiling cavity within the envelope of the apartment. Numerous electrical penetrations pass through large holes that have intentionally been cut in this air barrier, compromising it greatly. Initial tests on early-stage construction showed a serious need for sealing large service penetrations. Spray foam was used effectively, and the largest holes were substantially plugged by the time sealing began.

Figure 10. Effective drywall layering in ceiling cavity (L); compromised ceiling cavity air barrier (R)

The left image of Figure 11 shows an apartment at the stage of construction in which the installation and tests were conducted. The drywall was hung and taped, but the walls were not painted. Finish materials, such as cabinets, hardwood floors, and electrical fixtures were not installed. The right image shows an apartment in a finished state in a very similar sister building, which was much further along in construction.

Figure 11. Apartment state at time of sealing (L); finished apartment (R)

3.2 Test Descriptions

3.2.1 Air Leakage Testing

TECTITE software from The Energy Conservatory was used to control a blower door to determine air leakage before and after sealing. TECLOG software was used to control the pressurization fan during the sealing process, holding it at a constant pressure.

3.2.2 Point-Source Leakage Tests

Using a rigid box as a capture hood, measurements of individual leaks were made before and after sealing. The size and shape of the capture hood limited the number and type of penetrations that could be measured, but most electrical outlets and other service penetrations were measured. Diffuse leaks such as cracks along the base of the wall were not measurable with this device. The process measures leakage from a point source using a powered-flow hood concept (Figure 12). A fan on the device maintains a zero pressure difference between inside the capture hood and outside, indicating that the flow entering the hood equals the flow exiting it. The fan measures the flow across an accessory orifice plate and can accurately measure flows as low as 2.4 CFM. By using this device inside the apartment with a pressurization fan maintaining 50 Pa of negative pressure, the leakage measurements can be reported in terms of CFM50.

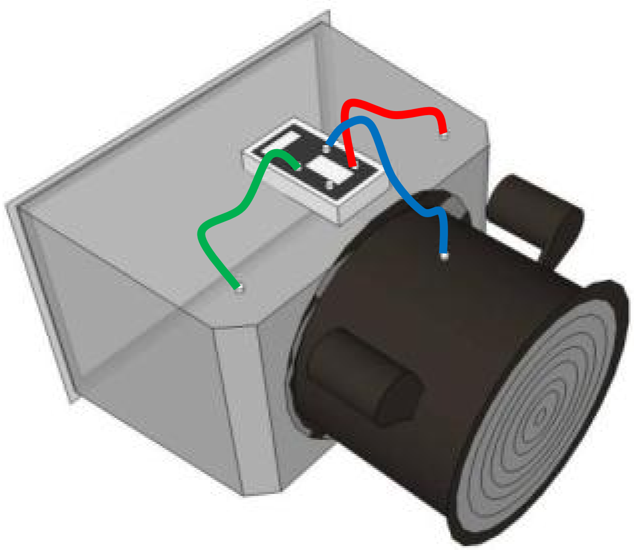


Figure 12. Powered flow hood device for measuring point source leaks (L); device being used to measure leakage from an electrical outlet (R)

3.2.3 Wall Pressure Monitoring

During an apartment pressurization or depressurization, pressures in adjacent spaces, such as neighboring apartments and the walls making up the apartment air barrier, are affected as well. If the apartment is pressurized, the pressure in the wall cavity is raised somewhat by air that travels into it through leaks. Monitoring the pressure in the walls during pressurization or depressurization reveals the nature of the leaks in the air barrier.

To illustrate this concept, Figure 13 shows how the location of an air barrier in a shared wall assembly space affects the pressure drop measured across various surfaces. In scenario A, a theoretically complete air barrier on the "far" surface of a wall allows no way for air enteringthat wall to escape, and the pressure in the wall rises to the point that it equals the apartment pressure. The wall cavity is perfectly connected to the apartment, included in its air barrier. In scenario B, a perfect air barrier on the "near" surface prevents any air from traveling into the wall. This causes a pressure drop across the wall equal to the apartment pressure. Of course, in practice, no air barrier is completely impervious and air constantly leaks from an apartment under pressure to the surrounding walls (scenario C). The pressure in the wall cavity is then related to the relative size of the leaks on its near and far surfaces.

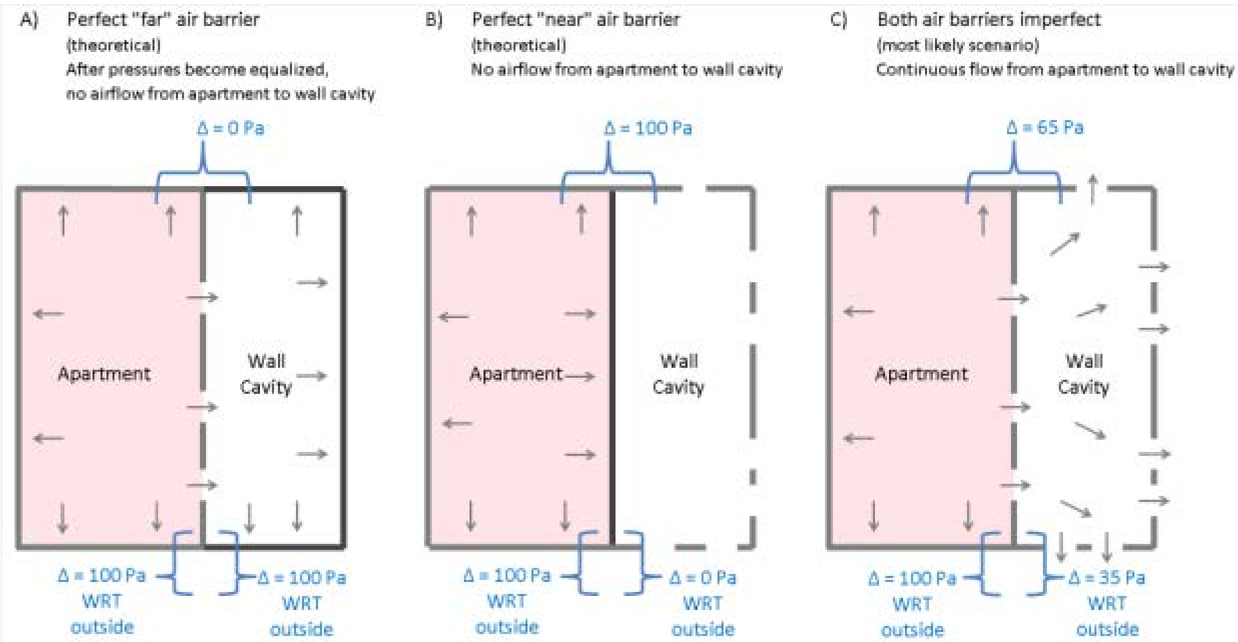


Figure 13. Locations of air barriers in walls

During the aerosol sealing process that pressurizes the apartment, the pressure inside the walls rises in relation to the amount of leakage connecting the wall to the apartment. In general, the leakier the wall, the lesser pressure drop across the wall to the apartment; the tighter the wall, the greater the pressure drop across it.

During the sealing process, air currents carry suspended sealant particles through leaks where they begin to collect on their edges, reducing the diameter of the leak (Figure 14). Eventually, some of the holes are effectively closed off (stage 1). Some particles make it through holes and travel throughout the wall, where they collect on leaks throughout, including on the far side of the wall (stage 2). Some particles even make it out of the wall cavity into the neighboring apartment. As this is happening, the pressure drop from the apartment to the wall changes. As sealant collects on the "near" surface of the wall, the pressure drop increases because the interior of the wall becomes more and more isolated from the apartment. As the air barrier becomes more complete (stage 3), the pressure drop across this wall approaches the pressure of the apartment.

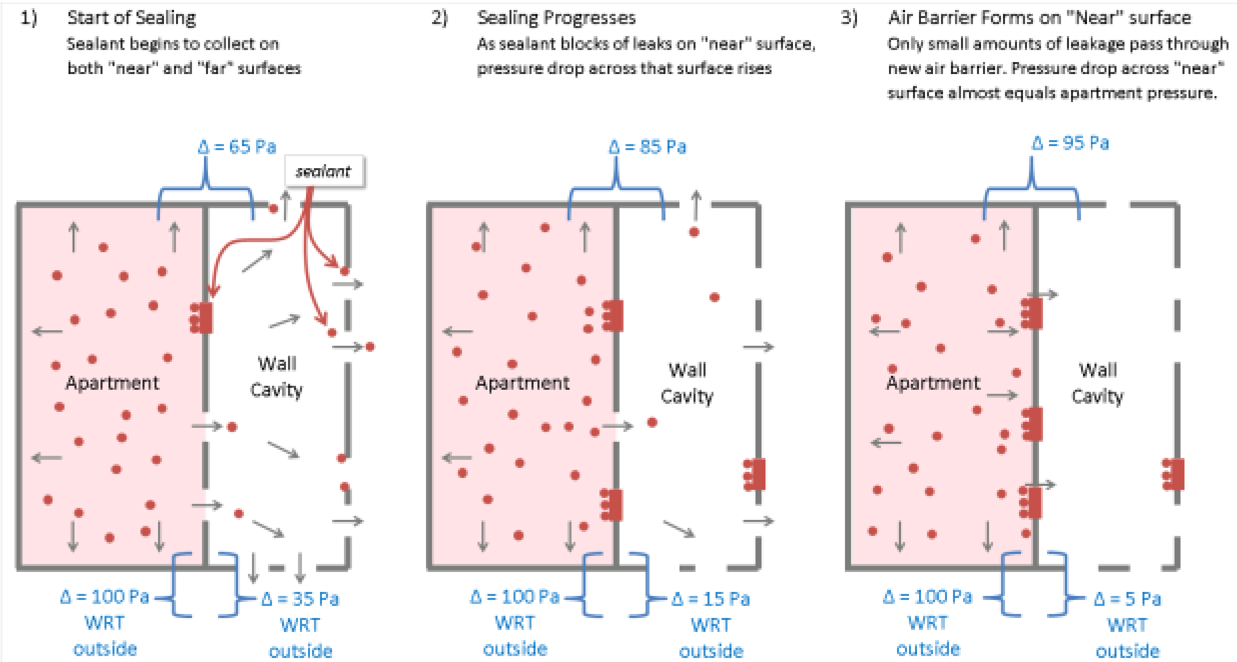
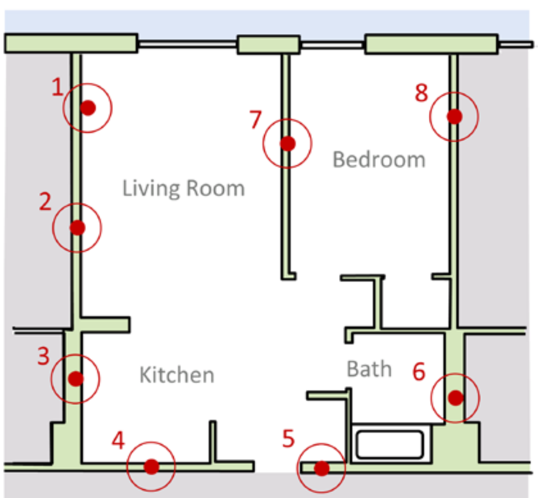


Figure 14. The effect of aerosol sealing on location of air barriers in walls

During this evaluation, the pressure in the walls was monitored at several points in the apartment being sealed (Figure 15). The objective was to observe the relative leakiness of different walls and the effectiveness of sealing on each. A secondary goal was to determine the location of the air barrier resulting from the aerosol process.



Pressure Sampling Points

1. Living Room Wall
2. Living Room Soffit
3. Kitchen/Neighbor
4. Kitchen/Corridor Wall
5. Entryway Wall
6. Bathroom Wall
7. Bedroom Interior
8. Bedroom/Neighbor Wall

Figure 15. Locations of pressure sampling points

4 Testing Results

Sealing was successful by several measures. Many individual leaks that are labor-intensive to address separately were well sealed by the aerosol particles. In addition, many diffuse leaks that are difficult to identify and treat were also sealed. The locations of leaks were identified afterward by the presence of sealant. Figure 16 shows a typical outlet before sealing and a different outlet after sealing. The sealant dries significantly while it is suspended in the air, but it remains tacky, which allows the particles to stick to edge of leakage pathways and to each other to eventually plug the leak.

Figure 16. Typical electrical outlet before sealing; another outlet after sealing

The leaks most noticeably sealed were small penetrations such as outlets in the unit walls. These leaks are often easy to identify during a preliminary blower door test, but can be difficult to address because of their complicated geometry. Other leaks sealed include otherwise difficult-to-reach cracks such as the bottom edge of drywall at wall/floor joints (Figure 17). Seals on holes that may be disturbed by continuing work are susceptible to damage and subsequent leakage. The electrical penetration shown in Figure 17 is a good example of a leak that will likely become worse as construction is completed.

Figure 17. Effective seal at drywall joint (L);
sealed leak susceptible to damage from construction (R)

4.1 Air Leakage Testing

Overall, the aerosol process resulted in an average reduction of 71% in air leakage across three apartments and an average apartment airtightness of 0.08 CFM50/ft^2. The sealing process took an average of less than 2 hours for each apartment. Results for the three apartments are shown in Table 2.

Table 2. Air Leakage Test Results From Three Sealed Apartments (All Values in CFM50)

Apartment	Pre-Sealing	Post-Sealing	Construction Completion	Leakage Reduction
202	659	182	183	72%
303	514	85	159	69%
402	511	166	145	72%

The apartments were tested with TECTITE software before sealing, then again immediately after sealing, and again once the apartments were finally finished. In general, the leakage was reduced dramatically as a result of sealing at this early stage of construction. At construction completion, though, apartment 303 was noticeably leakier than it was immediately following sealing. The windows in some apartments were difficult to close tightly, not because of the sealing, but because of troublesome lock mechanisms. In one instance, however, a seal around a pipe penetration was disrupted and effectively removed by workers installing sprinkler pipes. Some of this disruption is expected as a part of normal construction (Table 2). Alternatively, the results are shown in graphical form in Figure 18.

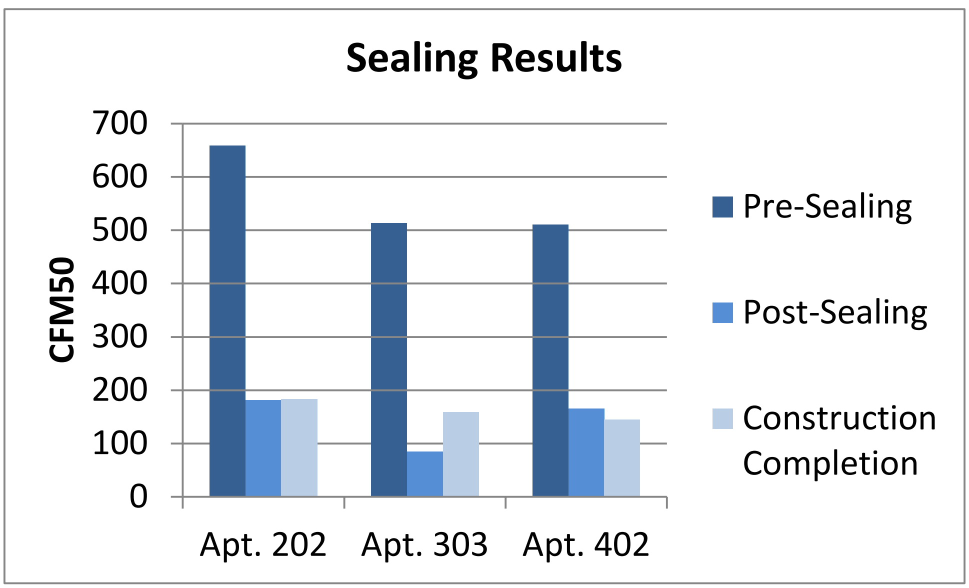


Figure 18. Air leakage results for three sealed apartments

The Energy Conservatory TECLOG 3.0 was used to continuously monitor the rate of sealing. Figure 19 shows that after a short initial period of slow progress, sealing begins to rapidly decrease the leakage rate of the apartment for the first hour, after which the progress begins to gradually wane. The amount of time spent sealing each apartment was somewhat subjective. The process was run for 90 minutes in each apartment. If after that time, the curve did not appear to be relatively horizontal, the process was continued for an additional 30 minutes. Figure 19 depicts all four apartments that were sealed with aerosol, but tests with TECTITE software were done on apartments 202, 303, and 402 only.

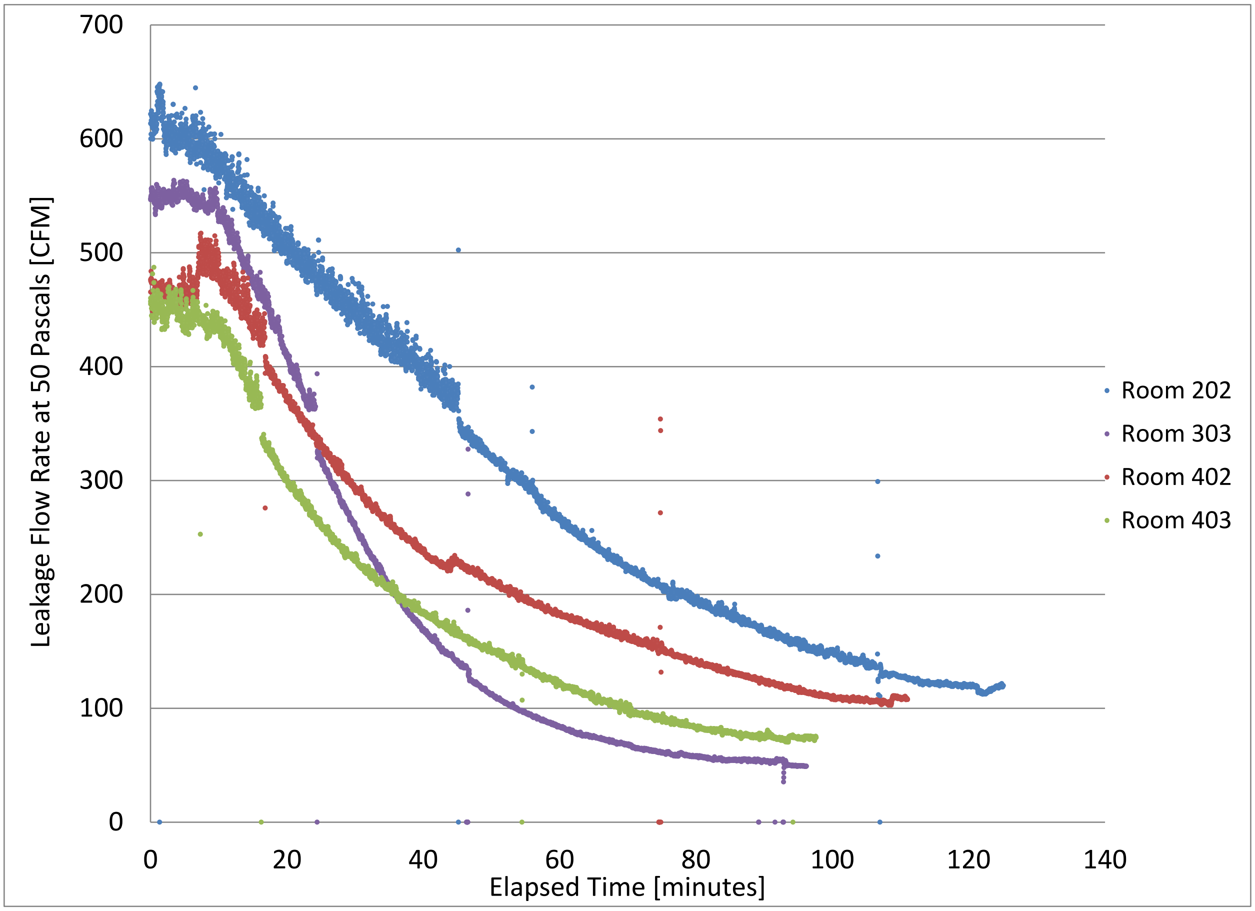


Figure 19. Apartment leakage over time during sealing

4.2 Point-Source Leakage Tests

Using a powered flow hood, leakage from individual point sources was initially measured (prior to sealing) at a prevailing apartment pressure of –50 Pa. Figure 20 illustrates the types of penetrations measured in apartment 303 and the leakage in CFM50 from each. Colors indicate relative leakiness of the various walls as indicated by the measurements. Green indicates relatively tight walls, while red indicates relatively leaky walls. The powered flow hood can measure flows as low as 2.4 CFM50, below which measurements are unreliable. The initial map of leaks shows that the exterior walls (poured insulated concrete forms) are extremely tight. The walls connected to these walls, such as the living room/bedroom, do not leak as a result. Effective use of drywall layering techniques also means that some walls, such as the low wall separating the kitchen and living room, do not leak either. These techniques were described previously in Section 2.1.

Figure 20. Leakage from point sources in apartment 303 before sealing

After aerosol sealing, virtually every point-source leak that can be accessed with the powered flow hood was reduced to "zero" (Figure 21). In reality, many of these penetrations probably leak a very small amount, below the measurement range of the instrument of 2.4 CFM but above zero. Interestingly, no sealant was observed on penetrations where leakage was minimal to begin with. Without airflow to carry particles to leaks, many holes that are connected to airtight walls were not sealed at all. This is true for the bedroom/living room wall, which was connected to the very airtight exterior wall that leaks very little. Sealant did not collect on the bedroom/living room wall penetrations, demonstrating that this technology can target gaps only in construction that leak air.

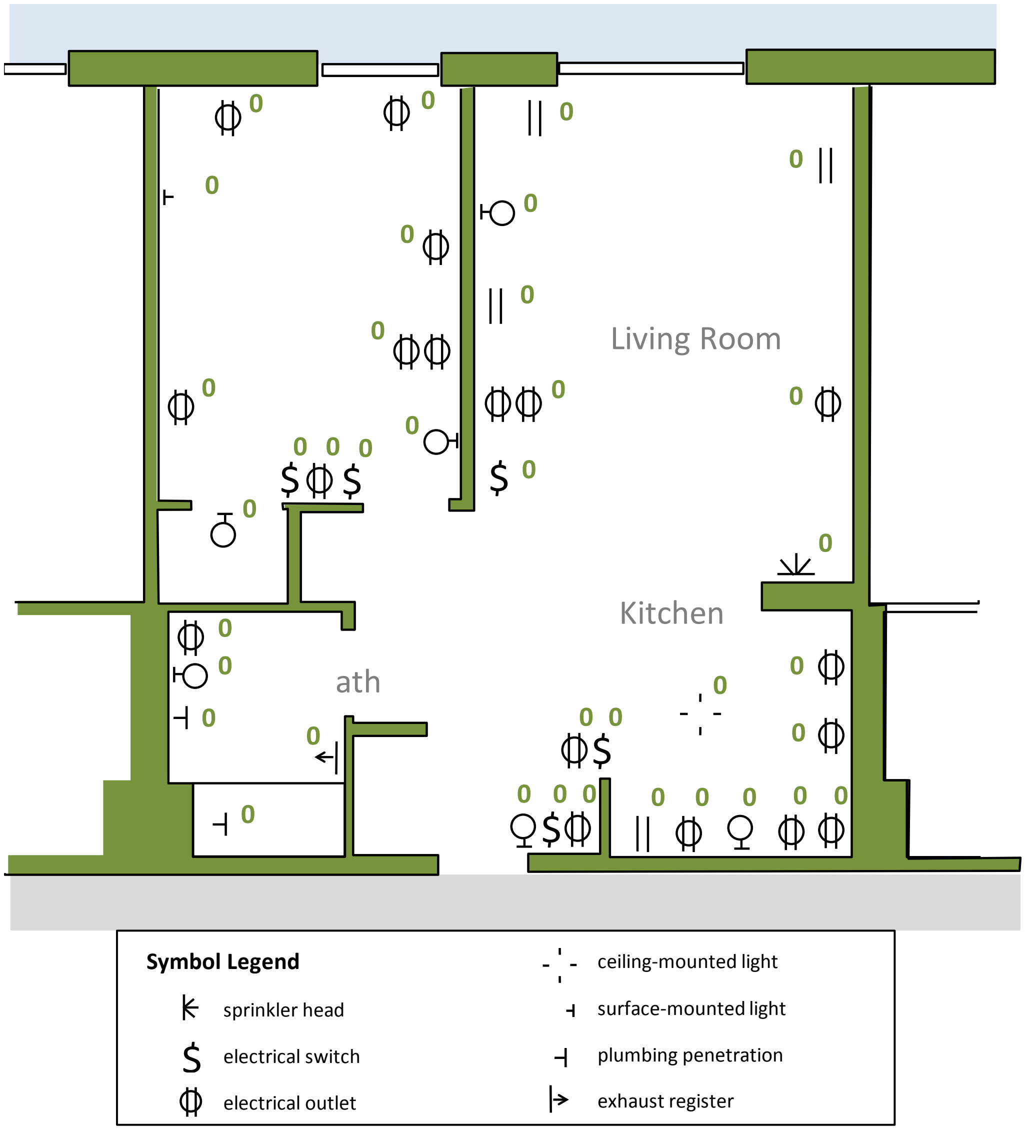


Figure 21. Leakage from point sources in apartment 303 after sealing

The use of the powered flow hood to measure leaks directly allows investigation of the relative importance of leaks in the overall leakage of the apartment. The total and average measured values from different types of leakage are shown in Table 3.

Table 3. Leakage Rates for Different Types of Penetrations in Two Apartments (CFM50)

Penetration	Location	202	303
Electrical Outlets (total)		**98.4**	**118.3**
	Demising wall (average)	8.8	10.4
	Exterior wall (average)	2.0	0.0*
	Interior wall (average)	0.3*	0.6
Electrical Switches (total)		**7.0**	**13.4**
	Demising wall (average)	7.0	9.0
	Interior wall (average)	0.0*	1.5
Exhaust Registers (total)		**29.5**	**11.0**
	Demising wall (average)	14.8	11.0
Plumbing Penetrations (total)		**4.1**	**4.2**
	Demising wall (average)	1.4	4.2
Sprinkler Heads (total)		**2.5**	**0.0**
	Demising wall (average)	–	0.0*
	Interior wall (average)	2.5	–
Surface-Mounted lights (total)		**33.2**	**23.9**
	Demising wall (average)	11.1	6.0
	Interior wall (average)	0.0*	0.0*
Grand Total		**174.7**	**170.8**

* Indicates flow was below measurable range on the instrument

In both apartments, the leakage contributed by these identified point sources is a quarter to a third of the total leakage, constituting 175 CFM (27%) in one apartment and 171 CFM (33%) in another. Comparing the percentage of leaks sealed to those left unsealed provides some understanding of the nature of the leakage that the aerosol is proficient at sealing. Point-source leaks that could be measured constituted a significant percentage of the total leakage reduction, but the largest gains came from sealing leaks that could not be measured or pinpointed (Table 4 and Figure 22).

Table 4. Share of Leakage From Point-Source Leaks

	Apt. 202	Apt. 303
Total Leakage Before Sealing	659	514
Total Leakage After Sealing	182	85
Leakage Reduction	477	429
Point-Source Leaks Sealed	175	171
% of Total Original Leakage	27%	33%
Other Leaks Sealed	302	258
% of Total Original Leakage	46%	50%
Other Leaks Not Sealed	182	85
% of Total Original Leakage	28%	17%

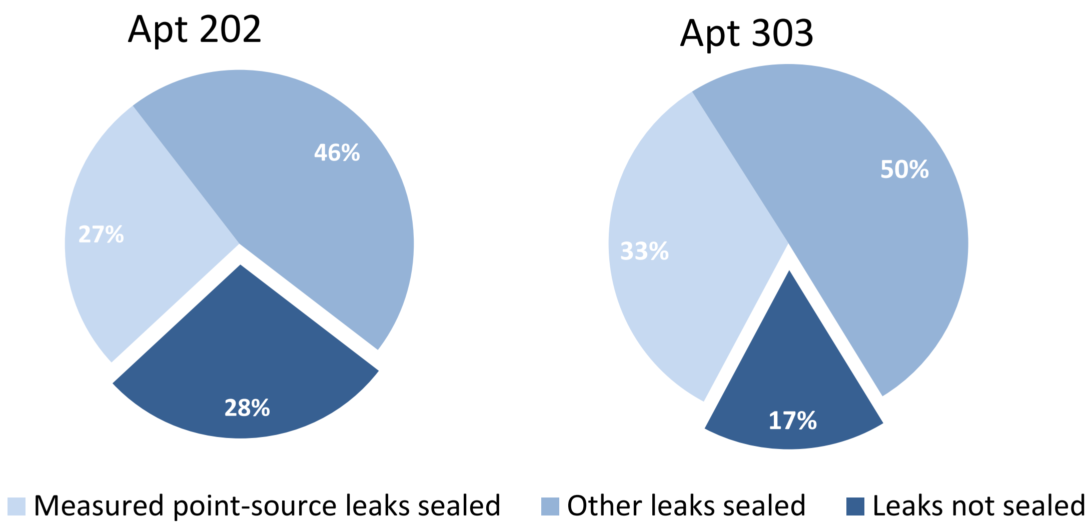


Figure 22. Share of leaks sealed and unsealed

One leakage point that could not be measured was a penetration for an access door for the inline fan providing exhaust for the apartment kitchens and bathrooms. This square hole was located in the soffit of the living room. It was the source of significant leakage during the blower door test, and after sealing, a great deal of sealant traveled into this cavity. Figure 23 shows that sealant collected on the edges of the fan housing, the switch, and the framing of the soffit. Leaks much further into the soffit were the ultimate culprit, because the soffit was supposed to be built entirely within the air barrier of the apartment, which would have made it leakproof. Clearly, the drywall details creating this soffit were not executed correctly. A visit to another apartment at an earlier stage of construction shows a patchwork of drywall where there should be continuous floor to ceiling coverage.

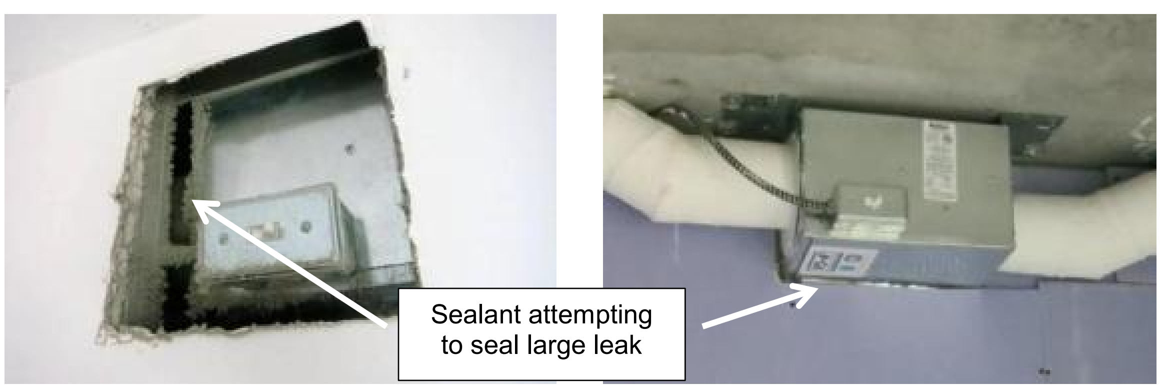


Figure 23. Soffit was leaky before and after sealing (L);
patchwork of drywall behind soffit in another apartment (R)

Other leaks such as the plenums above the entryways in the apartments were weak points as well. The holes found here are large and difficult to seal with aerosol, which excels at sealing small holes. Given enough time, however, the sealant would eventually plug even these holes, though at considerable expense of time and material.

4.3 Wall Pressure Monitoring

Wall pressure monitoring was used to confirm the expectation that aerosol particles would form an air barrier on the interior-most surface of the apartment. This hypothesis was largely confirmed. Of course, aerosol particles were observed on nearly every interior crack and hole, but where large holes occurred, such as the open ceiling plenum or the soffit for the ventilation fan admitted large amounts of aerosol, some sealing of more distant air barriers was expected. The wall pressure monitoring showed that a large pressure drop was measured across almost every interior surface, and that the pressure drop increased as a result of sealing. This is interpreted as a confirmation that the air barriers resulting from aerosol sealing are at the interior-most surfaces.

In this discussion we will refer to "near" and "far" air barriers constituting the boundaries of an enclosed building cavity such as a wall. The near air barrier is anything functioning as an entry point into the cavity; the far air barrier is anything functioning as an exit point from the cavity.

Air leakage across these two air barriers in series is always equal, and the volume of air entering the near air barrier equals the volume exiting the far air barrier. When the area of leakage of one air barrier is greater than the other, the same airflow is spread out over a larger area. The pressure drop across each of those multiple leaks is comparatively much smaller than it would be across the single leak. Figure 24 shows the theoretical pressure drop across both air barriers in three situations: with equally leaky near and far air barriers, with a leakier far air barrier, and with a leakier near air barrier. An airflow of 11.5 CFM is chosen for illustrative purposes.

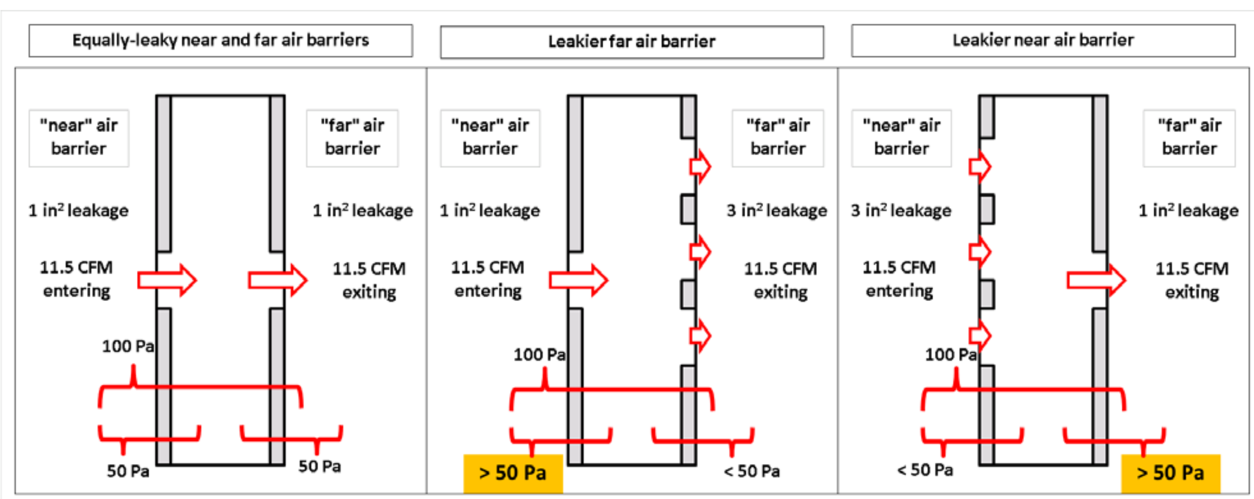


Figure 24. Leakage and pressure drops through multiple air barriers

The relationship between leakage areas and pressure drop is not linear, but because the airflow volumes through both are equal, we can use the orifice flow equation to solve for the pressure drop across both air barriers and the relative leakiness of each. The derivation of an equation to express this relative figure is shown in the Appendix. The leakage data collected indicated an average flow exponent of 0.60 for the apartments sealed, so this is the exponent used in the equation.

$$\text{Leakage Ratio} = \frac{\text{Leakage area on near surface}}{\text{Leakage area on far surface}} = \left(\frac{\Delta P_{\text{total}} - \Delta P_{\text{wall}}}{\Delta P_{\text{wall}}}\right)^{0.6}$$

ΔP_{wall} = Pressure drop measured from wall to a common reference

ΔP_{total} = Total test pressure

The leakage ratio is simply a way of comparing the leakiness of the near surface to the far surface. Figure 25 shows the effective arrangement of manometers for making the measurements described here. Both the manometer measuring the apartment pressure and the one measuring the wall pressure are read with respect to a common reference. In this study, the reference is the hallway outside the apartment. When the pressure measured inside the wall is close to zero with respect to the reference, this indicates that the near air barrier is tight compared to the far air barrier. Conversely, when the pressure inside the wall is close to apartment pressure, this indicates that the far air barrier is tighter. When the pressure in the wall is half the pressure in the apartment, the near and far surfaces of the wall are considered equally leaky.

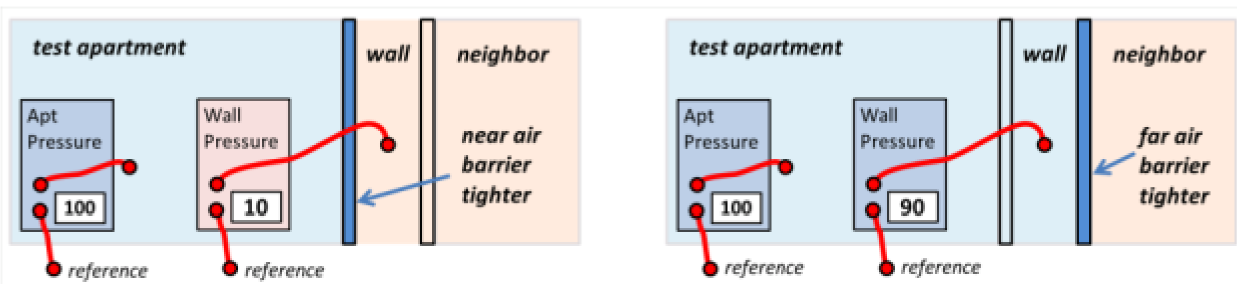


Figure 25. Pressure measured inside a wall in relation to location of air barrier

Figure 26 shows the relationship between the pressure measured across the near surface (taken here to be the pressure measured inside the wall with respect to a common reference) and the relative leakiness of the near and far air barriers.

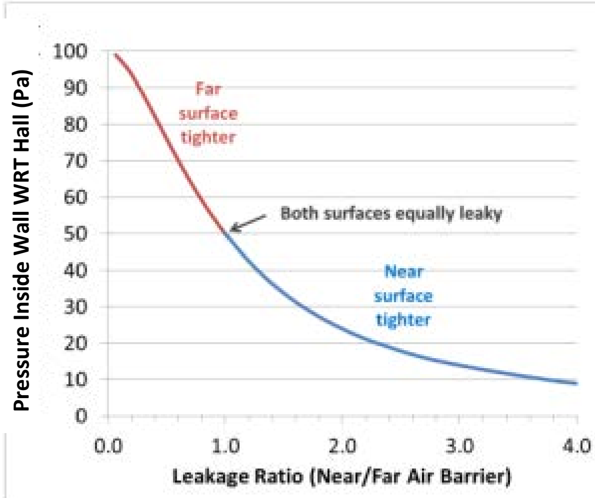


Figure 26. Pressure inside a wall with respect to apartment as a function of leakage ratio

In Table 5, the relationship is shown for example pressures, with a flow exponent of 0.6, the approximate figure derived from blower door tests of the study apartments.

Table 5. Relationship Between Pressure Measured Inside Wall and Relative Leakiness of Air Barriers

Pressure Inside Wall WRT Reference (Pascals)	
0	Theoretical perfect far air barrier (no air movement)
14	Near surface is 3 times as leaky as far surface
24	Near surface is 2 times as leaky as far surface
34	Near surface is 1.5 times as leaky as far surface
42	Near surface is 1.2 times as leaky as far surface
50	Near surface is as leaky as far surface
59	Near surface is 4/5 as leaky as far surface
66	Near surface is 2/3 as leaky as far surface
76	Near surface is 1/2 as leaky as far surface
86	Near surface is 1/3 as leaky as far surface
100	Theoretical perfect near air barrier (no air movement)

The pressure drop measured in the wall is not a direct measure of how “connected” the wall is to the apartment, nor is it a measure of how leaky the wall is. It is merely a way of comparing the relative leakiness of the near and far air barriers of the cavity, but it helps to illustrate some properties of the aerosol sealing and the nature of leakage in the apartments and surrounding cavities before and after sealing.

Figure 27 shows a small segment of wall pressure monitoring that took place in one apartment, over a period of 3 minutes, for a snapshot of conditions before sealing took place. It shows the pressure drop from the apartment to various cavities around the apartment. To review, a large pressure drop between the apartment and the wall interior means that the air barrier is tighter at the near surface. A slight pressure drop between the apartment and the wall interior indicates the air barrier is primarily at the far surface.

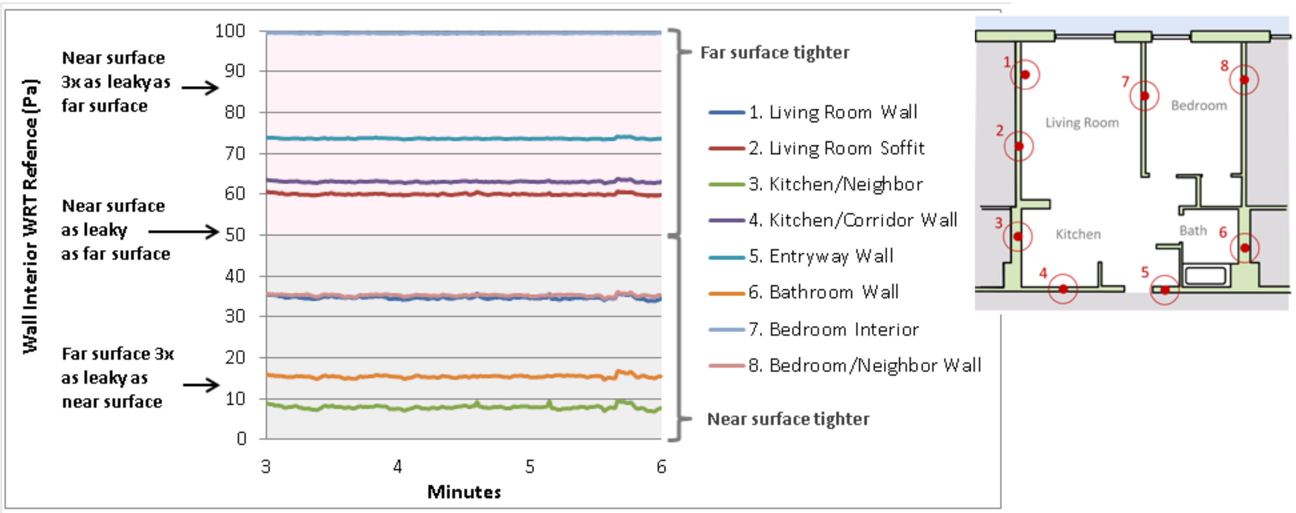


Figure 27. Leakage characteristics of walls before sealing

The chart shows that the bedroom interior wall has virtually no air movement in or out of it. This makes sense, given that this wall was built inside of the effectively airtight exterior poured concrete wall. This corroborates indications in Figure 15 that no measurable air was leaking out of the penetrations in this wall.

Some cavities are leakier on the near side than the far side. Examples are the entryway wall, the living room soffit, and the kitchen/corridor wall. Photos of these walls indeed indicate very large leaks on the near side, visible in Figure 28. The living room soffit was built inside of the demising wall, boxed in over continuous floor-to-ceiling drywall. The return plenum for the unit air handler, open to the room below and with several large penetrations from the plenum to the kitchen and entryway walls, was another example of significant leakage on the near side of the wall cavity. A great deal of air made its way to these walls from penetrations from this plenum into these walls.

Figure 28. Living room soffit open cavity (L); open plenum near entryway and kitchen walls (R)

The kitchen/neighbor wall and the bathroom/neighbor wall had significant leakage on their far sides, and the greater pressure drop across these air barriers indicates this. Behind both walls were bathrooms in the neighboring units, with very large openings for plumbing penetrations such as the shower valve body. The penetrations were not taped on the far side before the test so that air would carry sealant particles through these walls and seal them in the process. Figure 27 shows that three times as much leakage was present on the far side of the kitchen wall as on the near side. This is consistent with the procedure of taping over the largest hole in the bathroom in the target apartment, the access door for water valves (Figure 29). In the neighboring apartment, these holes were not taped, so the relative leakiness of the far side was much greater.

Figure 29. Tape on large penetration in bathroom wall to protect plumbing elements

During sealing, wall pressures were monitored in real time. This allows the observation of the position of the primary air barrier in a wall over time. Figure 30 shows wall pressures over time. Periodic spikes in the pressures were caused by changes to the blower door equipment, such as changing a flow ring on the duct blaster used to pressurize the apartment.

Most of the walls were leakier on the far side of the wall than on the near side to begin with, particularly those that bordered a leaky wall on the neighbor's side. One example is the kitchen wall that bordered a bathroom wall with large penetrations in the neighboring apartment. Some walls, such as the entryway wall, the kitchen/corridor wall, and the living room soffit wall, were leakier on the near side to begin with. These walls had large penetrations on their near sides, such as open access doors or open plenums.

As sealing begins in earnest around the 10th minute, leaks on the near side of the wall begin to block off, and pressure in the affected walls changes in response. The pressure responses show that the near air barrier becomes tighter in relation to the far air barrier for all walls, particularly the entryway wall, the kitchen/corridor wall, and the living room soffit. All three of these change from being leaky primarily on the near side to being leaky primarily on the far side. This confirms a hypothesis that the aerosol forms an air barrier primarily on the first surface that it encounters, the near side of the wall.

The bathroom wall pressure shows some unusual behavior. Every bathroom of this building had a large penetration for the shower valve body (Figure 29). In this case, the bathroom of the target apartment shared a wall with the bathroom of its neighbor. Air leaking into one bathroom wall would exit through the same penetration as its neighbor. During the sealing, excess aerosol exited the penetration of the neighbor's bathroom, resulting in "fogging" of the neighboring apartment. About 45 minutes into the sealing, the penetration in the neighbor was taped off. The pressure in the bathroom wall then rose with respect to the reference.

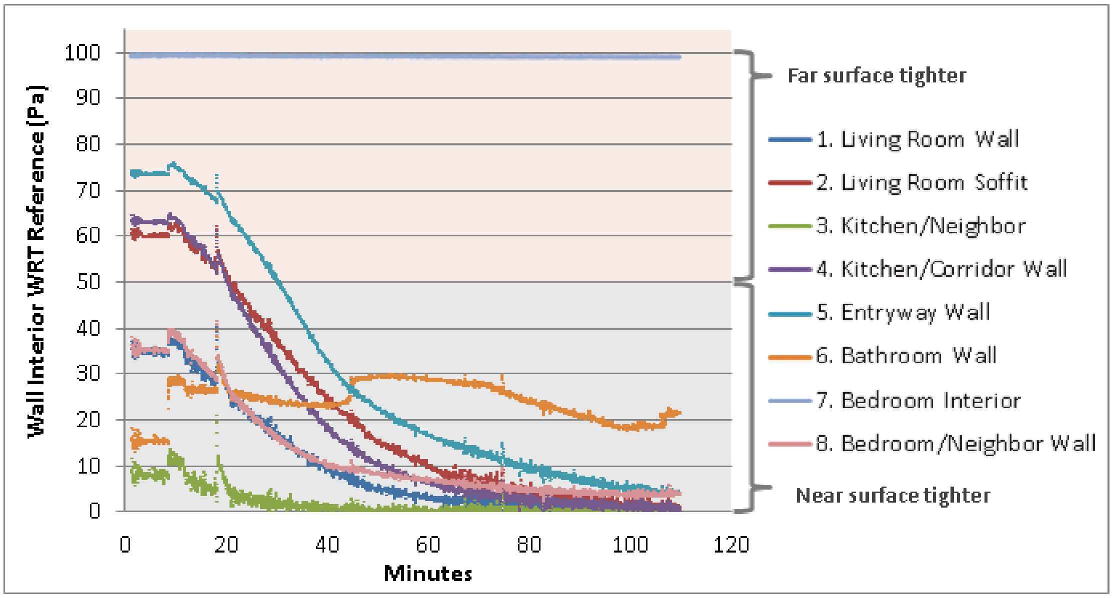


Figure 30. Pressures in walls during sealing

To observe what happens when the same wall is sealed from both the near and far sides; that is, from two neighboring apartments, the same wall was monitored at the same location both times. Figure 31 shows the results. The blue plot is the same data from the chart above (bedroom/neighbor wall), showing sealing of the wall from the near side of the first apartment. The manometer was left in the same location, in the same wall of the first apartment. The second apartment on the other (far) side of the wall was then sealed.

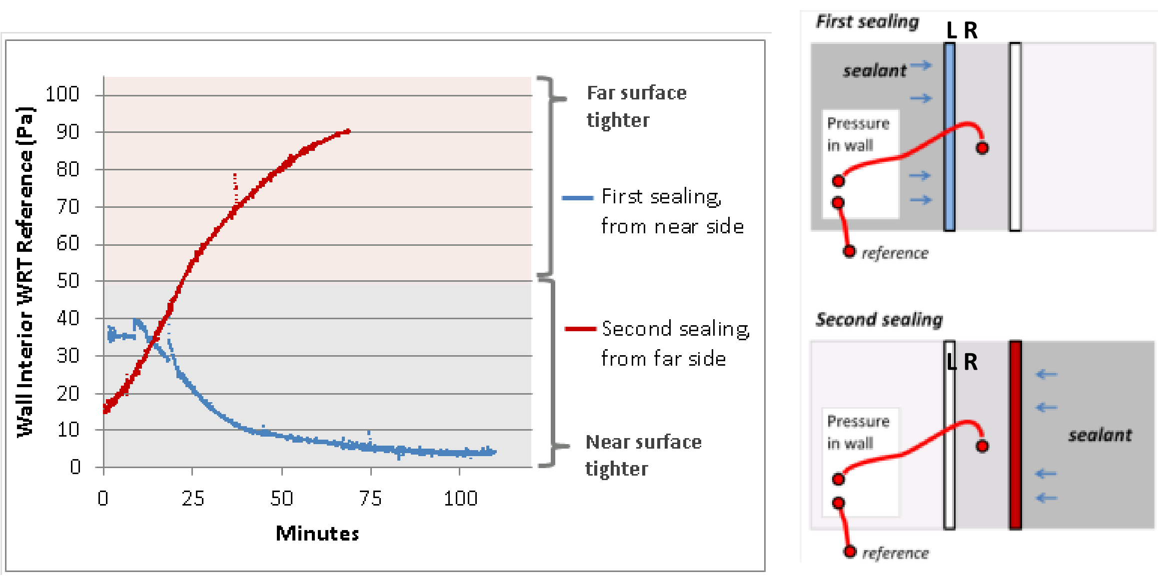


Figure 31. Bedroom/neighbor wall sealed from both sides successively

The chart shows that upon pressurizing the neighboring apartment for sealing, the air barrier begins tighter on the left wall (L), a result of aerosol particles sealing much of the leakage from that side during the first sealing. As the second sealing progresses, the location of the air barrier effectively migrates, with the right wall (R) becoming the primary air barrier as it becomes sealed with aerosol particles.

There is a noticeable discrepancy between the measured wall pressure at the end of the first test (4 Pa) and the beginning of the second test (16 Pa) of about 12 Pa. This is due to other leakage paths that are not described by the simplified leakage model. If the flow had no other path to escape the wall cavity other than the far wall surface, the pressure measured at the beginning of the second test would be the same as at the end of the first test. We would also expect the leakage ratio to approach unity if each surface were sealed to a similar level. That is, we would expect the pressure measured inside the wall to be one-half the total pressure, or 50 Pa, in both cases if both surfaces were equally leaky and there were no other leakage pathways. The pressure measured inside the wall would likely be the same regardless of which apartment it is applied.

Consider the following circuit diagrams illustrating the leakage behavior through the wall where pressure is analogous to voltage and flow is analogous to current (Figure 32 and Figure 33).

First Sealing

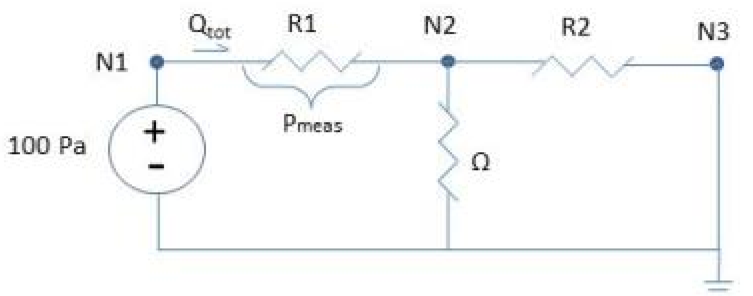


Figure 32. Circuit diagram representation of leakage paths through a wall, first sealing

$$P_{meas} = N1 - N2 = Q_{tot} * R1$$

Second Sealing

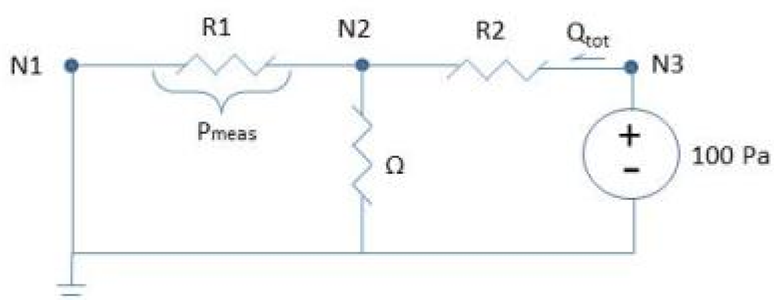


Figure 33. Leakage paths through a wall, second sealing

$$P_{meas} = N2 - N1 = Q_{tot} * \frac{1}{\left(\frac{1}{R1} + \frac{1}{\Omega}\right)}$$

where,

N1 = pressure in the first apartment
R1 = flow resistance of the near wall
N2 = pressure in the wall between apartments
Ω = flow resistance of an alternative leakage path
R2 = flow resistance of the far wall
N3 = pressure in the second apartment
P_{meas} = the pressure in the wall with respect to the reference, referred to elsewhere as P_{wall}
Q_{tot} = the total airflow into the wall = total airflow out of all exit air barriers

The circuit analysis demonstrates how other leakage paths within the wall impact the measured pressure across the near wall surface. The extra flow path acts as a parallel flow resistance that, depending on where the pressure source is located, can run parallel to either the near wall flow resistor or the far wall flow resistor. Thus, the total flow resistance of the wall circuit changes when pressurizing one room versus pressurizing another room. This impacts the total flow across the wall and the size of the flow resistance across which the pressure is measured.

5 Discussion

5.1 Sealing of Cavities

The collection of aerosol particles on the near surface of a cavity was significant for several reasons:

- The location of the primary air barrier can change based on secondary sealing of the same cavity.
- Even though the air barrier formed on the near surface of a cavity is substantially airtight, there are still sufficient air leakage pathways out of the air cavity to draw air carrying aerosol particles in. This reinforces the notion that interstitial spaces such as wall cavities are complex air pathways and that airflow into these cavities will easily find an exit point (Figure 34).
- The result is a cavity that is sealed well on two sides, but that remains largely unsealed at its ultimate exit points somewhere else in the wall.
- As a result of this process, cavities between apartments may remain substantially leaky to non-apartment spaces even after sealing.

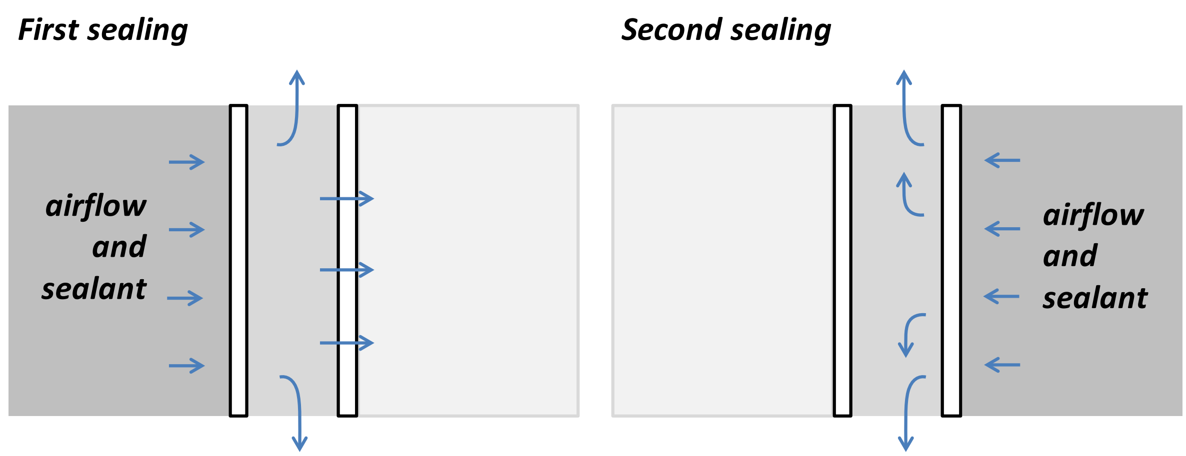


Figure 34. Airflow and sealant pathways through a cavity sealed from an apartment on one side, then the other

These observations have implications for the ability of aerosol compartmentalization to affect a driver of energy use in a multifamily building, stack effect. The result of aerosol sealing is in effect a number of airtight "boxes within a larger box." These boxes are situated between leaky cavities containing such air transfer pathways as pipe chases, duct chases, incomplete fire separations, electrical penetrations, and so on. The aerosol may effectively seal the apartments from the inside, but it cannot combat interfloor or interzone leakage using the current configuration. Perhaps some investigation could be made into making intentional openings into difficult-to-seal cavities so that the aerosol can penetrate deeper inside to seal more distant leaks.

5.2 Aerosol Process Setup, Sealing, and Cleanup

Setup for aerosol sealing for this project was straightforward once the system was refined. On the third day, two apartments were set up, tested, and sealed in a single day. It is quite reasonable that an experienced crew of two people could set up and seal a total of three to four apartments per day.

The team was able to seal four apartments in 3-½ days of field work, with a crew of four people. Much of the time was spent evaluating, testing, and documenting the apartment conditions and the results of sealing. All this work, including testing, took approximately four man-days per apartment. Obviously a more efficient setup and sealing process would be desirable, and a goal for further research is to determine ways to minimize the time required for setup, sealing, and cleanup.

Cleanup at this stage of construction was fairly straightforward, because few finishes had been installed other than tile floors in bathrooms. Where plastic sheeting failed to cover the whole floor or was disturbed during setup, the sealant had to be cleaned with paper towels and water, which was not a large task but did take some time (Figure 35). The undried sealant has fluorescent dye, but it dries to a dull gray color. In most areas of the apartment, floor finishes were absent, so the sealant collected on the concrete floor, but this was not a problem because it dries quickly and will be covered by flooring. Where sealant did collect on surfaces such as windows, rubbing with a dry cloth removed the sealant quite easily.

Figure 35. Sealant on tile floor where plastic protection was not well secured

Sealant did not harm windows, ductwork, or electrical equipment. Windows were installed and were already substantially airtight, so airflow carrying aerosol particles did not enter them. Ductwork for ventilation was taped closed to prevent sealant particles from penetrating into fan equipment. Electrical equipment was not affected significantly. Electrical outlets had already been protected for the purposes of painting. Any aerosol that entered the outlet boxes sealed the box but did not touch the outlets or electrical contacts. The electrical load center door prevented sealant particles from entering the breaker box; however, because the breakers are not a leakage pathway, no sealant collected on them.

5.3 Recommendations for Future Research

Aerosol sealing has obvious benefits where serious compartmentalization is required. For example, ventilation designs that rely on pressurizing a space to deliver fresh air, such as exhaust-only ventilation, would benefit. Makeup air for exhaust-only ventilation is intended to come from the outdoors, a source preferable to door undercuts or other building spaces where the air may be polluted by contaminants or smoke. Unfortunately, the CARB team's research has shown that makeup air for many ventilation schemes most often comes from just such undesirable places (Maxwell et al. 2014). The main reason is that apartments are not built tight enough to control pressures to the extent that the makeup air comes primarily from outdoors and not from other building spaces. Pending CARB publications will address details on the links between compartmentalization and exhaust-only ventilation.

Aerosol sealing has the potential to shortcut other very labor-intensive methods for sealing apartments, including the airtight drywall approach. If labor costs are taken into account, and if the efficiency of the process can be improved, aerosol sealing could be competitive with conventional means for sealing apartments tight enough to make exhaust-only ventilation work.

Further research might address the following questions:

- In studying the airflow patterns in wall cavities sealed on both sides by aerosol: does air still move freely through these cavities? Does it have an impact on energy use? Do air currents develop in these dead spaces that affect insulation or wall performance?
- Can manipulating air barriers by strategically opening holes seal interstitial spaces such as wall cavities and chases?
- Can aerosol be used in a retrofit environment to improve the airtightness of existing apartments?
- Does hyper-compartmentalizing (less than 1.0 ACH50 or 0.07 CFM50/ft^2) apartments reduce stack effect as measured by pressures in various parts of a building? Are energy impacts large enough to measure?
- Does hyper-compartmentalizing make a building as a system more resilient to changes made by occupants, such as opening windows and doors throughout the year?
- Can compartmentalized units reliably draw air from the exterior in exhaust-only ventilation schemes, including during normal building operation and occupant interaction with systems, and across all segments of a building?
- How cost effective can aerosol be as the primary method of ensuring apartment airtightness? What details, if any, may be foregone from traditional approaches to compartmentalization that might make the process more competitive?
- How does aerosol perform in other construction types? Could units be sealed in a comparable amount of time, or will other construction types require much more sealant time?

6 Conclusions

To summarize this research, several of the research questions outlined in Section 1 of this report are answered here.

How effective is the aerosol process in a typical block-and-plank construction apartment? Can it reach levels of airtightness recommended by common standards such as ASHRAE 62.2-2013?

The aerosol process was very effective at achieving compartmentalization and easily surpassed the thresholds set by ASHRAE 62.2-2013 and other standards. ASHRAE 62.2-2013 calls for compartmentalization of 0.2 $CFM50/ft^2$ of enclosure, while all three apartments sealed with aerosol had leakage less than 0.1 $CFM50/ft^2$.

What are the effects of using this technology on the typical air barrier locations in an apartment? What does this tell us about the nature of apartment leakage and how the aerosol process affects it?

The aerosol particles generally create an air barrier on the closest plane of leakage they encounter. This means that in a wall cavity that is shared with other apartments, the near surface of that wall cavity is sealed. Successive sealing tests show that wall cavities between apartments are complex structures, exhibiting multiple leakage pathways. Aerosol sealing will deal only with the surfaces of those cavities shared with the apartment being treated. In other words, this aerosol process cannot be used to address inter-wall leakage pathways.

What types of leaks are best sealed by the sealant, and can the process be altered to target certain types of leaks?

Generally, smaller leaks are easily sealed by the aerosol, while larger leaks take too much time to effectively seal. This has certain advantages, because larger leaks are generally more accessible and addressable by conventional means, while smaller leaks are less cost effective to address in the same way. The process probably cannot be adjusted to address significantly larger leaks more effectively.

What are the likely expenditures of time and materials for a typical apartment during this evaluation?

An experienced team of two people using the aerosol process in the state of development studied here can probably seal three to four apartments per day to a very tight level. Materials for setup and sealing may total $100–$200 per apartment.

Can this approach be used to simplify the construction process? Can it supplement or replace certain materials and practices?

The aerosol process can be adapted to fit into the typical construction process. The ideal time to apply the process is after drywall has been hung and joints taped, but before other finishes are installed. The sealant can be painted over or hidden behind trim and baseboards. Typically an apartment is prepared for painting and finishes after drywall has been hung and joints taped. This is the ideal time to apply the aerosol process.

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Appendix

Derivation of leakage ratio

A_N is the area of the leakage in the near air barrier
A_F is the area of the leakage in the far air barrier
$Ratio_L$ is ratio of the leakage area of the near air barrier to the leakage area of the far air barrier
P_N is the pressure drop across the near air barrier; can also be expressed as P_{Wall}, the pressure measured in the wall cavity
P_F is the pressure drop across the far air barrier
P_{Tot} is the total pressure drop across both air barriers.
C_d is the coefficient of discharge for an air leak
ρ is the density of air

$$P_{Tot} = P_N + P_F \quad \text{and} \quad Ratio_L = \frac{A_N}{A_F} \quad \text{and} \quad A_N = Ratio_L * A_F$$

$$C_d * A_N * \left(\frac{2P_N}{\rho}\right)^{0.6} = C_d * A_F * \left(\frac{2P_F}{\rho}\right)^{0.6}$$

$$A_N * \left(\frac{2P_N}{\rho}\right)^{0.6} = A_F * \left(\frac{2P_F}{\rho}\right)^{0.6}$$

$$Ratio_L * A_F * \left(\frac{2P_N}{\rho}\right)^{0.6} = A_F * \left(\frac{2P_F}{\rho}\right)^{0.6}$$

$$Ratio_L * \left(\frac{2P_N}{\rho}\right)^{0.6} = \left(\frac{2P_F}{\rho}\right)^{0.6}$$

$$(Ratio_L)^{\frac{1}{0.6}} * \frac{2P_N}{\rho} = \frac{2P_F}{\rho}$$

$$(Ratio_L)^{\frac{1}{0.6}} * P_N = P_F$$

$$(Ratio_L)^{\frac{1}{0.6}} = \frac{P_F}{P_N}$$

$$Ratio_L = \left(\frac{P_F}{P_N}\right)^{0.6}$$

$$Ratio_L = \left(\frac{P_{Tot} - P_N}{P_N}\right)^{0.6}$$

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