December 2016

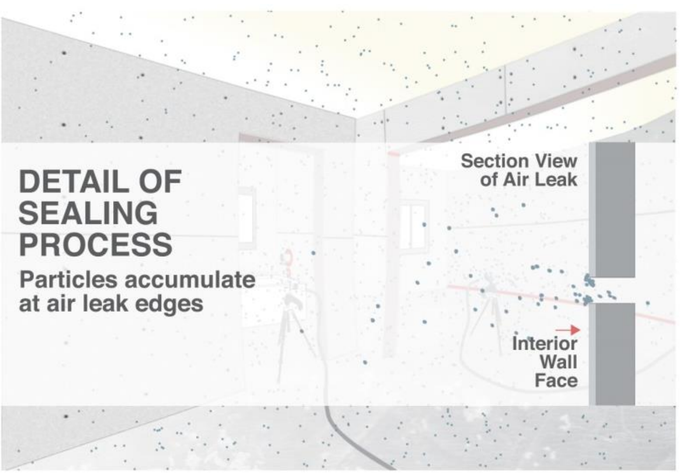
RESEARCH SUMMARY

Demonstrating the Effectiveness of an Aerosol Sealant to Reduce Multifamily Envelope Air Leakage

INTRODUCTION/BACKGROUND

While tight exterior envelopes have become standard for single-family homes, similar construction practices have been slow to reach the multifamily sector. Multifamily buildings have many of the same leakage paths as houses, as well as additional paths hidden in walls or other cavities that are difficult to seal with conventional methods. Researchers recently developed an aerosol sealant to seal leaks in building walls, floors, and ceilings. The process has the potential to be more effective and convenient than conventional sealing methods because it requires less time and effort, and it can seal a larger portion of a leakage area more quickly.

Figure E1. Image of particles sealing a gap



How it Works

The aerosol envelope sealing technology developed by the Western Cooling Efficiency Center at UC Davis uses an automated approach to produce extremely tight envelopes. Air is blown into a unit while an aerosol sealant "fog" is released in the interior. As air escapes the building through leaks in the envelope, the sealant particles are carried to the leaks where they impact and stick to the edges of the leaks, eventually sealing them. A standard house or duct air leakage test fan is used to pressurize the building and provide real-time feedback and a permanent record of the sealing. The technology is thus capable of simultaneously measuring, locating, and sealing leaks in a building.

Figure E2. Visual images of sealed air leaks

MN Code Envelope Air Tightness Requirements

In 2015 the State of Minnesota adopted the 2012 versions of the International Residential Building Code, International Building Code, and International Energy Conservation Code (Residential and Commercial Provisions) with state amendments. These changes require that multifamily buildings between one and three stories meet the residential energy code envelope tightness requirement of 3.0 ACH50. For multifamily buildings four stories and above, the envelope tightness requirement can be met using sufficiently tight materials, tight assemblies, or an envelope air leakage test. In Minnesota, all multifamily buildings four stories and above comply by using tight materials or assemblies and instead of tightness tests. However, some funding agencies require lenders to comply with the Minnesota Overlay and Guide to the Enterprise Green Communities Criteria. This requires that units meet the EPA ENERGY STAR Multifamily High Rise

Requirements requirement for a maximum air leakage rate of 0.30 cfm50 per square feet of enclosure (EPA 2013).

Study Objectives

At the start of this project the technology was in pre-commercial development. The project team performed aerosol envelope sealing demonstrations on three new construction and three existing multifamily buildings. The objectives for the study were to:

- measure the envelope leakage reduction and final tightness
- refine the unit preparation and sealing process
- model the impact of envelope tightness on outdoor air and inter-unit air flow rates
- estimate energy savings for tighter envelopes.

METHODOLOGY

Air Sealing

Aerosol envelope air sealing was performed on nine existing and 18 new construction multifamily units to measure air leakage reductions, document labor hours required, and help identify best practices for sealing preparation and implementation. The air sealing protocol was adapted based on experience with past laboratory and field projects. The type of sealant deposition protection measures, temporary seals, manual pre-sealing, and time required for all tasks were broken out for a subset of the sealed units. Multi-point, total unit air leakage tests were conducted on all units before and after sealing. The leakage test was repeated for a subset on units after the unit sealing was finished. Multiple fan, guarded air leakage tests were also performed to break out exterior and interior envelope leakage. Pre/post-acoustic tests and documentation of sealant locations using a fluorescent dye in the sealant and black-light photography were conducted for some of the units.

Figure E3. Image of air sealing process in the field

Airflow and Energy Modeling

The airflow and energy use modeling was performed with EnergyPlus simulations to determine building airflows from wind, stack, and mechanical effects as well as the air leakage characteristics of each unit. Whole building simulations often assume a constant air infiltration rate to represent the effects of uncontrolled infiltration driven by the natural forces of wind and stack effect and unbalanced mechanical ventilation. However, comparing the performance of different multifamily envelope tightness and ventilation strategies requires simulations that compute actual infiltration. The building airflows were computed from detailed information on the location and size of envelope air leaks along with inside air temperature/RH, outside air temperature/RH, wind speed/direction, and mechanical ventilation flow rates. The models were developed for four ventilation strategies and the energy consumption was compared for each strategy before and after sealing.

Aerosol Sealing Process

1. Pre-seal large gaps and temporary sealing — Any gaps wider than 3/8" and any leaks located where the aerosol will not stay in suspension need to be manually sealed.
2. Cover finished horizontal surfaces — Some of the sealant will settle on horizontal

surfaces during the process so they should be protected with plastic, duck mask, or masking tape.

3. Setup equipment and perform sealing — One nozzle is typically placed in every bedroom and living area; the unit is then pressurized while an aerosol sealant "fog" is released in the interior.
4. Remove coverings and clean surfaces — Windows must be opened and fans set at high to purge remaining sealant; surface protection should be removed and any extra residue cleaned.
5. Post-sealing air leakage test — An air leakage test should be conducted when all penetrations in the envelope have been made.

RESULTS

Air Sealing

Aerosol envelope sealing was performed on a convenience sample of 18 units in three new construction buildings and nine units in three existing buildings. Key characteristics and pre-sealing leakage results are listed in Table E1.

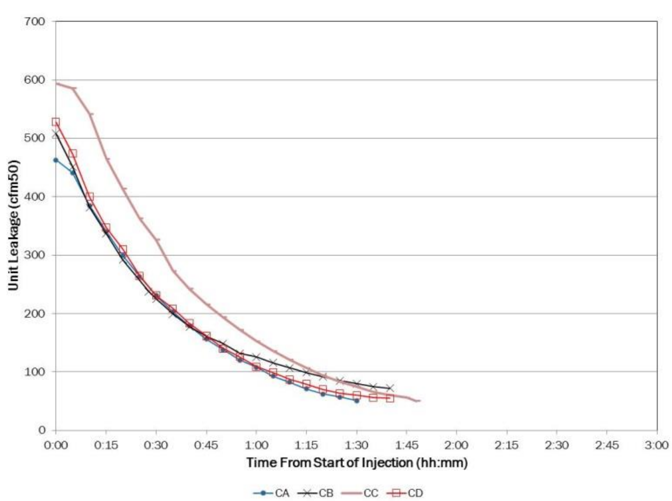
The research team conducted the sealing using an equipment design modified from previous field tests and the protocol described in the methodology section. Figure E4 displays an example of the reduction in envelope leakage through the aerosol sealing process for four new construction and six existing building units. In general, the sealing rate was greatest for the first 30 minutes and steadily decreased after that.

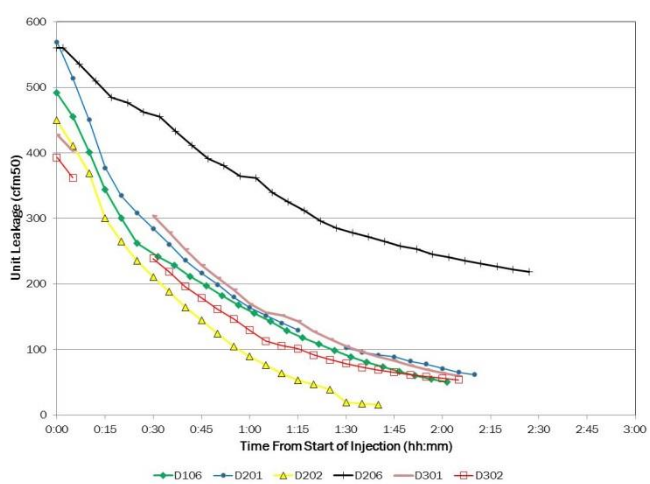
Table E1. Building characteristics

			# Units		Avg. Floor	Pre-Seal Leakage (ACH50)		
Type	ID	Stories	Total	Tested	Area (ft^2)	Min	Max	Avg
NC	A	4	36	6	451	3.11	3.50	3.22
NC	B	4	42	8	1,044	1.98	2.85	2.39
NC	C	5	107	4	384	7.08	8.41	7.75
Ex	D	3	16	6	237	12.0	17.2	13.4
Ex	E	2	2	1	1,579			13.7
Ex	F	2	4	2	760	15.8	17.2	16.5

*NC = new construction, EX – existing buildings

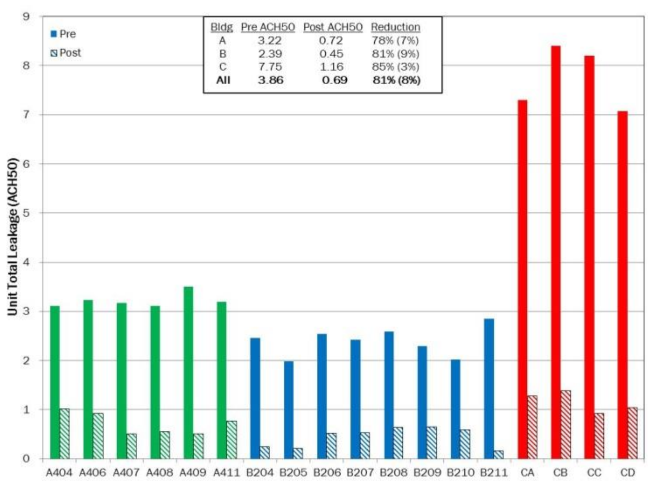
Figure E4. Variation in unit leakage (cfm50) through aerosol sealing process for units in new construction building C (left) and existing building D (right)





The aerosol envelope sealing of new construction and existing building units successfully demonstrated high levels of air leakage reduction with no damage to the finished surfaces. For the new construction units the reduction varied from 67% to 94% with an average of 81%, as shown in Figure E5. All of the units were more than 50% tighter than the 3.0 ACH50 code requirement for low-rise residential buildings, and half of the units met the Passive House tightness requirement of 0.6 ACH50. In addition, all of the units were at least 80% tighter than the EPA ENERGY STAR Multifamily High Rise requirement of 0.3 CFM50/ft^2.

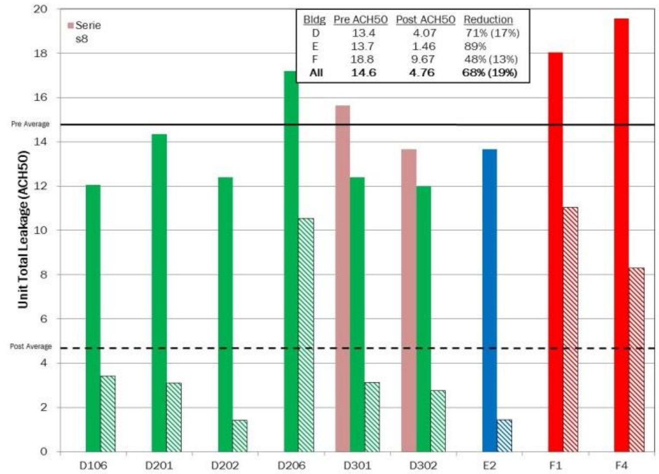
Figure E5. Pre and post sealing unit leakage and percent reduction for new construction units



As shown in Figure E6, results were equally impressive for existing buildings, sealing an average of 68% of the unit leakage. The tightness achieved was less consistent for two of the tests, where only 39% of the available leakage was sealed. In one case this was due to large unforeseen leaks behind a kitchen cabinet.

The pre-sealing results show initial leakage levels of 12.0 ACH50 to 17.0 ACH50 and post-sealing results from 1.4 ACH50 to 10.5 ACH50. This indicates that with manual pre-sealing of larger leaks, the aerosol sealing process can realistically reduce air leakage in existing apartments to meet or exceed the new construction low-rise residential code requirement of 3.0 ACH50.

Figure E6. Pre and post sealing unit leakage and percent reduction for existing units

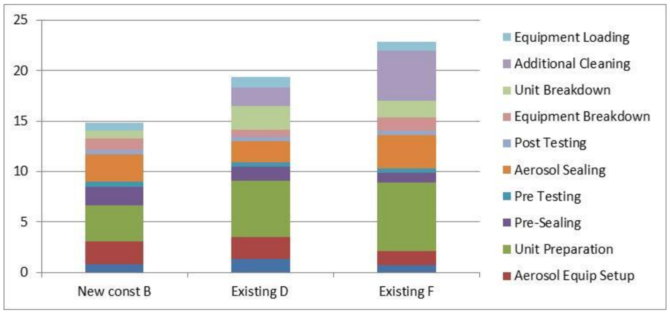


Labor Requirements

The total time required to complete the six different tasks for the air sealing process was tracked for three of the six buildings. The average task labor times for all sealed units for the three buildings are displayed in Figure E7. The total time per unit for the sealing process varied from 14 to 22 person-hours. However, this was a research project with staff that was being trained on the process and it is likely that with trained personal there would be a reduction in labor time by a factor of two or greater. There are opportunities to reduce labor time by:

- Pre-sealing large leaks;
- Performing sealing at a time when there are minimum finished surfaces to cover; and
- Using new, more portable and automated equipment.

Figure E7. Average task labor times in person-hours per unit for sealed units in three existing buildings



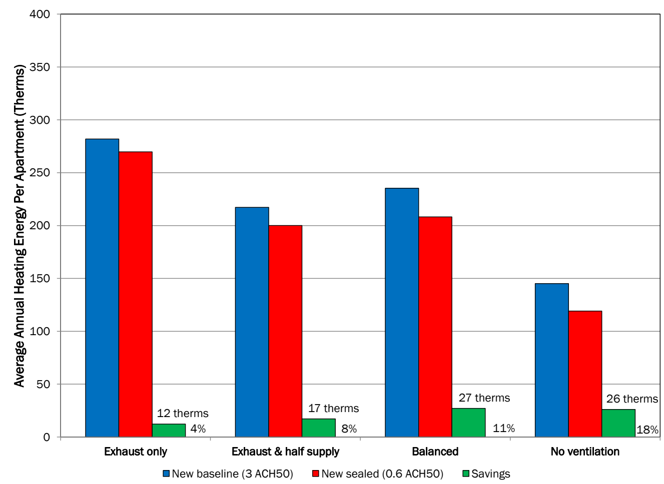
Energy Savings Modeling — New Construction

Figure E8 shows the new construction modeling compared the energy performance for a building with units that have a total (exterior and interior) envelope leakage of 3.0 ACH50 to a building that was sealed 80% tighter (e.g. 0.6 ACH50) with the aerosol process. The 80% reduction in envelope leakage is approximately equal to the 81% average reduction for the aerosol sealing of the 18 new construction units completed for this project.

The results show an 4% to 18% reduction in heating energy use due to sealing the envelope with annual gas savings of 12 to 27 therms and cost savings from $7 to $16. An annual cost savings of $15 for a tightness reduction from 3.0 to 0.6 ACH50 and balanced ventilation indicates that the sealing cost would have to be $150 to $225 per unit for a 10 to 15 year payback, assuming that the aerosol process is an "add-on" that reduces the leakage of a unit in a low-rise multifamily building from the code required value to a very tight level. However, aerosol sealing might eliminate the need for conventional methods and the higher levels of quality control that would be necessary to achieve tighter envelopes, ultimately costing less than conventional alternatives.

When the modeling for this project was performed, it was expected that the 3.0 ACH50 code requirement would apply to the *total* unit leakage. However, Minnesota code officials have indicated that the 3.0 ACH50 requirement applies to *exterior leakage only*, which allows units to be leakier than if the requirement applied to the total leakage. Increasing the leakage of the baseline model results in higher absolute savings for the new construction sealing, which is closer to the savings reported for the sealing of existing buildings as a part of this project.

Figure E8. Modeled annual space heating energy use and savings for new construction units



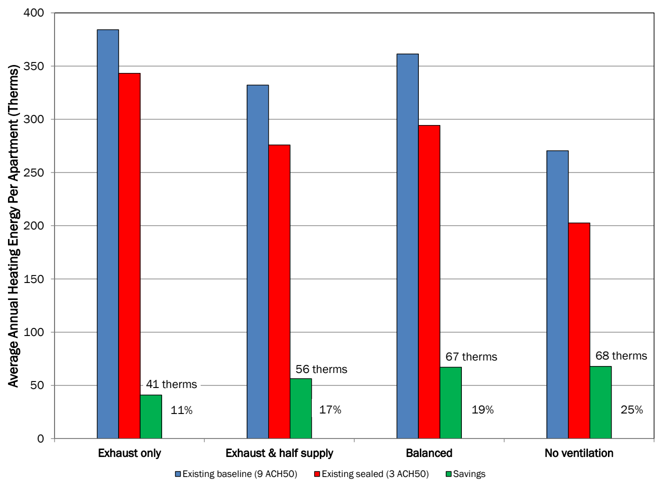
Energy Savings Modeling — Existing Buildings

The modeling for existing construction, Figure E9, focused on comparing the energy performance of an existing building that was sealed to the low-rise multifamily code requirement for new construction. The two total envelope leakage levels modeled for the existing buildings were 9.5 ACH50 and 3.0 ACH50.

The results show an 11% to 25% reduction in heating energy use due to sealing the envelope with annual gas savings of 41 to 68 therms and cost savings from $24 to $39, which may not be sufficient for many building owners. However, the modeling results were based on a 68% reduction from a starting leakage of 9.5 ACH50, and the average pre-sealing leakage of the nine existing units was over 14 ACH50. A pre-sealing leakage of 15 ACH50 and a reduction of 75% would increase annual savings by about a factor of two. The simulations assumed that 43% to 47% of the total leakage was to the exterior. If the percent exterior leakage for the models was 68%, the savings would have been about 50%

greater. Under certain factors, leakier units could see higher savings of three times or more (e.g. $70 to $120 per year).

Figure E9. Modeled annual space heating energy use and savings for existing building units



Another advantage of the aerosol sealing method in both new construction and existing buildings is that it greatly reduces airflow between units and common spaces. The modeling showed that the 80% reduction in total unit leakage reduced airflows between units by 68% to 80%.

CIP RECOMMENDATIONS

New Construction

Xcel Energy and CenterPoint Energy offer design assistance programs for commercial and industrial new construction and major renovation, including for multifamily buildings. The program provides consulting services and energy modeling as well as electricity and natural gas efficiency implementation rebates. Although a tighter building envelope and associated air infiltration reduction is not a standard measure for the program, it can be modeled if requested by the design team. The modeled air infiltration results from this project should be used for baseline and reduced envelope tightness infiltration values for design assistance programs.

The airflow modeling conducted for this project suggests that design assistance program building energy models should use a baseline air infiltration rate of 0.16 ACH for buildings with normal wind shielding. The baseline is reduced to 0.13 ACH for well shielded buildings and increased to 0.18 ACH for exposed buildings. The percent reduction in modeled air infiltration should be the difference between the measured exterior envelope leakage and the low-rise residential code requirement of 3.0 ACH50. Given the high level of energy savings achieved in this project, aerosol envelope sealing will likely be the most cost-effective sealing method for multifamily units required to meet more stringent compartmentalization requirements.

Existing Buildings

The CenterPoint Energy/Xcel Energy Multifamily Building Efficiency program will include envelope air sealing as a custom measure beginning in 2017. The payback for the air sealing work will need to be less than the measure life of 20 years to qualify for an incentive. The Minnesota Energy Resources Multifamily Direct Install Plus program does allow envelope air sealing as one of the targeted measures for investigation, and air sealing work may qualify for a custom rebate. All Minnesota utility programs for existing multifamily buildings should include incentives for envelope air sealing.

The State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs (2016) includes an algorithm for residential and small commercial buildings, but it is not directly applicable to multifamily units and there is currently no generally accepted methodology for computing multifamily envelope air sealing savings. The current calculation includes a value for “n_heat” which is the conversion factor from leakage at 50 Pa to leakage at natural conditions, building height, and exposure level. The modeling results from this project indicate that a value of 25 should be used for n_heat of existing multifamily buildings with less than 50 cfm of continuous, unbalanced mechanical ventilation and well shielded from wind. The value should be reduced to

21 for normal wind shielding and 19 for exposed shielding.

An evaluation of the building ventilation system should be conducted and recommended upgrades completed when any significant exterior envelope air sealing is performed. Exterior air sealing is not recommended when the unit does not have a mechanical ventilation system.

Author Contact:
David L. Bohac
Director of Research
(612) 802-1697
dbohac@mncee.org

This project was supported in part by the Minnesota Department of Commerce, Division of Energy Resources, through its Conservation Applied Research and Development (CARD) program, with co-funding by CEE in support of its nonprofit mission to advance research, program design, and knowledge dissemination in the field of energy efficiency.