Air Distribution Retrofit Strategies for Affordable Housing

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ABSTRACT

In multi-unit buildings, traditional duct sealing methods are often impractical, costly and/or disruptive because of the difficulty in accessing leakage sites. In this project, supported by the U.S. Department of Energy's Building America™ program, two retrofit duct sealing techniques—manually-applied sealants and injecting a spray sealant (Aeroseal®[1]) in combination with manual sealing, were implemented in several duplex buildings in North Carolina. Each method was used in twenty housing units. Duct leakage to the outside was reduced by an average of 59% through the use of manual methods, and by 90% in the units where a combination of aerosol and hand sealing was used. The cost of manually-applying sealant ranged from $275 to $511 per unit and for the Aeroseal®-treated ducts the cost was $700 per unit. Modeling suggests a short simple payback of 1.2 years for manual sealing and 1.5 years for the Aeroseal® system.

INTRODUCTION

Retrofit duct sealing techniques for low-rise multi-unit housing are not as well documented or developed as those for single family detached construction. Multi-unit housing is complicated by the inaccessibility of the ducts, the disturbance to numerous occupants when work is being performed, and the range of construction methods, styles of buildings, and construction details unique to these structures.

Duct leakage is recognized by the Department of Energy as a significant problem in many older residential buildings (U.S. Department of Energy Building Technologies Program 2011). It can contribute to energy waste, poor comfort, poor indoor environmental quality (IEQ) and moisture problems (U.S. Department of Energy Building Technologies Program 2011). Duct sealing alone can save up to 20% of home heating and cooling energy expenditure (U.S. Department of Energy 2009). Sealing ducts, therefore, is important to improve building performance. Unfortunately, ducts can be difficult to access (e.g. when

[1] Aeroseal is a registered trademark of Aeroseal, LLC, a division of JMD Corporation.

located in floors, cramped crawlspaces or under low sloped roofs), making the repairs expensive or impossible with traditional manual methods.

Traditional duct sealing involves manually inspecting and sealing holes in the ductwork with mastic adhesive and tape from the outside. A new duct sealing method is available that allows sealing of inaccessible ducts (that have an interior air barrier[2]) from the inside using an aerosol sealant injected into the airstream with a special blowing apparatus. The aerosol system, known as Aeroseal®, is a proprietary system that was developed at the Lawrence Berkeley National Laboratory in 1994 and has been commercially available since 1997 (Aeroseal, LLC 2011). Additional field data is needed to verify its performance, cost and suitability in a variety of building types

FIELD STUDY

In a project supported by the U.S. Department of Energy's Building America program, air distribution systems were repaired in 40 apartments in two affordable housing developments (Terrace Park and Berkshire Village) owned and managed by the Raleigh Housing Authority (RHA) in North Carolina. Two repair approaches were used to compare their respective costs and effectiveness: hand sealing with mastic and fiberglass mesh (for larger gaps), and the Aeroseal® system in combination with mastic at easily accessible locations. Duct systems were evaluated before and after the repairs. Four typical unit types were modeled to estimate the effect of the two repair techniques on energy use. The one- and two-story units are about 50 years old, about 1,000 ft^2 , have central air conditioning and natural gas fired forced air heating.

Technical Approach

Each treatment group contained a similar number of one and two story housing units. Each duct sealing method was used in half of the 40 apartments, split between the two developments (Table 1). Existing heating and cooling equipment remained in place. The only changes to the units were the duct repairs. All units were occupied at the time of the retrofit.

Table 1. Unit types

Development	Unit type	Hand sealing	Aeroseal®
Terrace Park	1 story 2 bedroom	0	2
	1 story 3 bedroom	3	2
	2 story 3 bedroom	7	6
Berkshire Village	1 story 3 bedroom	7	7
	2 story 3 bedroom	3	3

[2] The Aeroseal system may not be suitable for certain duct types such as flex ducts without an inner liner or unlined duct board.

The effects of the duct repairs were assessed by measuring duct leakage (total and to the outside), system airflow (using an Energy Conservatory TrueFlow® Air Handler Flow Meter) and air flow at each register (using an Energy Conservatory FlowBlaster) before and after the retrofit in each housing unit using recommended test protocols (The Energy Conservatory, Inc. 2006, 2011, 2012). To support the modeling effort, building enclosure leakage was measured in all units (pre and post retrofit) using an Energy Conservatory Blower Door. Three guarded blower door tests were also conducted to estimate the amount of leakage between units compared to the shell leakage directed only to the outside. Primary duct system characteristics are provided in Table 2.

Table 2. Duct configurations

	Terrace Park		Berkshire Village	
Unit type	1-story	2-story	1-story	2-story
Supply duct construction	Flex	Unknown (inaccessible)	Metal trunk with flex branches	Metal trunk with flex branches for 2nd floor; Unknown for 1st floor
Supply duct location	Attic	Floor cavity	Attic	Floor cavity and attic
Return duct construction	Metal	Metal	Metal	Metal
Return duct location	Conditioned space	Conditioned space	Conditioned space	Conditioned space
Air handler location	Conditioned space 1st floor	Conditioned space 2nd floor	Conditioned space 1st floor	Conditioned space 2nd floor
Returns	1	2 (1 on each floor)	1	2 (1 on each floor)

Hand sealing application

Hand sealing consisted primarily of sealing register boots to the ceiling with mastic or foil tape from below; sealing register boots to floors with mastic or foil tape from above; sealing returns from the inside with mastic; sealing the air handler with mastic; and sealing rigid trunk duct and trunk to flex duct connections in the attic with mastic. A set of instructions was provided to the heating and air conditioning contractor for hand sealing.

Aeroseal application

Aeroseal® is a proprietary aerosol applied sealant system that is injected into pressurized supply and return ducts. Sealant particles accumulate at leakage locations, gradually closing the leak. Gaps larger than 5/8 inch are recommended to be sealed manually with fiberglass and mastic, and the duct material must have an interior air barrier (Aeroseal, LLC 2011). The injection system continuously measures airflow and leakage throughout the sealing process, which is halted when the leakage has been reduced to the desired level.

The connections from the duct system to the air handler as well as to registers are blocked to prevent the sealant from fouling HVAC equipment or escaping into the living space. Most local codes will require a licensed HVAC contractor to perform this invasive work. The Aeroseal® system treats the ductwork but, because the registers and air handler are blocked off, it does not seal leaks in the return, air handler, or at the junction between registers and finish surfaces (wall/ceiling/floor). These areas must be sealed by hand, which is possible because they are usually accessible.

At the RHA properties, sealing of the Aeroseal® units included the Aeroseal® system (sealing to the maximum level achievable); plus sealing of the boot-to-finish gaps, returns, and air handler by hand with mastic. The register boot, return plenum and air handler hand sealing was done after the Aeroseal® process was complete and was done the same way as the sealing of those areas in the hand-sealed housing units. No additional sealing beyond Aeroseal® was carried out in the attic. Figure 1 illustrates the Aeroseal® application process.

Figure 1. Aeroseal® equipment (left) connected to supply plenum (right).

RESULTS

As expected, duct leakage was lower after the retrofit. The ducts in the Aeroseal®-treated units improved more than in the units sealed solely by hand. Return flow and supply register flows on average increased in all retrofit units with the exception of the supply register flows from the hand-sealed Berkshire Village 2-story units. One possible explanation is that certain ducts or supply boots were damaged (compressed or kinked) during the hand sealing, which restricted their post-retrofit flows.

Test results

A summary of the test results before and after duct sealing using Aeroseal® (red bars) and hand sealing (blue bars) is presented in Figure 2.

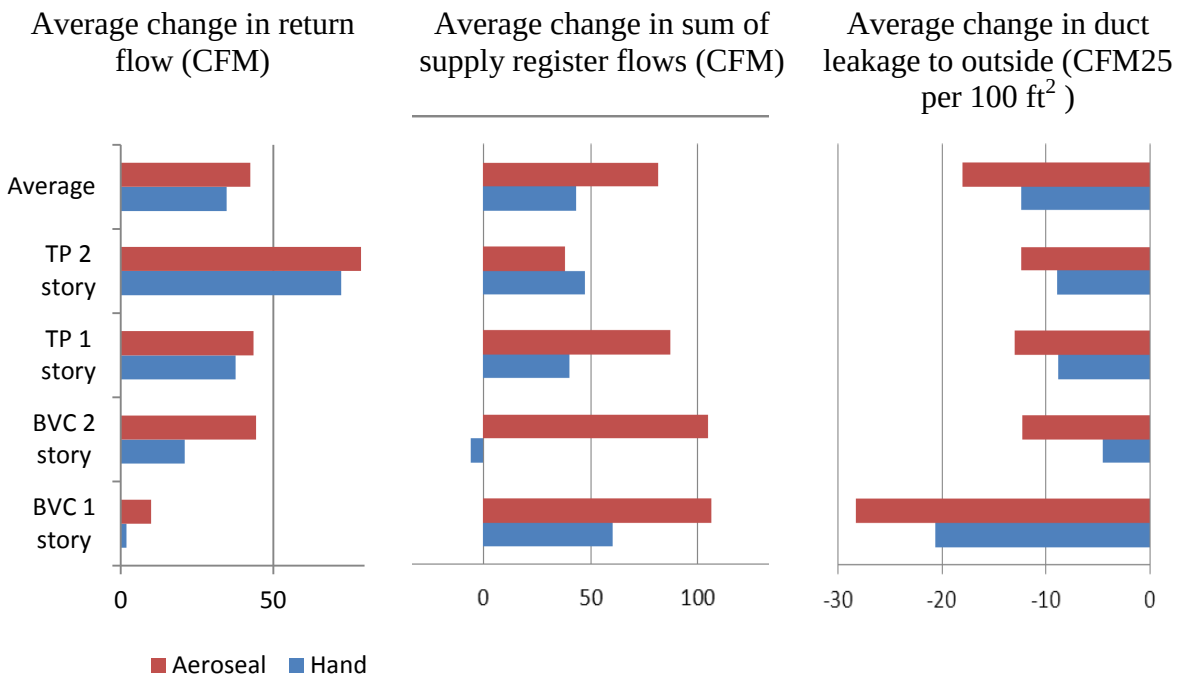

Figure 2. Duct sealing results comparing units with Aeroseal to hand sealed units by unit type (TP = Terrace Park; BVC = Berkshire Village Court)

Return flow (as measured at the return air register) increased by an average of about 40 CFM, slightly over 7% on average, with the Aeroseal units tending to have a slightly greater increase. The Berkshire Village Court one-story units showed very small flow improvement possibly due to a wide filter slot that was open when the filter was removed for testing (per the test equipment manufacturer's specified protocol). The open slot on the return side of the air handler drew in air that bypassed the return register and flow measurement device. The open slot also resulted in higher duct leakage measurements in these units.

As a result of duct sealing, supply register flows increased in most, but not all homes. On average, flow increased more for the Aeroseal® units than the hand sealed units.

A significant change in duct leakage to the outside was noted in all home types[3], with the Aeroseal® method achieving greater leakage reductions on average among all unit types. Pre-retrofit duct leakage to the outside averaged 15.8 CFM25/100 ft^2 of floor area and ranged from 7.2 to 27.2 CFM25/100 ft^2 of floor area for all units, up to four times higher than the North Carolina building code requirement of 6.0 CFM25/100 ft^2 for new construction (NC Building Code Council 2010). In post-retrofit measurements, the duct leakage was reduced to an average of 1.5 CFM25/100 ft^2 for the Aeroseal® units (with a range of 1.2 – 2.5 CFM25/100ft^2) and 7.0 CFM25/100 ft^2 for the hand sealed units (with a range of 1.3 – 21.2 CFM25/100ft^2).

[3] Measured individually (unguarded) to other units.

Reductions in total duct leakage were similar in magnitude. Pre-retrofit leakage averaged 27.5 CFM25/100ft^2 of floor area and ranged from 13.0 to 50.1 CFM25/100 ft^2 of floor area. In post-retrofit measurements, the duct leakage was reduced to an average of 7.9 CFM25/100 ft^2 for the Aeroseal® units (with a range of 4.3 to 19.5 CFM25/100 ft^2) and 16.0 CFM25/100 ft^2 for the hand sealed units (with a range of 6.3 to 38.3 CFM25/100 ft^2).

The Aeroseal® system records total duct leakage during the sealing process,[4] while the air handler, return and registers (the areas that are later sealed by hand) are blocked off. The Aeroseal® diagnostic reports reveal that on average approximately 70% of the total leakage reduction was due to hand sealing at the air handler and at the junction of the registers and the ceiling/floor, and not from the Aeroseal® product. The Aeroseal® system does not record leakage to outside, so it is not possible to determine from this data the degree to which Aeroseal® or hand sealing is responsible for its reduction.

Lessons

Researchers had the opportunity to learn from the experience of working on the duct systems in these affordable housing units relating to a variety of issues, including: the suitability of using standard testing protocols; using the two duct sealing approaches; and efficiency of production scale duct sealing in occupied units.

Approaches to duct sealing

The Aeroseal-treated units averaged 35% lower duct leakage to the outside (measured in CFM25/100 ft^2 of floor area) than the hand-sealed units. But it also has a number of other advantages over manually sealing ducts. Using Aeroseal® avoids having to work in what are often dark, hot, dirty and cramped attics. It allows sealing of otherwise inaccessible ducts inside floor cavities and low-clearance attics. It avoids the risks of workers damaging ducts, ceiling insulation or the ceiling itself as they move about the attic. Temporary flooring over the ceiling joists may mitigate this problem, but at significant added cost and time.

Difficulties with sealing ducts by hand can limit its effectiveness. To manually seal ducts wrapped with insulation, the wrap must first be removed, the duct exterior surface cleaned and then the duct connections then sealed with mastic. After 12-24 hours dry time the old wrap may be reinstalled (if undamaged) or new insulation applied. Quality control is more difficult and potentially expensive with manual sealing because of the additional labor required for an inspector to visit completed jobs and view the work in the attic. Duct testing could be conducted on a sample of units or visual inspection could be included, however, both would increase costs. Aeroseal®, on the other hand, provides a built-in test report that verifies the improvement of the supply ducts (but not the seals at register boots and return plenums).

Some challenges with the Aeroseal® system were encountered on these small homes. The Aeroseal® system is not well suited for sealing systems to less than 40-60 CFM of leakage.

[4] The Aeroseal® system includes a calibrated fan that continuously records total duct leakage during the sealing operation when the supply registers and air handler (including return) are blocked off.

A minimum airflow speed is necessary to keep the sealant suspended in the airstream. When leakage gets below 40-60 CFM, the flow becomes too low and the system may be shut down by the Aeroseal® software. The small RHA units had excessive duct leakage for their size, however much of that leakage was at the register boots, which are not treated by the Aeroseal® system and were hand-sealed. Most units had starting total leakage in the 70-80 CFM25 range (not including leakage at boots and the air handler), which is significant for apartments of less than 1,000 ft^2 , however the Aeroseal® system was constantly on the verge of shutting down due to low flow. Also, the nozzle that emits the sealant into the airstream became clogged more frequently than expected because of the many sequential low-airflow jobs that resulted in slower flow of sealant through the system.

The high ambient relative humidity during this project also served to depress flow rates. The Aeroseal® sealant needs to enter the duct system "dry"; i.e. a skin should form around each droplet of sealant. This is accomplished by a heating element in combination with an 8-10 foot plastic tunnel through which the sealant passes prior to entry into the duct system. Under humid conditions, the sealant needs more time in the tunnel to dry out, requiring slower airflow or a longer tunnel.

Connecting the Aeroseal® system to the supply duct proved challenging for these units. The lack of clearance between the top of the air handler heating coil and the ceiling required workers to custom fabricate fittings to make this transition. Arranging the equipment to provide an 8-10 foot straight run (the aforementioned tunnel) from the Aeroseal® nozzle to the duct entry point was also challenging in these small apartments. Often some portion of the equipment needed to be placed out of doors, which would not be possible in inclement weather conditions.

Production scale retrofits

To achieve greater market penetration in the affordable multi-housing segment, it will be beneficial to devise techniques that maximize the efficiency of sealing ducts in multiple similar co-located units in succession.

The run-time of the Aeroseal® equipment was approximately one hour per apartment; however, in an eight hour day, only two apartments could be completed. The equipment was idle, being moved or set-up 75% of the time. The Aeroseal® crew consisted of 2-3 people; one operating the equipment and 1-2 others doing set-up, clean-up and hand sealing of the returns and register boots. Adding another 2-person crew to prepare the next unit and restore the completed unit (re-install supply registers, repair the hole cut for the Aeroseal® entry point and general clean up) may enable the completion of three and perhaps even four units in one day with a single Aeroseal® system. Multiple spray nozzles would be required in case one became clogged due to the low sealant flow rate. The additional crew would increase labor costs, but perhaps be offset by the added productivity of the entire team (i.e. they may be able to complete twice the units per day with twice the labor but still with a single Aeroseal® system).

Another option for improving Aeroseal® productivity would be to connect two duct systems simultaneously using a "Y" connector. This would not provide an individual test

result or certificate for each living unit, but it could reduce the time and cost of sealing systems in close proximity to each other. Finally, a smaller Aeroseal® system, perhaps suitable for lower levels of absolute duct leakage, would have made work in these units simpler and quicker.

MODELING

Four representative units (a one and a two story unit at each development) were modeled using BEopt, the Building America simulation tool. Pre- and post- retrofit conditions were modeled to predict energy cost savings based on measured duct leakage reductions. Average duct leakage to outside as a percentage of total flow, per unit type and per sealing type, were used for modeling the test results.

Table 3. Duct leakage characteristics from field tests for BEopt models

Method	Number floors	Average pre-retrofit duct leakage to outside (cfm/100 ft2)	Average post-retrofit duct leakage to outside (cfm/100 ft2)	Leakage to outside reduction (%)
Hand sealing	1 story	16.0	5.1	68%
	2 story	15.6	8.0	49%
Aeroseal®	1 story	17.5	1.6	91%
	2 story	13.6	1.3	91%

The results of the BEopt modeling for each of the four unit types are provided in Table 4. The Aeroseal method results in higher energy savings than hand sealing. Greater savings are predicted in the one story units than the two story units because a greater portion of the ductwork is in unconditioned space in the one story homes. Hand sealed units and units sealed with Aeroseal had similar pre-retrofit characteristics on average. The units treated with Aeroseal have lower (7% average) post retrofit duct leakage and slightly lower source energy use compared to the hand sealed units.

Table 4. BEopt analysis results – Annual whole house MBtu savings from duct sealing

Method	Number floors	Terrace Park	Berkshire
Hand sealing	1 story	24%	28%
	2 story	16%	8%
Aeroseal	1 story	34%	31%
	2 story	19%	19%

COST EFFECTIVENESS

Costs from the contractor for hand sealing were $511 per unit for the one story units where work included accessing the attics and sealing metal trunk ducts; and $275 per unit for the two story homes where ducts were inaccessible in the floor and work only included sealing boots, the air handler and the return. Contractor costs for the Aeroseal®-treated units were $700 per unit regardless of unit type, and include the hand sealing that was done in these units at the boots, returns and air handler. Most of the time spent on the Aeroseal® process is in the setup and cleanup so unit size is less important. Table 5 provides the estimated annualized energy expense[5] based on a 15-year lifespan for each retrofit method as calculated using BEopt. Based on these results, a simple payback was calculated of 1.2 years for hand sealing, and 1.5 years for the Aeroseal® process with the aforementioned hand sealing. The marginal payback for Aeroseal over hand sealing ranged from less than one year to 15 years depending on unit type.

Table 5 BEopt analysis results – annualized energy expense and savings

Method	Plan	Pre-retrofit annualized energy expense	Post-retrofit annualized energy expense	Annual savings	% Change	Marginal payback for Aeroseal® (years)
Hand sealing	TP1	$1,820	$1,415	$405	-22%	NA
	TP2	$1,837	$1,563	$274	-15%	NA
	BV1	$2,052	$1,505	$547	-27%	NA
	BV2	$1,747	$1,615	$132	-8%	NA
Aeroseal®	TP1	$2,055	$1,404	$651	-32%	0.8
	TP2	$1,772	$1,470	$302	-17%	15.2
	BV1	$2,008	$1,423	$585	-29%	5.0
	BV2	$1,729	$1,419	$310	-18%	2.4

CONCLUSION

[5] BEopt calculates the *annualized energy related costs* by annualizing the energy related cash flows over the analysis period. Cash flows consist of mortgage/loan payments, replacement costs, utility bill payments, mortgage tax deductions (for new construction), and residual values. Costs, excluding mortgage/loan payments, are inflated based on the time they occur in the analysis period. The cash flows are annualized by determining the present worth of the cash flow by converting the total cost for each year to the value at the beginning of the analysis period (National Renewable Energy Laboratory 2012).

A field evaluation was conducted in forty attached public housing units comparing hand sealing of ducts with mastic to a combination of aerosol duct sealing (Aeroseal®) with hand sealing at some easily accessible locations. Both methods were effective in reducing total duct leakage and duct leakage to the outside. Leakage reduction was greater for the ducts sealed with Aeroseal®, especially for ducts in inaccessible locations. Some of this difference is likely due to the fact that aerosol sealing reached portions of the duct system that were inaccessible to manual methods. Significant manual sealing was required even for the units treated with Aeroseal® because that system does not address air handler leakage nor the connection between duct register boots and the ceiling or floor.

Modeling indicated that both duct sealing techniques will result in lower annualized energy expenditures (accounting for the cost of the retrofit) than not sealing the ducts. Despite being more expensive to implement, the annualized energy expenditure for the Aeroseal® system was 1-16% lower than for hand sealing, depending on unit type. The marginal payback for Aeroseal over hand sealing ranged from 10 months to 15 years. Annual savings (based on BEopt annualized costs) ranged from $302 to $651 for Aeroseal® and $132 to $547 for hand sealing. The one story apartments are predicted to achieve greater savings than the two-story units because a majority of their ducts are in unconditioned attic space. While Aeroseal® is available in the market today and offered by many local applicators (Aeroseal, LLC 2011), room exists to streamline the technology, especially for production scale work and for smaller spaces such as conducted in this project.

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