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Air Distribution Retrofit Strategies for Affordable Housing

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Advanced Residential Integrated Energy Systems (ARIES) Collaborative

March 2014

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Air Distribution Retrofit Strategies for Affordable Housing

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Definitions

A/C	Air conditioning
ADS	Air distribution system
ARIES	The Advanced Residential Integrated Energy Solutions Building America Team
BVC	Berkshire Village Court housing development
CFM(25/50)	Cubic feet per minute at 25/50 Pascals air pressure
DOE	U.S. Department of Energy
HVAC	Heating, ventilation, and air conditioning
IEQ	Indoor environmental quality
LBNL	Lawrence Berkeley National Laboratory
NREL	National Renewable Energy Laboratory
Pa	Pascal – unit of pressure measurement
RHA	Raleigh Housing Authority
TP	Terrace Park housing development

Executive Summary

In multifamily and attached buildings, manual duct sealing methods are often impractical or very costly and disruptive because of the difficulty in accessing leakage sites. In this project, two retrofit duct sealing techniques—manually applied sealants and injecting a spray sealant (Aeroseal[1]) in combination with some manual sealing—were implemented in several low-rise multiunit buildings in North Carolina. An analysis of the cost and performance of the two methods is presented. Each method was used in 20 housing units: approximately half of each group of units are single story and the remainder are two story. Results show that 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 injected spray sealant and manual sealing was used. Some of this difference is likely due to the fact that injected spray sealing reached portions of the duct system that were inaccessible to manual methods. It was found that 73% of the leakage reduction in homes that were treated with injected spray sealant was attributable to the manual sealing done at boots, returns, and the air handler.

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. Utility bills were collected and compared for 1 year before and after the retrofits for each unit. Energy savings based on utility bills were within 25%–50% of those predicted by the models for most unit types. Utility bill analysis shows 14% and 16% energy savings using the Aeroseal and hand sealing procedures, respectively, in heating season whereas in cooling season, energy savings using Aeroseal and hand sealing were both 16%. Average simple payback based on utility bills was 2.2 years for manual units and 4.7 years for the Aeroseal units. Only 18 of 40 units had usable utility bills.

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

1 Introduction

Retrofit duct sealing techniques for low-rise multifamily buildings and other attached housing units are not as well documented or developed as those for single-family detached construction. Attached housing units are complicated by the inaccessibility of the duct system, 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 U.S. Department of Energy (DOE) as a significant problem in many older residential buildings (DOE 2011). Duct leakage can contribute to energy waste, poor comfort, poor indoor environmental quality (IEQ) and moisture problems (DOE 2011).

Duct sealing alone can save up to 20% of home heating and cooling energy expenditures (DOE 2009). Sealing ducts, therefore, is important to improve building performance and meet Building America retrofit goals of 30%–50% energy efficiency improvements in existing homes. Unfortunately, ducts can be difficult to access (e.g., when located in floors, in 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 now on the market that allows sealing of inaccessible ducts (that have a non-porous interior surface[2]) from the inside using an aerosol sealant injected into the airstream with a special blowing apparatus. The aerosol system, known as Aeroseal, was developed at Lawrence Berkeley National Laboratory (LBNL) in 1994 and has been commercially available since 1997 (Aeroseal, LLC 2011a). Additional field data are needed to verify its performance, cost, and suitability in a variety of building types.

Owners of affordable rental properties are particularly in need of cost-effective methods to repair ducts because of limited capital budgets and high energy costs as a proportion of resident income. In addition, owners of affordable rental properties undergoing renovations are strongly motivated to minimize resident disruption and limit the length of time units are out of service, as these result in lost rental income. Owners of these properties sometimes include the utility bills in the tenants' rents or provide a fixed utility allowance based on previous bills.

1.1 Importance of Reducing Duct Leakage

Cost-effective solutions for heating, ventilation, and air conditioning (HVAC) air distribution system (ADS) retrofits suitable for various building types is important to meet Building America's goals. Such retrofits provide:

1. Reduced heating and cooling distribution losses through leaky ducts.
2. Avoidance of unbalanced pressures that can result from excessive duct loss and that can result in moisture and/or IEQ problems.
3. Improved IEQ by reducing potential contamination from attics, crawlspaces, and other interstitial spaces when contaminated air is drawn into the return duct system through leaks.

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

4. Possible opportunity to downsize heating and cooling systems at the time of equipment wear out, which may have been oversized on initial installation or became oversized as a result of building envelope improvements. Oversizing can cause inefficient operation, and in cooling systems can lead to poor humidity control.

Improving ADSs in older existing buildings is an essential ingredient to improving building energy efficiency. Reducing duct leakage is a necessary step in a comprehensive deep energy retrofit and a complementary measure to upgrading equipment.

Many low-rise housing developments were constructed using forced ADSs before the importance of duct leakage and duct insulation was fully realized. Sealing the leaks in these duct systems presents an attractive and potentially low-cost option for reducing heating and cooling energy use. Many of these units were originally built without air conditioning (A/C). Subsequently, when A/C systems were installed, often little or no attempt was made to improve the ADS and address the leaks.

1.2 Background

The literature was searched for published results describing the effectiveness and cost of manual and aerosol-based retrofit duct sealing. No studies on low-rise multiunit buildings with independent systems for each apartment were located. Most of the information summarized below relates to single-family homes. Two studies were of large commercial buildings. While system configurations in attached, multiunit housing are similar to single-family homes, ducts in multiunit buildings are often less accessible. Savings estimates from single-family homes are thus generally applicable to multiunit buildings, but the expense of accessing and sealing the ducts may be underestimated.

1.2.1 Manual Duct Sealing

The following results from manual duct sealing field research were identified.

1. A study performed by LBNL on 24 single-family homes in Sacramento, California found that standard duct sealing and insulating measures resulted in an average of 18% energy savings and had a simple payback of approximately 5 years or less (Jump, Walker and Modera 1996). This study also found that labor costs, at 77% of the total, greatly exceeded the material costs. The normalized costs of duct sealing measures were reported to be $\$0.45/ft^2$ for labor and $\$0.15/ft^2$ for materials.
2. Palmiter and Francisco (1994) made pre- and post-duct system retrofit measurements in six houses and found a 70% reduction in duct leakage post-retrofit and a 16% reduction in heating energy consumption.
3. Cummings *et al*. (1990) performed pre- and post-duct retrofit measurements in 24 houses. They found an average energy reduction of 18% at a retrofit cost of about $200 per house.
4. An article in *Home Energy* magazine (Haskell 1996) reported on duct sealing measures from 15 homes. He found that sealing reduced the average leakiness from 340 CFM50

(cubic feet per minute)[3] to 160 CFM50, at an average cost of $335 per house for duct sealing alone, with a range of $120 to $630. The average cost per CFM50 was $3, but the range varied greatly.

5. The National Residential Efficiency Measures Database developed by the National Renewable Energy Laboratory (NREL) lists the average costs of sealing and insulating existing ductwork in a single-family home as (NREL 2011):
    a. $1.80/ft^2 for sealing from 15% leakage to 6% leakage
    b. $1.80/ft^2 for sealing from 30% leakage to 15% leakage
    c. $3.60/ft^2 for sealing from 30% leakage to 6% leakage
    d. $1.10/ft^2 for adding R-6 insulation
    e. $1.30/ft^2 for adding R-8 insulation.

1.2.2 Aerosol Sealing System

1. The Sacramento Municipal Utility District initiated a program in 1999 to stimulate the local market for residential duct improvement services, and focused its efforts around an aerosol applied sealant (Aeroseal) that is injected into pressurized supply and return ducts. The district found that duct leakage was reduced by 80% within 1–1.5 hours of injection, as opposed to 60%–70% leakage reduction by traditional sealing measures (visual inspection followed by mastic and fiberglass repair). The average cost for the Aeroseal process was $1,009 (Kallett, et al. 1994). Studies on the costs of manual duct sealing were referenced from this study, as a comparison, and include:
    a. Lerman (Lerman 1996) reported an average contractor cost of $450 for sealing ducts of 194 centrally heated homes using conventional methods in a Tacoma pilot program.
    b. In Sacramento, researchers found contractor costs ranged from $335 to $1,069 and averaged $635, for conventional duct sealing plus duct insulation in 24 homes of varying sizes and heating and cooling equipment (Jump, Walker and Modera 1996).

    Based on this limited dataset, the Aeroseal system seals 10%–20% more leaks, but can cost double that of traditional methods. The Sacramento Municipal Utility District program results indicate that the technology holds promise if costs can be lowered or for situations where traditional methods are impractical.

2. Another study on the cost effectiveness of the aerosol-based product was performed on 47 houses in Florida. The average time required for the complete sealing protocol was 5.5 labor-hours per house, which corresponded to a 60% reduction of labor versus traditional sealing. Furthermore, approximately 75% of the time required for the aerosol sealing protocol was used for setup and cleanup, suggesting that future efforts can be even more time efficient, with practice (Modera, Dickerhoff and Nilssen 1996).
3. In a field test of advanced duct sealing technologies conducted on 80 homes in Iowa, Virginia, West Virginia, Washington, and Wyoming, the DOE Weatherization Assistance

[3] Researchers used 50 Pa instead of the more common 25 Pa as a duct test pressure to reduce potential errors from wind.

Program found that aerosol spray technology is 16%–60% more effective at sealing ducts and can potentially reduce labor time and costs for duct sealing by 30%, or almost 4 crew-hours, compared to the traditional best-practice approach (Ternes and Hwang 2001).

4. In a presentation to the State Energy Advisory Board by Dr. Mark Modera, he advocates for the use of aerosol sealants in large buildings. He shows the average duct leakage in large buildings to be approximately 39% (includes apartments, hospitals, barracks, dormitories, and offices). Duct leakage creates the need for larger air handling equipment and/or increased runtime to move more air to meet minimum flow requirements into rooms, and because pressure varies with the square of the ventilation flow, a small reduction in leakage can yield a high reduction in fan electricity consumption. A 36% exhaust leak results in 56% excess flow, which results in 281% excess fan power. Sealing 86% of that same leakage would yield a 69% reduction in fan power plus a 15% reduction in heating and cooling loads. The economics of this reduction for an apartment with 175 CFM of ventilation results in a savings of $208/year (assuming $0.15/kWh for fan, $0.20/kWh for A/C, and $1.50/therm) (Modera 2008). Often, manual duct sealing methods are impractical or very costly and disruptive for sealing the largely inaccessible ducts in these building types.

5. In laboratory and field testing performed by LBNL on two large commercial buildings, the feasibility of using aerosol duct sealants in these types of buildings, instead of residential buildings, was investigated. The results were promising and are summarized below (Carrie, et al. 2002):

   a. There is no need to improve the strength of the seals (although longevity issues should be studied).

   b. Adding a single compact injector to their existing apparatus increased the sealing rate by a factor of four.

   c. Reductions in duct leakage were more than 80% in one building and more than 90% in the other.[4]

   Further improvement in some areas was necessary:

   d. The sealing rates in the field tests were low, suggesting that further optimization of the hardware is needed to increase the efficiency of the technology.

   e. The two systems in the study did not have components that could be harmed by sticky aerosol deposition, such as hot-wire anemometers, smoke or indoor air quality sensors, or heating and cooling coils at terminal units, but these issues should be properly addressed before this technique is viable for large and complex systems. However, aerosol sealing did not modify the calibration of the pressure sensors in a variable air volume unit.

[4] This included some initial mastic and/or tape sealing.

1.3 Tradeoffs and Risks

Air distribution improvements have a number of implications on occupant comfort and other issues. Table 1 describes those impacts and associated risks that must be managed.

Table 1. Impacts and Tradeoffs

Issue	Impact/Tradeoff/Risk
Occupant Comfort	**Impact:** More even air distribution (volume and temperature) provides superior comfort in all rooms compared to leaky unbalanced systems. **Risk:** In extreme cases, reducing duct leakage may increase airflow to spaces beyond what is desired, potentially requiring the rebalancing of the ADS or reducing air handler fan speed to compensate.
Occupant Health and Safety	**Impact:** Tighter duct systems improve IEQ by reducing potential contamination and/or excess humidity from attics, crawlspaces, and other interstitial spaces when contaminated air is drawn into the return duct system through leaks. More even air distribution also reduces pressure differentials, which can lead to excess infiltration from neighboring units in multiunit buildings, and can reduce the flow of contaminants such as secondhand smoke. **Risk:** Changing pressure dynamics of the home by reducing duct leakage may affect combustion safety and/or pressure balance of the home. For example, sealing only one side of the system (supply or return) can potentially create a back-drafting situation (e.g., supply leaks only in a basement, or return leaks only in the attic). This can be mitigated by pressure mapping and depressurization testing.
Building and Equipment Durability and Maintainability	**Impact:** Tighter ducts draw in fewer particulates from unconditioned spaces, which will improve equipment and filter lifetimes. This will reduce the frequency of filter changes that are required and prevent particulate matter from fouling heat exchangers and other equipment. The condensation risk in unconditioned spaces from duct leaks (hot air on cold surfaces in winter and cold air cooling metal surfaces in summer) is reduced when duct leakage is reduced. **Risks:** There is a risk of damaging the supply plenum when setting up the Aeroseal apparatus or ineffectively resealing it, as well as a risk of accidentally injecting sealant into the air handler. These risks can be minimized through careful workmanship and inspection. Cutting open the supply plenum can risk voiding a mechanical system warranty; however, most older homes will be out of the warranty period.
System Performance	**Impact:** HVAC systems perform better when they are matched to the building sensible and latent loads. With excessive duct leakage thermal and moisture loads are much less predictable.
Building Code Compliance Issues	**Tradeoff:** In North Carolina, where this research was conducted, and possibly in other jurisdictions, significant ADS retrofits (new systems) in multilevel structures trigger a requirement to “either provide a separate HVAC system for each floor or to install automatically controlled zoning equipment for each level with individual thermostats on each level to control the temperature for that level.” (North Carolina Office of Administrative Hearings, 2010). For affordable properties this is a major expense. Reducing duct leakage improves comfort without triggering this requirement and is often preferred by building owners.

2 Field Study

ADSs were repaired in 40 apartments in two affordable housing developments 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 a proprietary aerosol spray system known as Aeroseal, 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. Utility bills were collected to compare the models to actual use before and after the retrofit for both heating and cooling seasons. Significant characteristics of the two housing developments are provided in Table 2. Exterior photos of the homes are provided in Figure 1 and Figure 2.

Table 2. Housing Development Characteristics

	TP[a]	BVC[b]
Location	Raleigh, North Carolina	Raleigh, North Carolina
Age	Approximately 50 years (the flex ducts were added at an unknown later date)	Approximately 50 years (the flex ducts were added at an unknown later date)
Total Units at Development	50	40
Unit Types	One- and two-story duplexes	One- and two-story duplexes
Heating System	Natural gas-fired storage tank water heater supplying domestic hot water and hot water to hydronic coil in the air handler for space heating	Natural gas furnace
Cooling System	Central A/C	Central A/C
Average Conditioned Floor Area	One-story: 858 ft^2 Two-story: 979 ft^2	One-story: 1,025 ft^2 Two-story: 1,122 ft^2

[a] Terrace Park
[b] Berkshire Village Court

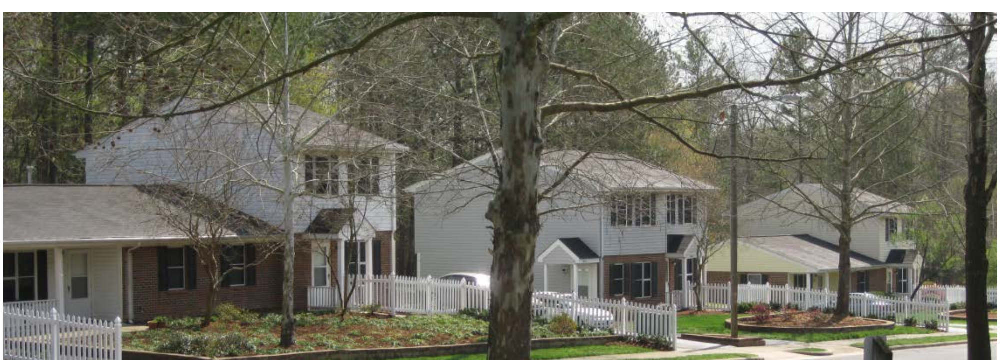

Figure 1. One- and two-story attached homes at TP

Figure 2. One- and two-story attached homes at BVC

2.1 Research Questions

This research addressed the following questions:

1. What is the cost (for a community-scale project) and effectiveness (in terms of leakage reduction, increase in conditioned air delivered to the living space and energy savings) of duct sealing using the Aeroseal system compared to traditional manual duct sealing for this building type?
2. What logistical and technical issues might affect community scale duct sealing retrofit productivity and effectiveness?

2.2 Technical Approach

Each treatment group contained a similar number of one story and two story housing units. Each duct sealing method was used in half of the 40 apartments, split between the two developments (Table 3).

Table 3. Unit Types

Development	Unit Type	Plan Name	Hand Sealing	Aeroseal
TP	One-story two-bedroom	TP1/2	0	2
	One-story three-bedroom	TP1/3	3	2
	Two-story three-bedroom	TP2/3	7	6

Development	Unit Type	Plan Name	Hand Sealing	Aeroseal
BVC	One-story three-bedroom	BV1/3	7	7
	Two-story three-bedroom	BV2/3	3	3

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.

The effects of the duct repairs were assessed by measuring the following items before and after the retrofit in each housing unit using recommended test protocols (The Energy Conservatory, Inc. 2006, 2011, 2012):

1. Duct leakage (total and to outside) in CFM25 using an Energy Conservatory Duct Blaster.
2. Total system airflow in CFM using an Energy Conservatory TrueFlow Air Handler Flow Meter.
3. Airflow at each register in CFM using an Energy Conservatory powered flow hood (FlowBlaster).

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.

2.3 Retrofit

Primary duct system characteristics are provided in Table 4. Portions of the pre-existing ADSs are pictured in Figure 3 and Figure 4.

Table 4. Duct Configurations

	TP		BVC	
Unit Type	One-story	Two-story	One-story	Two-story
Supply Duct Construction	Flex	Unknown (inaccessible)	Metal trunk with flex branches	Metal trunk with flex branches for second floor; unknown for first floor
Supply Duct Location	Attic	Floor cavity	Attic	Floor cavity and attic
Return Duct Construction	Metal	Metal	Metal	Metal
Return Duct Location	Conditioned space[6]	Conditioned space[6]	Conditioned space[6]	Conditioned space[5]
Air Handler Location	Conditioned space first floor	Conditioned space second floor	Conditioned space first floor	Conditioned space second floor
Returns	1	2 (1 on each floor)	1	2 (1 on each floor)

[5] Some portion of return air may have been pulled from unconditioned space.

Figure 3. Register boot pulling away from floor (left) and ceiling (right)

Figure 4. Attic ductwork

2.4 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 HVAC contractor for hand sealing (Appendix A). Figure 5 through Figure 7 illustrate hand sealing application.

Figure 5. Applying mastic to ceiling register boot (left) and register boot sealed to floor with foil tape

Figure 6. Applying mastic inside metal return plenum[6]

Figure 7. Air handler sealed with foil tape (left) and return plenum sealed with mastic (right)

2.5 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 ⅝ in. are recommended to be sealed manually with fiberglass and mastic, and the duct material must have an interior air barrier (Aeroseal, LLC 2011a). 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 off to prevent the sealant from fouling HVAC equipment or escaping into the living space. Most local codes require a licensed HVAC contractor to perform this invasive work. The Aeroseal system treats the ductwork; however, 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 less than 5 CFM25 total leakage or to where leakage reduction stopped), plus sealing of the boot-

[6] What appears to be brown insulation is actually accumulated dust. Workers cleaned only areas that were getting mastic.

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 the same as the sealing of the areas in the hand-sealed housing units. No additional sealing beyond Aeroseal was carried out in the attic. Figure 8 and Figure 9 illustrate the Aeroseal application process.

Figure 8. Aeroseal equipment (left) connected to supply plenum (right)

Figure 9. Register plugged during Aeroseal process, showing gaps that must be hand-sealed (left); supply plenum repaired after Aeroseal process (right)

3 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 increased, on average, in all retrofit units with the exception of the supply register flows from the hand-sealed BVC two-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 greater than the added flow due to the sealing.

3.1 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 10.

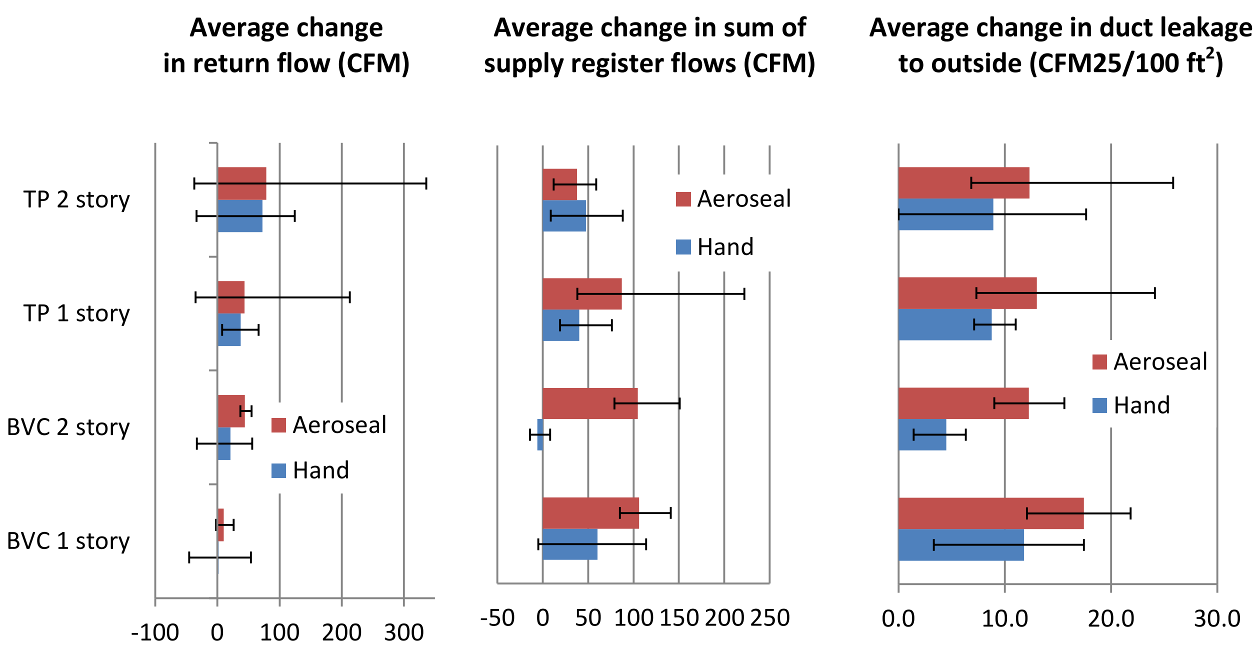

Figure 10. Duct sealing results comparing units with Aeroseal to hand sealed units by unit type

Return flow (as measured at the return air register) increased by an average of about 40 CFM, slightly more than 7% on average, with the Aeroseal units tending to have a slightly greater increase. The BVC 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. An analysis of the effects of this slot on flow and leakage measurements is presented in Section 3.2.1 below.

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 for the units sealed by hand.

A significant change in duct leakage to the outside was noted in all home types,[7] 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).

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 4.3–19.5 CFM25/100 ft^2) and 16.0 CFM25/100 ft^2 for the hand sealed units (with a range of 6.3–38.3 CFM25/100 ft^2).

The Aeroseal system records total duct leakage during the sealing process, while the air handler, return, and registers (the areas that are later sealed by hand) are blocked off. A closer look at the Aeroseal diagnostic reports reveals that, on average, approximately 73% 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. Table 5 shows the Aeroseal leakage reduction as a percentage of the total leakage reduction. The Aeroseal system does not record leakage to outside, so it is not possible to determine from these data the degree to which Aeroseal or hand sealing is responsible for its reduction.

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

Table 5. Aeroseal Leakage Reduction as a Percentage of Total Leakage Reduction

Unit Address	Total Leakage (CFM25)			Aeroseal Leakage (CFM25)			Reduction Due to Aeroseal as % of Total Reduction
	Before	After	Reduction	Before	After	Reduction	
8405 Berkshire Village Ct	450	230	220	74	8	66	30%
8407 Berkshire Village Ct	610	245	365	98	7	91	25%
8421 Berkshire Village Ct	532	208	324	63	18	45	14%
8423 Berkshire Village Ct	702	204	498	97	4	93	19%
8425 Berkshire Village Ct	480	220	260	77	12	65	25%
8427 Berkshire Village Ct	560	280	280	210	14	196	70%
8441 Berkshire Village Ct	618	301	317	80	0	80	25%
8401 Berkshire Village Ct	216	61	155	45	7	38	25%
8402 Berkshire Village Ct	350	48	302	81	39	42	14%
8403 Berkshire Village Ct	252	58	194	58	5	53	27%
6701 Winter Place	119	56	63	34	2	32	51%
6714 Winter Place	130	46	84	28	2	26	31%
6707 Winter Place	147	53	94	31	2	29	31%
6712 Winter Place	289	140	149	36	2	34	23%
6703 Winter Place	490	68	422	47	3	44	10%
6706 Winter Place	188	61	127	56	6	50	39%
6708 Winter Place	181	77	104	29	5	24	23%
6709 Winter Place	460	87	373	21	1	20	5%
6713 Winter Place	311	65	246	73	7	66	27%
6715 Winter Place	238	56	182	47	1	46	25%
Average							27%

3.2 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.

3.2.1 Standard Test Protocols

The standard test protocol as provided by the manufacturer of the Duct Blaster and TrueFlow Plates (The Energy Conservatory, Inc. 2006, 2011) calls for these tests to be conducted with the filter removed from the HVAC system, which is how the tests were performed. The one-story units at BVC were configured with a vertical filter slot between the short return and the air handler (Figure 11).

Figure 11. Filter slot at BVC one-story unit

In these units, removing the filter left an approximately 1.5 in. by 16 in. opening in the short return duct. Duct blaster measurements of total duct leakage were artificially inflated because during normal operation, approximately two-thirds of the filter slot was blocked by the edge of the 1 in. thick by 16 in. wide filter, the only gaps being due to an imprecise fit. Ideally, leakage to outside testing would eliminate this issue by eliminating leakage through gaps to the conditioned space; however this is not the case in these circumstances. Separate duct leakage measurements were also made with the filter slot open, and sealed with tape to completely block the opening (Table 6 and Table 7).

Table 6. Duct Leakage (CFM25/100 ft²) With Filter Slot Open and Closed—Pre-Retrofit

Unit Number (all at BVC)	Hand (H) or Aero-Sealed (A)	Duct Leakage Total: Filter Slot Open	Duct Leakage Total: Filter Slot Closed	Duct Leakage Total: % Difference[i]	Duct Leakage to Outside: Filter Slot Open	Duct Leakage to Outside: Filter Slot Closed	Duct Leakage to Outside:% Difference[*]
8421	A	52	22	-57%	27	14	-48%
8423	A	68	30	-57%	42	20	-52%
8425	A	47	25	-46%	27	17	-35%
8427	A	55	41	-25%	33	24	-25%
8441	A	60	40	-34%	34	21	-38%
Average		56	32	-44%	32	19	-40%

[*] Discrepancies in the percentage calculations are due to rounding errors of decimal values that aren't shown for simplicity. The values reported are the accurate numbers.

Table 7. Duct Leakage (CFM25/100 ft^2) With Filter Slot Open and Closed—Post-Retrofit

Unit Number (All at BVC)	Hand (H) or Aero-Sealed (A)	Duct Leakage Total: Filter Slot Open	Duct Leakage Total: Filter Slot Closed	Duct Leakage Total: % Difference	Duct Leakage to Outside: Filter Slot Open	Duct Leakage to Outside: Filter Slot Closed	Duct Leakage to Outside:% Difference
8407	A	24	8	–206%	4	1	–65%
8421	A	20	7	–193%	3	1	–54%
8423	A	20	6	–209%	3	1	–55%
8425	A	21	7	–224%	4	1	–71%
8427	A	27	15	–77%	4	3	–28%
8441	A	29	11	–157%	3	1	–62%
8406	H	27	18	–54%	11	8	–32%
8416	H	34	21	–57%	12	9	–24%
8418	H	23	12	–100%	7	4	–49%
8424	H	33	19	–76%	7	4	–50%
8426	H	26	13	–93%	8	4	–52%
8436	H	29	15	–93%	7	4	–39%
8404	H	36	25	–47%	14	10	–24%
Average		27	14	–122%	7	4	–46%

It is hypothesized that the pressure at the filter slot was much greater than the counteracting pressure of the blower door (25 Pa) applied during a leakage to outside test. The duct blaster was set up at the return grille, and the pressure was measured in the nearest supply duct. The pressure drop across the air handler coils requires a greater than 25 Pa pressure at the air handler in order to obtain a 25 Pa duct pressure at the location of supply duct pressure measurement, due to the obstruction of the airflow by the fan. This leads to inflated test results as compared to leakage during normal operation.

Measurements of total return flow using the TrueFlow Plate were also made in some units with the filter slot sealed with tape. A comparison of measurements taken with open and sealed slots is provided in Table 8 and Table 9. Return flow is between 9% and 17% higher when the filter slot is sealed, for measurements taken both before and after the retrofit, respectively. If this experiment were repeated, the filter media could be cut out of the cardboard edge of the filter, retaining the original configuration so as not to skew the measurements.

Table 8. Total Return Flow With TrueFlow Plate (CFM)—Pre-Retrofit

Unit Number (All at BVC)	Filter Slot Open	Filter Slot Closed	% Difference
8425	535	616	15%
8427	539	590	9%
8441	434	495	14%
Average	503	567	13%

Table 9. Total Return Flow with TrueFlow Plate (CFM)—Post-Retrofit

Unit Number (All at BVC)	Filter Slot Open	Filter Slot Closed	% Difference
8421	497	567	14%
8423	550	643	17%
8425	534	609	14%
8427	537	585	9%
8441	460	523	14%
Average	516	585	14%

While the filter slot clearly had an impact on duct leakage and flow measurements, it did not greatly affect the calculation of the improvement (reduction) in duct leakage or increase in flow before and after retrofit (Table 10). Duct leakage to outside declined by approximately 90% in both cases (these units were all treated with Aeroseal) and the change in return flow was very consistent in measurements taken with the filter slot both open and closed. Return flow through the measuring device increased in unit 8441, perhaps due to sealing of return leakage.

Table 10. Effect of Filter Slot on Retrofit Improvement Measurements

Unit (All at BVC)	Change in Duct Leakage to Outside—Measured With Filter Slot Open	Change in Duct Leakage to Outside—Measured With Filter Slot Closed	Change in Return Flow—Measured With Filter Slot Open	Change in Return Flow—Measured With Filter Slot Closed
8421	–88%	–91%	–	–
8423	–91%	–94%	–	–
8425	–82%	–93%	0%	–1%
8427	–91%	–89%	0%	–1%
8441	–92%	–94%	6%	6%
Average	–89%	–92%	2%	1%

3.2.2 Approaches to Duct Sealing

Both manual and injected spray sealant methods of ADS sealing produced excellent results. Each method has advantages and disadvantages, some of which are described here.

Manual sealing can be accomplished with semi-skilled workers and very little equipment, capital, or materials cost. The materials and tools required are readily available anywhere. Manual methods can seal any size and type of duct leak. However, 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 should be cleaned, and then the duct connections can be sealed with mastic. After 12–24 hours dry time, the old wrap may be reinstalled (if undamaged) or new insulation applied. Work must be conducted in what are often dark, hot, dirty, and cramped attics. Ducts inside floor cavities and low-clearance attics are often inaccessible, an especially significant drawback in multifamily buildings. Workers risk 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.

Quality control may be 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 provides more complete sealing of all small leaks, even in inaccessible spaces. In this study, Aeroseal provided an average of 35% additional leakage reduction (duct leakage to the outside, measured in CFM25/100 ft^2 of floor area) than solely manual methods. Aeroseal also 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 as configured for this test was not ideally suited for sealing systems to less than 40–60 CFM of leakage. A minimum airflow speed is necessary to keep the sealant suspended in the airstream. When leakage fell below 40–60 CFM, the flow became too low and the system was 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 sealed by hand. Most units had starting total leakage in the 70–80 CFM25 range (not including leakage at boots and the air handler),[8] which is significant for apartments smaller 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. This is accomplished by a heating element in combination with an 8- to 10-ft plastic tunnel through which the sealant passes prior to entry into

[8] 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.

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- to 10-ft 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.

Isolating the space conditioning equipment from the duct system is crucial to avoiding damage to that equipment from an accumulation of sealant. At times this was a challenge. Finally, whenever technology replaces manual methods, the possibility of equipment failure arises that can delay or halt a job. Table 11 summarizes the relative advantages and disadvantages of the two methods.

Table 11. Advantages and Risks Involved With Using Aeroseal

	Manual Sealing	Injected Spray Sealant
Performance	Good for accessible areas	Excellent, if manual areas are also sealed well
Quality Control	Requires additional test	Included for duct portion, inspection required for manual areas
Cost	Low for small systems, increases proportionally with system size	High fixed cost, but increases more slowly with system size
Skill Required	Semi-skilled	Highly trained lead operator with semi-skilled assistants
Applicability to All Conditions	Yes, very flexible	Some conditions may be challenging such as cramped spaces. Also, large leaks must be sealed manually.
Seals Inaccessible Ducts	No	Yes

4 Modeling

Four representative units (a one- and a two-story unit at each development) were modeled using BEopt version 2.1, the Building America simulation tool. Pre- and post-retrofit conditions were modeled to predict energy cost savings based on measured duct leakage reductions. Table 12 shows the unit characteristics (except duct leakage) that were used to generate the models. Average duct leakage to the outside in terms of CFM25/100 ft^2 floor area, per unit type and per sealing type, were used for modeling the test results. The steps used for this calculation are described later in this section. Table 13 shows the unit characteristics used for the BEopt models.

Table 12. Unit Characteristics for BEopt Model

Characteristic	Entry
Infiltration	Custom values based on test data
Duct Leakage	Custom values based on test data
Water Heater (Both Units)	BEopt's built-in entry for a "Gas Standard" water heater (0.59 EF)
A/C	Seasonal energy efficiency ratio 10
TP Space Heating	Furnace, gas, 60 annual fuel utilization efficiency
Berkshire Furnace	Furnace, gas, 80 annual fuel utilization efficiency
Clothes Washer	Yes
Clothes Dryer	Yes
Fluorescent Lighting	None
Domestic Hot Water Distribution	Trunk branch copper, no insulation
Dishwasher	No
Cooking Fuel	Electric
Refrigerator	Old, top mount freezer
Mechanical Ventilation	None
Window Type	Double pane metal frame, no thermal break
Wall Construction	R-11 grade 3 batt insulation
Attic Insulation	R-30 grade 3 batt insulation
Floor Cavities Between Units	Assumed to be in conditioned space
Roof Type	Gray asphalt shingle
Supply Duct Location	Attic—unconditioned space
Attic Type	Vented
Slab Insulation	None
Carpeting	None

Table 13. Duct Leakage Characteristics From Field Tests for BEopt Models

Method	No. of Floors	Average Pre-Retrofit Duct Leakage to Outside (CFM/100 ft^2)	Average Post-Retrofit Duct Leakage to Outside (CFM/100 ft^2)	Leakage to Outside Reduction (%)
Hand Sealing	1	16.0	5.1	68%
	2	15.6	8.0	49%
Aeroseal	1	17.5	1.6	91%
	2	13.6	1.3	91%

The results of the BEopt modeling for each of the four unit types are provided in Table 14. 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. The average duct leakage of all units (in CFM/100 ft^2) is shown beside the annualized energy expenditure (MMBtu/yr) from the BEopt models in Figure 12. Hand sealed units and units sealed with Aeroseal had similar pre-retrofit characteristics on average. The units treated with Aeroseal have lower post-retrofit duct leakage and slightly lower source energy use compared to the hand sealed units.

**Table 14. BEopt Analysis Results—
Annual Whole House Source MMBtu Savings From Duct Sealing**

Method	No. of Floors	TP	BVC
Hand Sealing	1	3.9%	4.8%
	2	4.2%	3.2%
Aeroseal	1	4.8%	7.0%
	2	5.9%	6.9%

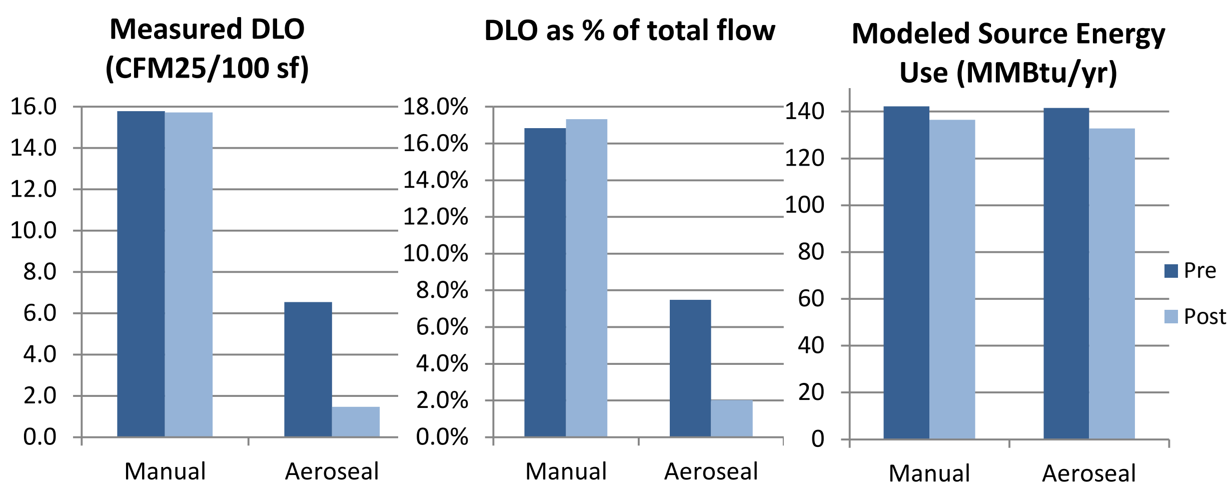

Figure 12. Aeroseal versus hand sealing for average duct leakage of all units and modeled energy use of the four unit types

5 Cost Effectiveness From Modeling

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 included only 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 for the Aeroseal process is in the setup and cleanup so unit size is less of an issue. Table 15 shows the cost per unit of leakage reduction for each method and unit type.

Table 16 provides the estimated annualized energy expense[9] based on a 15-year lifespan for each retrofit method as calculated using BEopt. Based on these results, a simple payback was calculated ranging from 4 to 10 years depending on method and unit type.

Table 15. BEopt Capital Cost Assumptions for Duct Improvements

Method	No. of Floors	Cost per Unit	Cost per Unit of Measured Leakage Reduction ($/Average CFM/100 ft^2)
Hand Sealing	1	$511	$47
	2	$275	$36
Aeroseal	1	$700	$44
	2	$700	$57

Table 16. BEopt Analysis Results – Annualized Energy Expense and Savings

Method	Plan	Pre-Retrofit Annualized Energy Expense	Post-Retrofit Annualized Energy Expense	Annual Savings	% Change	Simple Payback (years)
Hand Sealing	TP1	$1,550	$1,514	$36	2.3%	9.4
	TP2	$1,667	$1,615	$52	3.1%	4.2
	BV1	$1,567	$1,517	$50	3.2%	7.2
	BV2	$1,673	$1,594	$79	4.7%	5.6
Aeroseal	TP1	$1,565	$1,520	$45	2.9%	9.9
	TP2	$1,670	$1,605	$65	3.9%	7.6
	BV1	$1,568	$1,495	$73	4.7%	6.9
	BV2	$1,717	$1,679	$38	2.2%	6.5

[9] 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 (NREL 2012).

6 Billing Analysis

One year of post-retrofit utility bills were collected and compared to 1 year of pre-retrofit utility bills for most of the units in which the primary leaseholder remained constant. The post-retrofit heating and cooling energy consumption are compared to pre-retrofit usage, normalizing for outdoor air temperature. The following procedure was used to calculate both heating and cooling energy savings due to duct sealing.

In order to estimate the reduction in heating and cooling energy consumption due to duct sealing, a regression technique was used. Regression is a statistical technique that estimates the dependence of a variable of interest (such as energy consumption) on one or more independent variables, such as ambient temperature, and can be used to estimate the effects on the dependent variable of a given independent variable while simultaneously controlling for the influence of other variables. This procedure can also be used to provide a deeper understanding of how and when energy is used. In addition to estimating energy savings, the uncertainty in energy savings calculations can also be calculated.

In order to obtain accurate predictions, the sample of energy data used for a regression model should be representative of the overall heating/cooling season. For energy consumption, the baseline modeling period should cover most of the full range of operating conditions. For this project, we obtained monthly energy consumption data from energy bills that differ month-to-month, not only because of the weather, but also because the number of days in the months may differ. To cope with this situation, we divided total energy use (dependent variable) in each month by the number of days in each month to obtain the average therms/day. Note that linear regression assumes that the x-values (outdoor temperatures) are known exactly, with no measurement errors. There are various types of linear regression models used for estimating energy consumption or savings. In this work, a three-parameter heating change point model was used as described below.

In this analysis, it is assumed that heating energy use may be proportional to ambient temperature, yet only below a certain threshold; if outdoor air temperature goes above 65°F, the heating energy use does not continue to increase. Likewise for the summer season, if outdoor air temperature goes below 75°F, the cooling energy use does not continue to increase. Energy associated with hot water use is similar across all seasons. Under these circumstances, a three-parameter *change-point* linear regression has a better fit than a simple regression model. Because of the physical characteristics of buildings, the data points have a natural two-line angled pattern to them.

The following equation was used to calculate energy consumption using a three-point model:

$$Y = Y_c + m \times (T - T_c)^-$$

Y	= The value of the dependent variable (energy use)
Yc	= Temperature-independent energy use
m	= The linear dependence on the independent variable (slope)
T	= The value of the independent variable (ambient temperature)
Tc	= Change-point temperature

(T - Tc)- = Indicates that the values of the parenthetic term are set to 0 when they are positive (heating season).

(T - Tc)- = Indicates that the values of the parenthetic term are set to 0 when they are negative (cooling season).

The change point temperature (Tc) was taken as 65°F for all buildings' pre- and post-retrofit for heating energy savings analysis and 75°F for all buildings' pre- and post-retrofit for cooling energy analysis. Ambient hourly temperature data are used from the Raleigh-Durham International Airport.

In total, based on weather normalized utility bills, heating and cooling savings in units with ducts sealed by hand were 16.2% and 16.3%, respectively, whereas heating and cooling savings units where ducts were sealed using Aeroseal were 13.7% and 15.5%, respectively. Table 17 shows statistical data from utility billing analysis for all four types of units. Utility bill savings were usually greater in one-story apartments, presumably because a larger portion of the ductwork in those units is in unconditioned space.

Table 17. Statistical Data From Utility Bills for All Four Types of Units

Method	No. of Floors	Heating Energy Savings	Heating Energy Savings Range		Cooling Energy Savings	Cooling Energy Savings Range		No. of Units	Overall Average Savings	
		%	%	%	%	%	%		Heating	Cooling
Hand Sealing	1	30%	48%	4.7%	20%	48%	5%	7	16%	16%
	2	3%	10%	0.0%	13%	32%	8%	4		
Aeroseal	1	17%	57%	1.4%	13%	41%	0%	5	14%	16%
	2	11%	14%	9.2%	18%	20%	17%	2		

Table 18 compares heating and cooling energy savings from utility bills to the modeled savings due to duct sealing by hand and Aeroseal for each of the four unit types. Utility bill results for each unit are provided in Appendix C. Utility bill and modeled savings percentages were within 25%–50% with the exception of the heating bills for the two-story hand sealed units where only 3% gas bill savings were achieved (Table 17).

Absolute heating energy consumption and savings was similar in models and utility bills, however predicted cooling energy was much lower (approximately 30%–50%) than cooling energy calculated from utility bills. This results in a shorter simple payback when considering the utility bills than predicted the models.

Table 18. Comparison Between BEopt Analysis Results and Utility Bills Analysis Results

Method	No. of Floors	Heating Gas Energy Savings From Utility Bills	Beopt Model Prediction-Heating Gas Energy Savings	Cooling Energy Savings From Utility Bills	BEopt Model Prediction-Cooling Energy Savings	Utility Bill Sample Size
Hand Sealing	1	30%	14%	20%	10%	7
	2	3%	12%	13%	7%	4
Aeroseal	1	17%	19%	13%	15%	5
	2	11%	20%	18%	13%	2

The annual average utility bill savings and simple payback based on the billing analysis is presented in Table 19.

Table 19. Annual Average Utility Bill Savings and Simple Payback

Method	Energy Savings (therms)	Energy Savings (kWh)	Utility Bill Savings/Unit	Simple Payback (years)	Sample Size
Hand Sealing	30	809	$179	2.2	7, 1-story 4, 2-story
Aeroseal	19	731	$150	4.7	5, 1-story 2, 2-story

7 Conclusion

A field evaluation was conducted in 40 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 or the connection between duct register boots and the ceiling or floor. Seventy-three percent of the leakage reduction in the Aeroseal units was attributable to the manual sealing at these locations.

Measurement and modeling of duct leakage was complicated by unique characteristics of these systems and by inconsistency between field measurement techniques and BEopt modeling input requirements. These issues required a number of adjustments and work-arounds utilizing flow measurement data that were also gathered on site for all systems.

This project addressed the two primary research questions, listed below with their respective answers.

1. What is the cost (for a community-scale project) and effectiveness (in terms of leakage reduction, increase in conditioned air delivered to the living space and energy savings) of duct sealing using an aerosol system compared to traditional manual duct sealing for this building type?

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 modeled reduction in annualized energy expenditures was nearly equal for both methods, averaging $54 for manual sealing and $55 for Aeroseal.

Utility bills (gas and electric) were collected for 1 year before and after the retrofits and compared for all apartments where the leaseholder remained constant. Energy savings based on utility bills were within 25%–50% of those predicted by the models for most unit types. It should be noted that while sealing ducts by hand, we could not seal all gaps in the duct system. Utility bill analysis shows 14% and 16% energy savings using Aeroseal and hand sealing procedure, respectively, in heating season whereas in cooling season, energy savings using Aeroseal and hand sealing were each 16%. Average simple payback based on utility bills was 2.2 years for manual units and 4.7 years for the Aeroseal units. Note that only 18 of 40 units had usable utility bills. This sample size may not have been adequate to average out all occupancy effects.

2. What logistical and technical issues might affect community-scale duct sealing retrofit productivity and effectiveness?

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.

While Aeroseal is available in the market today and offered by many local applicators (Aeroseal, LLC 2011b), room exists to streamline the technology, especially for production-scale work and for smaller spaces such as conducted in this project.

Injected spray sealant is less suitable for sealing systems to less than 40–60 CFM of leakage. A minimum airflow speed is necessary to keep the sealant suspended in the airstream. When leakage gets below 40–60 CFM, the airflow becomes too low and the system may no longer function properly. The tubing in the Aeroseal pump could be modified to produce a lower liquid flow rate and thereby eliminate software shutdowns. Another option for small multifamily systems that would allow greater airflow and may also improve productivity is 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. Ultimately, a smaller Aeroseal system, perhaps suitable for lower levels of absolute duct leakage, would have made work in these units simpler and quicker.

Connecting the sealant injection system to supply ductwork can be challenging for small homes or cramped areas, or where clearance between the top of the air handler heating coil and the ceiling is small. In some cases, a portion of the equipment may need to be placed out of doors, which can be difficult in inclement weather conditions. Some contractors leave the equipment in a van, and run the tubing into the home. This can be done for homes with the air handler on the first floor where the tubing can be kept below 100 ft in length.

High ambient relative humidity also complicated application. The sealant needs to enter the duct system dry. This is accomplished by a heating element in combination with an 8- to 10-ft 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.

The runtime of the Aeroseal equipment was approximately 1 hour per apartment; however, in an 8-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 two to three people; one operating the equipment and one to two others doing setup, cleanup, and hand sealing of the returns and register boots. Adding another two-person crew to prepare the next unit and restore the completed unit (reinstall supply registers, repair the hole cut for the Aeroseal entry point, and generally clean up) may enable the completion of three and perhaps even four units in 1 day with a single Aeroseal system. Multiple spray nozzles would be required to be on hand 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).

The spray sealant system treats the ductwork; however, 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. To save time, the boots and parts of the air handler can sometimes be sealed during the aerosol sealing process. Isolating the space conditioning equipment from the duct system also is crucial to avoiding damage to that equipment from an accumulation of sealant. Finally, whenever technology replaces manual methods, the possibility of equipment failure arises that can delay or halt a job.

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Appendix A: Duct Sealing Instructions

Desired Outcome

Deliver all air between the air handler and the supply grille terminations without air leakage. Ducts need to be sufficiently airtight to ensure economical and quiet performance of the HVAC system.

Contractor Requirements

Rebuild or repair all supply and return (if any) ducts using compatible materials to prevent air leakage according to the following procedure and in compliance with all manufacturer instructions:

1. Specific living units to be identified by owner.
2. Sealing/replacement will be limited to areas that are accessible without removing/breaching gypsum wall or ceiling boards. In townhouses, where the ducts are mainly inaccessible, sealing may be limited to boot-to-wall and boot-to-floor sealing. The definition of an "accessible" attic area includes a minimum of 30 in. between the top of the ceiling joists and the roofing material. This determination will be made by project representatives on site on a case-by case basis.
3. Determine type of ducts in the home.
4. Where possible, gain access to the joints and duct connections, including:
    a. Plenum connections
    b. Air handler cabinet to plenum
    c. Plenum to takeoff connections
    d. Branch connections
    e. Boot to duct connections
    f. Boot- to-floor/ceiling connections
    g. Boot joints
    h. Flex duct connections
5. Prepare ducts/connections for sealing. For mastic or tape-based sealant, prepare the surface for work according to product specifications (e.g., remove old tape, oil and debris) in order to receive new sealant.
6. Seal all accessible ducts/connections listed above with:
    a. Pliable, water-based sealant labeled as meeting UL-181 standards, or
    b. Foil or mastic HVAC tape labeled as meeting UL-181 standards, and
    c. Boot- to- floor/ceiling connections shall be sealed with silicone caulking, pliable mastic or other sealant
7. Replace damaged ducts or sections of ducts where it is more cost effective to replace than repair and air seal.

8. Repair or replace duct insulation as needed where accessible. New duct insulation shall be R-8. Repaired or replaced duct insulation shall have a complete vapor retarder.
9. Clean up all debris from duct sealing and replace any disturbed attic or floor insulation.
10. Clean any work-related debris, dirt, dust, etc. from within apartment unit living space.

Appendix B: Complete Duct Sealing Results

Pre-Retrofit Data (filter slot open)												
Unit Address	Dev.	No. of Floors	Area	Volume	Aero or Hand	Duct Leakage, Total (CFM25)	Duct Leakage, Total (CFM25/ 100CFA)	Duct Leakage to Outside (CFM25)	Duct Leakage to Outside (CFM25/ 100CFA)	Return Flow Tot (CFM)	Air Handler Pressure (Pa)	Sum of Register Flows (CFM)
8406 Berkshire Village Court	B	1	1025	8284	H	308	30	192	19	538	32	529
8416 Berkshire Village Court	B	1	1025	8284	H	527	51	380	37	595	57	631
8418 Berkshire Village Court	B	1	1025	8284	H	345	34	301	29	551	34	505
8424 Berkshire Village Court	B	1	1025	8284	H	460	45	362	35	504	37	474
8426 Berkshire Village Court	B	1	1025	8284	H	381	37	271	26	512	37	522
8436 Berkshire Village Court	B	1	1025	8284	H	592	58	287	28	500	28	567
8404 Berkshire Village Court	B	1	1025	8284	H	413	40	367	36	484	27	539
8405 Berkshire Village Court	B	1	1025	8284	A	450	44	245	24	500	32	538
8407 Berkshire Village Court	B	1	1025	8284	A	610	60	390	38	561	42	524
8421 Berkshire Village Court	B	1	1025	8284	A	532	52	274	27	495	38	479
8423 Berkshire Village Court	B	1	1025	8284	A	702	68	426	42	537	25	534

Pre-Retrofit Data (filter slot open)												
Unit Address	Dev.	No. of Floors	Area	Volume	Aero or Hand	Duct Leakage, Total (CFM25)	Duct Leakage, Total (CFM25/ 100CFA)	Duct Leakage to Outside (CFM25)	Duct Leakage to Outside (CFM25/ 100CFA)	Return Flow Tot (CFM)	Air Handler Pressure (Pa)	Sum of Register Flows (CFM)
8425 Berkshire Village Court	B	1	1025	8284	A	480	47	273	27	535	25	533
8427 Berkshire Village Court	B	1	1025	8284	A	560	55	334	33	539	40	566
8441 Berkshire Village Court	B	1	1025	8284	A	618	60	347	34	434	34	522
8339 #101 Berkshire Village Court	B	2	1122	9067	H	430	38	254	23	618	12	543
8339 #102 Berkshire Village Court	B	2	1122	9067	H	309	28	140	12	440	13	487
8400 Berkshire Village Court	B	2	1122	9067	H	390	35	214	19	514	19	601
8401 Berkshire Village Court	B	2	1122	9067	A	216	19	114	10	580	18	578
8402 Berkshire Village Court	B	2	1122	9067	A	350	31	188	17	688	38	688
8403 Berkshire Village Court	B	2	1122	9067	A	252	22	150	13	566	30	527
6611 Terrace Park	T	1	915	7391	H	124	14	89	10	471	25	460
6620 Terrace Park	T	1	915	7391	H	176	19	114	12	514	39	404
6651 Terrace Park	T	1	915	7391	H	161	18	114	12	395	20	425

Pre-Retrofit Data (filter slot open)												
Unit Address	**Dev.**	**No. of Floors**	**Area**	**Volume**	**Aero or Hand**	**Duct Leakage, Total (CFM25)**	**Duct Leakage, Total (CFM25/ 100CFA)**	**Duct Leakage to Outside (CFM25)**	**Duct Leakage to Outside (CFM25/ 100CFA)**	**Return Flow Tot (CFM)**	**Air Handler Pressure (Pa)**	**Sum of Register Flows (CFM)**
6701 Winter Place	T	1	915	7391	A	119	13	80	9	385	30	339
6714 Winter Place	T	1	915	7391	A	130	14	87	10	480	37	456
6707 Winter Place	T	1	717	5790	A	147	21	103	14	324	31	256
6712 Winter Place	T	1	717	5790	A	289	40	190	26	550	48	432
6600 Terrace Park	T	2	979	7910	H	220	22	70	7	621	33	399
6602 Terrace Park	T	2	979	7910	H	350	36	104	11	690	38	422
6613 Terrace Park	T	2	979	7910	H	186	19	97	10	469	25	363
6618 Terrace Park	T	2	979	7910	H	357	36	186	19	552	24	429
6643 Terrace Park	T	2	979	7910	H	320	33	180	18	628	32	457
6645 Terrace Park	T	2	979	7910	H	299	31	181	18	490	36	449
6649 Terrace Park	T	2	979	7910	H	352	36	180	18	520	30	443
6703 Winter Place	T	2	978	7910	A	490	50	266	27	610	37	477
6706 Winter Place	T	2	978	7910	A	188	19	85	9	585	32	490
6708 Winter Place	T	2	978	7910	A	181	19	85	9	690	34	416
6709 Winter Place	T	2	978	7910	A	460	47	195	20	567	34	418
6713 Winter Place	T	2	978	7910	A	311	32	91	9	484	48	420
6715 Winter Place	T	2	978	7910	A	238	24	80	8	645	39	502
Average							**35**		**20**			

Pre-Retrofit Measured Averages				
		Hand- or Aeroseal-Sealed	Duct Leakage, Total (CFM25/ 100CFA)	Duct Leakage to Outside (CFM25/ 100CFA)
BVC	One-story	H	42	30
		A	37	23
	Two-story	H	34	18
		A	24	13
TP	One-story	H	17	12
		A	22	15
	Two-story	H	30	15
		A	32	14

Post-Retrofit Data (filter slot open)												
Unit Address	Dev.	No. of Floors	Area	Volume	Aero or Hand	Duct Leakage, Total (CFM25)	Duct Leakage, Total (CFM25/ 100CFA)	Duct Leakage to Outside (CFM25)	Duct Leakage to Outside (CFM25/ 100CFA)	Return Flow Tot (CFM)	Air Handler Pressure (Pa)	Sum of Register Flows (CFM)
8406 Berkshire Village Court	B	1	1025	8284	H	278	27	117	11.4	550	33	600
8416 Berkshire Village Court	B	1	1025	8284	H	345	34	125	12.2	545	49	626
8418 Berkshire Village Court	B	1	1025	8284	H	238	23	75	7.3	600	35	605
8424 Berkshire Village Court	B	1	1025	8284	H	338	33	72	7.0	500	43	588

Post-Retrofit Data (filter slot open)												
Unit Address	Dev.	No. of Floors	Area	Volume	Aero or Hand	Duct Leakage, Total (CFM25)	Duct Leakage, Total (CFM25/ 100CFA)	Duct Leakage to Outside (CFM25)	Duct Leakage to Outside (CFM25/ 100CFA)	Return Flow Tot (CFM)	Air Handler Pressure (Pa)	Sum of Register Flows (CFM)
8426 Berkshire Village Court	B	1	1025	8284	H	266	26	77	7.5	530	48	576
8436 Berkshire Village Court	B	1	1025	8284	H	293	29	69	6.7	520	40	613
8404 Berkshire Village Court	B	1	1025	8284	H	374	36	140	13.7	452	37	582
8405 Berkshire Village Court	B	1	1025	8284	A	230	22	47	4.6	508	32	645
8407 Berkshire Village Court	B	1	1025	8284	A	245	24	37	3.6	585	46	609
8421 Berkshire Village Court	B	1	1025	8284	A	208	20	28	2.7	497	38	620
8423 Berkshire Village Court	B	1	1025	8284	A	204	20	29	2.8	550	38	648
8425 Berkshire Village Court	B	1	1025	8284	A	220	21	45	4.4	534	24	624
8427 Berkshire Village Court	B	1	1025	8284	A	280	27	36	3.5	537	45	651
8441 Berkshire Village Court	B	1	1025	8284	A	301	29	34	3.3	460	43	642
8339 #101 Berkshire Village Court	B	2	1122	9067	H	430	38	238	21.2	620	12	531
8339 #102 Berkshire Village Court	B	2	1122	9067	H	206	18	69	6.1	515	16	473

Post-Retrofit Data (filter slot open)												
Unit Address	Dev.	No. of Floors	Area	Volume	Aero or Hand	Duct Leakage, Total (CFM25)	Duct Leakage, Total (CFM25/ 100CFA)	Duct Leakage to Outside (CFM25)	Duct Leakage to Outside (CFM25/ 100CFA)	Return Flow Tot (CFM)	Air Handler Pressure (Pa)	Sum of Register Flows (CFM)
8400 Berkshire Village Court	B	2	1122	9067	H	325	29	150	13.4	500	17	609
8401 Berkshire Village Court	B	2	1122	9067	A	61	5	13	1.2	617	13	662
8402 Berkshire Village Court	B	2	1122	9067	A	48	4	13	1.2	743	41	839
8403 Berkshire Village Court	B	2	1122	9067	A	58	5	13	1.2	607	17	606
6611 Terrace Park	T	1	915	7391	H	55	6	14	1.5	480	26	479
6620 Terrace Park	T	1	915	7391	H	109	12	49	5.4	550	44	480
6651 Terrace Park	T	1	915	7391	H	65	7	13	1.4	463	20	451
6701 Winter Place	T	1	915	7391	A	56	6	13	1.4	361	32	382
6714 Winter Place	T	1	915	7391	A	46	5	13	1.4	500	42	502
6707 Winter Place	T	1	717	5790	A	53	7	13	1.8	537	35	478
6712 Winter Place	T	1	717	5790	A	140	20	17	2.4	515	48	470
6600 Terrace Park	T	2	979	7910	H	155	16	70	7.2	710	38	455
6602 Terrace Park	T	2	979	7910	H	102	10	25	2.6	730	36	431
6613 Terrace Park	T	2	979	7910	H	76	8	25	2.6	647	32	451
6618 Terrace Park	T	2	979	7910	H	125	13	13	1.3	591	40	461

Post-Retrofit Data (filter slot open)												
Unit Addresss	**Dev.**	**No. of Floor s**	**Area**	**Volume**	**Aero or Hand**	**Duct Leakage, Total (CFM25)**	**Duct Leakage, Total (CFM25/ 100CFA)**	**Duct Leakage to Outside (CFM25)**	**Duct Leakage to Outside (CFM25/ 100CFA)**	**Return Flow Tot (CFM)**	**Air Handler Pressure (Pa)**	**Sum of Register Flows (CFM)**
6643 Terrace Park	T	2	979	7910	H	146	15	60	6.1	738	32	494
6645 Terrace Park	T	2	979	7910	H	120	12	155	15.8	520	32	505
6649 Terrace Park	T	2	979	7910	H	126	13	38	3.9	540	29	498
6703 Winter Place	T	2	978	7910	A	68	7	13	1.3	623	39	508
6706 Winter Place	T	2	978	7910	A	61	6	13	1.3	715	31	502
6708 Winter Place	T	2	978	7910	A	77	8	13	1.3	690	32	466
6709 Winter Place	T	2	978	7910	A	87	9	13	1.3	530	36	472
6713 Winter Place	T	2	978	7910	A	65	7	13	1.3	820	66	479
6715 Winter Place	T	2	978	7910	A	56	6	13	1.3	676	44	523
Average							**16.6**		**4.9**			

Post-Retrofit Measured Averages				
		Hand- or Aeroseal-Sealed	**Duct Leakage, Total (CFM25/ 100CFA)**	**Duct Leakage to Outside (CFM25/ 100CFA)**
Berkshire Village Court	One-story	H	42	30
		A	37	23
	Two-story	H	34	18
		A	24	13
Terrace Park	One-story	H	17	12
		A	22	15
	Two-story	H	30	15
		A	32	14

Appendix C: Utility Bill Analysis All Units

Normalized heating and cooling energy											
Unit Address	**Dev.**	**No. of Floors**	**Area**	**Volume**	**Aero or Hand**	**Duct Leakage, Total (CFM25)**	**Duct Leakage, Total (CFM25/ 100CFA)**	**Duct Leakage to Outside (CFM25)**	**Duct Leakage to Outside (CFM25/ 100CFA)**	**Return Flow Tot (CFM)**	**Air Handler Pressure (Pa)**
8406 Berkshire Village Court	B	1	H	Data Not Available							
8416 Berkshire Village Court*	B	1	H	129	166	-37	28.8%	6189	6678	-489	-7.9%
8418 Berkshire Village Court	B	1	H	193	134	59	30.8%	7011	4730	2280	32.5%
8424 Berkshire Village Court	B	1	H	Data Not Available							
8426 Berkshire Village Court	B	1	H	238	164	74	31.3%	5962	5694	268	4.5%
8436 Berkshire Village Court	B	1	H	143	136	7	4.7%	4803	4309	495	10.3%
8404 Berkshire Village Court	B	1	H	83	58	25	29.7%	6011	4969	1042	17.3%
8405 Berkshire Village Court	B	1	A	175	172	2	1.4%	7482	6107	1375	18.4%
8407 Berkshire Village Court	B	1	A	Partial Data Available							
8421 Berkshire Village Court	B	1	A	73	32	42	57.0%	6267	5934	332	5.3%
8423 Berkshire Village Court	B	1	A	Data Not Available							

Normalized Heating and Cooling Energy											
Unit Address	**Dev.**	**No. of Floors**	**Aero or Hand**	**Pre-Retrofit (Heating Energy Use)**	**Post-Retrofit (Heating Energy Use)**	**Reduction in Heating Energy**	**% Saving in Heating Energy**	**Pre-Retrofit (Cooling Energy Use)**	**Post-Retrofit Cooling Energy Use)**	**Reduction in Cooling Energy**	**% Saving in Cooling Energy**
8425 Berkshire Village Court	B	1	A	Partial Data Available							
8427 Berkshire Village Court	B	1	A	79	77	3	3.2%	7517	7541	-25	-0.3%
8441 Berkshire Village Court*	B	1	A	199	158	41	20.8%	3051	3871	-820	-26.9%
8339 #101 Berkshire Village Court	B	2	H	Data Not Available							
8339 #102 Berkshire Village Court*	B	2	H	145	150	-5	0.0%	6552	6260	293	4.5%
8400 Berkshire Village Court	B	2	H	85	77	8	9.9%	7908	7305	603	7.6%
8401 Berkshire Village Court*	B	2	A	97	84	13	13.5%	2673	3977	1304	-48.8%
8402 Berkshire Village Court	B	2	A	Data Not Available							
8403 Berkshire Village Court	B	2	A	Data Not Available							
6611 Terrace Park	T	1	H	172	106	66	38.5%	3599	2727	872	24.2%
6620 Terrace Park*	T	1	H	295	152	143	48.4%	1885	988	897	47.6%
6651 Terrace Park	T	1	H	189	175	14	7.3%	4473	3626	847	18.9%
6701 Winter Place	T	1	A	171	148	23	13.4%	6153	4713	1440	23.4%
6714 Winter Place	T	1	A	112	80	32	28.7%	1610	951	659	40.9%

Normalized Heating and Cooling Energy											
Unit Address	**Dev.**	**No. of Floors**	**Aero or Hand**	**Pre-Retrofit (Heating Energy Use)**	**Post-Retrofit (Heating Energy Use)**	**Reduction in Heating Energy**	**% Saving in Heating Energy**	**Pre-Retrofit (Cooling Energy Use)**	**Post-Retrofit Cooling Energy Use)**	**Reduction in Cooling Energy**	**% Saving in Cooling Energy**
6707 Winter Place	T	1	A	Data Not Available							
6712 Winter Place	T	1	A	Data Not Available							
6600 Terrace Park*	T	2	H	94	79	15	16.4%	2636	2888	-252	-9.6%
6602 Terrace Park	T	2	H	157	143	13	8.4%	6246	5751	495	7.9%
6613 Terrace Park	T	2	H	Data Not Available							
6618 Terrace Park	T	2	H	Partial Data Available							
6643 Terrace Park	T	2	H	149	156	-7	0.0%	3614	3056	558	15.4%
6645 Terrace Park	T	2	H	Data Not Available							
6649 Terrace Park	T	2	H	Data Not Available							
6703 Winter Place	T	2	A	Data Not Available							
6706 Winter Place	T	2	A	109	94	15	13.5%	2531	2019	513	20.3%
6708 Winter Place*	T	2	A	80	84	-5	-6.0%	3500	3698	-198	-5.7%
6709 Winter Place*	T	2	A	100	179	-80	79.7%	2863	2426	437	15.3%
6713 Winter Place	T	2	A	195	193	2	1.2%	3091	2103	988	32.0%
6715 Winter Place	T	2	A	208	189	19	9.2%	5322	4422	900	16.9%

Data Not Available is indicated where leaseholder changed during utility bill collection period or in one case were utility bill releases were not received. *Data for these apartments were not included in the analysis because post energy consumption was higher than that of pre energy consumption for either heating or cooling.

Solution Center Content

Element	Topic: HVAC.2.2.8c: Injected Spray Sealant
Scope of Work	**Duct Sealing Instructions** ***Desired Outcome*** Deliver all air between the air handler and the supply grille terminations without air leakage. Ducts to be sufficiently airtight to ensure economical and quiet performance of the HVAC system. For injected spray sealant applications, follow directions of system supplier – typically this work will be done by a factory-authorized technician. For manual duct sealing of portions of the duct system not treated by the injected spray sealant system, follow the scope described below. ***Contractor Requirements*** Rebuild or repair all supply and return (if any) ducts using compatible materials to prevent air leakage according to the following procedure and in compliance with all manufacturer instructions: 1. Sealing/replacement will be limited to areas that are accessible without removing/breaching gypsum wall or ceiling boards. 2. Determine type of ducts in the home. 3. Gain access to the joints and duct connections that will not be treated by the injected spray sealant system, including: A. Plenum connections B. Air-handler cabinet to plenum C. Plenum to take-off connections D. Boot to duct connections E. Boot- to-floor/ceiling connections 4. Prepare ducts/connections for sealing. For mastic or tape-based sealant, prepare the surface for work according to product specifications (e.g., remove old tape, oil and debris) in order to receive new sealant. 5. Seal all accessible ducts/connections listed above with: A. Pliable, water-based sealant labeled as meeting UL-181 standards, or B. Foil or mastic HVAC tape labeled as meeting UL-181 standards, and C. Boot- to- floor/ceiling connections shall be sealed with

	silicone caulking, pliable mastic or other sealant 6. Replace damaged ducts or sections of ducts where it is more cost effective to replace than repair and air seal. 7. Repair or replace duct insulation as needed where accessible. New duct insulation shall be R-8. Repaired or replaced duct insulation shall have a complete vapor retarder. 8. Clean up all debris from duct sealing and replace any disturbed insulation. 9. Clean any work-related debris, dirt, duct, etc. from within the living space.
Ensuring Success	Before and after duct leakage testing can be used to verify proper implementation and quantify the improvement. If the system was extremely leaky, duct sealing may result in significantly greater volumes of air being delivered to spaces. Rebalancing of the system is recommended in these cases so as not to over-heat or cool rooms. Usually duct sealing will reduce the risk of combustion safety problems such as back-drafting; however the effects of duct sealing on combustion appliances and venting should be tested to assure the tighter ducts do not negatively alter the pressure dynamics of the home to create such problems.
Climate-Specific Factors/Details	Ducts should be sealed in all climate zones. The more extreme the climate (either hot or cold) the greater benefit from duct sealing will be realized.
Description	1) Overall explanation of the measure a. Introduction Air-tight ductwork is important to prevent energy loss, provide comfort and to avoid unwanted pressure imbalances that can result from air leaking outside a home’s thermal envelope. Ideally, all air moved by the air handler should arrive at the supply grille terminations without air leakage, and all air entering the return duct grilles should arrive back at the air handler without leakage. Duct sealing is important for new construction and older homes. Often older duct systems are quite leaky. Remedial duct sealing can dramatically improve the performance of a home’s HVAC system. Duct sealing with an injected spray sealant is an effective way to eliminate duct leakage, when combined with manual sealing of other easily accessible areas. The spray sealant is injected into pressurized supply and return ducts. Sealant particles accumulate at leakage locations, gradually closing the

	leak. Gaps larger than 5/8 in. are recommended to be sealed manually with fiberglass and mastic, and the duct material must have an interior air barrier www.aeroseal.com/what-we-do/aeroseal-process.html. 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 off to prevent the sealant from fouling HVAC equipment or escaping into the living space. b. Issues The spray sealant system treats the ductwork, however 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. Injected spray sealant is less suitable for sealing systems to less than 40-60 CFM of leakage. 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 no longer function properly. High ambient relative humidity also complicated application. The 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 ft. 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 sealant injection system to supply ductwork can be challenging for small homes or cramped areas, or where clearance between the top of the air handler heating coil and the ceiling is small. In some cases, a portion of the equipment may need to be placed out of doors, which can be difficult in inclement weather conditions. Isolating the space conditioning equipment from the duct system is crucial to avoiding damage to that equipment from an accumulation of sealant. At times this was a challenge. Finally, whenever technology replaces manual methods, the possibility of equipment failure arises that can delay or halt a job. c. Materials The injected spray sealant system will include all equipment and materials necessary for its use, however the following additional materials are needed for the manual sealing portion of the project: A. Pliable, water-based sealant labeled as meeting UL-181

standards, or

B. Foil or mastic HVAC tape labeled as meeting UL-181 standards, and

C. Silicone caulk

D. Fiberglass mesh tape to reinforce mastic for large gaps

E. Rags and cleaning supplies to remove dirt and dust from duct surfaces to be sealed

F. Hand tools for removing and replacing register covers

d. Who Does the Work

Most local codes will require a licensed HVAC contractor to perform this work.

e. Metrics

The sealant injection system will typically measure total duct leakage of the system that the sealant is treating, however in order to measure duct leakage to the outside for the entire system (including air handler, returns, and at registers) a separate duct leakage test would need to be conducted.

2) "How-to" steps and images

Assembling the spray sealant injection system

Blocking off registers so sealant does not enter living space.
The same must be done inside the air handler to prevent sealant from fouling the mechanical equipment.

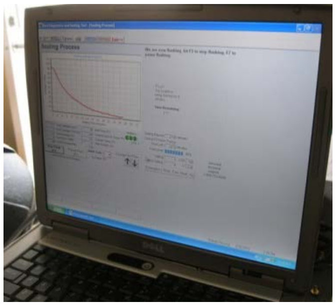
A container of sealant.

Connecting the plastic tunnels from the injection equipment (left) to the supply plenum (right)

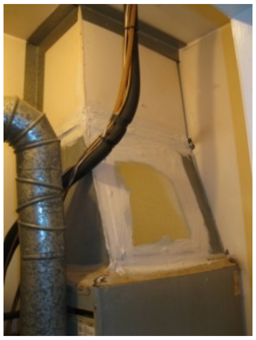
The Assembled injection system includes a blower/heater (background) and the sealant injection unit (foreground)

The tunnel is inflated as the injection system operates

Software tracks the sealing progress and controls the airflow



After completion, the opening to the supply plenum is sealed.

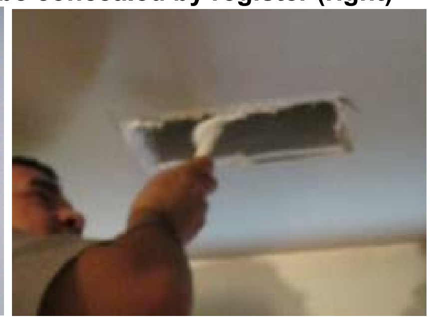


Supplementary manual sealing of the return (a and b), registers (c and d) and air handler (e) with mastic and/or foil tape.

a)

b)

	c)  d)  e) 
Right and Wrong Images	 **Air handler sealed with foil tape (left); return plenum sealed with mastic (right)**

	  **Duct boot pulling away from floor leaving large gap (left); floor register sealed to floor – foil tape will be concealed by register (right)**   **Duct boot in not sealed to ceiling, leaving gap through which air can leak into attic (left); mastic being applied to seal duct boot to sealing(right)**
Architectural CAD Files	N/A
Compliance	Duct sealing via injected spray sealant and/or manual methods can assist in meeting duct tightness requirements of the DOE Challenge Home (www1.eere.energy.gov/buildings/residential/ch_index.html), Energy Star (www.energystar.gov/index.cfm?c=bldrs_lenders_raters.nh_v3_guidelines), other programs and building codes.
Case Studies	Published separately.
References	ENERGY STAR new homes program: www1.eere.energy.gov/buildings/residential/ch_index.html), DOE Challenge Home: www.energystar.gov/index.cfm?c=bldrs_lenders_raters.nh_v3_guidelines Aeroseal website: www.aeroseal.com/what-we-do/aeroseal-process.html.
Training	N/A
Resources	Additional information on sealing ducts: www.energystar.gov/index.cfm?c=home_improvement.hm_improvement_ducts

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