Analysis Of Aeroseal Duct Sealing Impact On Whole House Leakage In "Basement Duct" Homes

Ducts "Inside The House" Can Also Leak To Outside

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1. Abstract

Eleven Cincinnati OH area homes with "basement duct systems inside the thermal boundary" had their duct systems sealed using the Aeroseal process.

As a by-product, the Aeroseal duct sealing simultaneously made the overall house thermal envelopes tighter. Blower door tests before & after the duct sealing measured whole house CFM50 leakage reductions, averaging 11.4% or 348 CFM50. All 11 homes showed increased tightness, with CFM50 reductions ranging from -1.1% to -28.8%.

If expressed at the lower 25 pa reference pressure for duct testing, 347 CFM50 is equivalent to 221 CFM25 (flow exponent n=0.65). Since only duct sealing was done to the homes, it is inferred that an average of 221 CFM25 of Duct Leakage to Outside was eliminated.

This data refutes the common misconception that duct systems in "basement-style" houses don't "leak to outside".

Although measured energy savings data from these homes is limited, this finding also contradicts the common opinion that duct sealing only saves energy if the leaky ducts are located in unconditioned spaces. Energy modelling performed by the Greater Cincinnati Energy Alliance estimates an average of 9.8% reduction in heating and cooling consumption. In the one house where two years before/two years after of utility consumption data was available, degree day and baseload adjusted heating and cooling savings were 16%.

Additional research is planned in order to see if the findings can be replicated, to better understand the variables involved, and to better document energy savings potential.

2. Methodology & House/Duct/Repair Descriptions

Project Description

The testing and duct sealing was performed between October 2012 and October 2013 during routine business by the installing contractor Hader Solutions. The blower door tests were performed for the Greater Cincinnati Energy Alliance for home performance rebate compliance. The homeowners paid for the work at normal retail pricing, and received a $500 GCEA rebate for the duct sealing.

This analysis was done retrospectively, on the data that had been collected four years earlier. The realization that there was blower door data which showed that the houses got tighter was serendipitous. This study involved visiting the homes in October-November 2017. The author visually inspected the work performed, confirmed house and duct characteristics, interviewed the homeowners and reviewed all the available data. Some static pressure and airflow measurements were taken. The blower door and duct leakage tests were not repeated.

The initial available pool was 20 houses. Those which had equipment & ducts in unconditioned spaces, or had also had thermal envelope air sealing or insulation performed, were excluded from this study. The remainder were contacted and 11 volunteered to have their homes re-visited.

Houses and Duct System Descriptions

Two of the homes were built pre-war (1909 and 1923). The rest were built between 1983-2007.

The supply ducts were hard ducted from the equipment to the outlets, (95%+ uninsulated sheet metal, some wire helix flex duct). Some of the supply ductwork was accessible and visible in unfinished basement areas, the rest was inaccessible and located inside hollow interstitial spaces (basement ceiling, interior partition walls, floor cavities between the first and second floor).

As is standard practice in the Northern Mid-West, the return side of the air distribution systems were "panned", rather than "hard ducted". The return system in the basement consists of horizontal rectangular sheet metal trunk ducting at ceiling level, with a vertical drop to the furnace inlet. The trunks line up under panned floor joists, which are in turn open into hollow interior partition wall cavities. In the two-story homes, the return pathway has to pass through the second story floor cavity. The houses typically had between 6 to 8 high wall return inlet grilles.

Figure 1: Typical Panned Return High Wall Return Inlet

(NOTE: House #2 did have a small second ductboard and flex duct system in an unconditioned attic serving the third floor, with the upflow equipment located in a closet. The Aeroseal duct leakage measurement data shows that sealing that attic flex duct system reduced its duct leakage by 100 CFM25 (equal to approximately 157 CFM50). We have chosen to include this home in the study, as this represents only approximately 18% of the total 889 CFM50 reduction measured for that home. We believe it is reasonable to assume that the remaining 732 CFM50 reduction in whole house leakage was from Aerosealing the main duct system. If the attic duct system were excluded from the study, the average whole house reduction for the 11 homes would instead be approximately 333 CFM50 (4% less).)

Ten houses had furnaces with external cooling coils downstream. One had a boiler, with a cooling only air handler.

All the houses had basement foundations. The basements were in the author's opinion conditioned, either intentionally or unintentionally. Approximately 50% of the basement exterior concrete foundation wall surfaces were finished and insulated. None of the basements had insulation in the basement ceiling. Apart from a few insulated supply flex duct branch lines, the metal ductwork was not insulated. Almost all had intentional supply air outlets in the basement. Most also had at least one return inlet in the basement.

Tests Performed

The Total Duct Leakage duct tests were performed by the installing contractor using a normally configured Aeroseal Smartseal (Gen2) system, which uses a calibrated sharp edge gate system for airflow measurement, and a TEC DG-700 2 channel micro-manometer for duct and gate pressures. Duct Leakage to Outside was not measured directly.

The before and after blower door tests were performed as single point CFM50 measurements, with basement doors open. Wind conditions during the tests were not documented.

Repairs Performed

The installing Aeroseal contractor sealed the return and supply sides of the system separately by injecting the fog of aerosolized sealant into the blocked duct system.

As is usual with the Aeroseal process, some larger accessible openings on the return side were sealed by hand using mastic, caulking and fire-retardant foam. Some of the leakiest return sides had to be partitioned and sealed in stages.

Figure 2 Foam Used To Seal Large Holes

In House # 9, open building cavity leakage was found where wood blocking was totally missing. It was observed that two 3.5" wide partition wall cavities at the first floor had been wide open up into the second floor joist cavities, which in turn were open into side attics (Cape Cod style house). The wall cavities had been sealed by the contractor using Thermopan cardboard panning material and canned one component urethane foam as part of the project. This house achieved the third greatest absolute reduction in whole house leakage, -439 CFM50 or -8.5%.

In House #6, the panned return system was tied into the drywalled ceiling of the unconditioned tuck-under garage.   This house achieved the greatest reduction in whole house leakage, -1265 CFM50 or -28.8%.

Figure 3 House 9 Wall Cavity Bypass (sealed)

3. Results

Test Results – Duct Leakage

All the duct systems had relatively high levels of Total Duct Leakage prior to sealing, averaging 1074 CFM25.

72% of the Total leakage was on the return sides vs. 28% on and supply side (returns averaged 771 CFM25 pre-seal; supply sides averaged 303 CFM25).

The installing Aeroseal contractor Hader Solutions Inc. achieved total duct leakage reductions averaging 89.1% (average of all CFMs sealed). The return side reduction averaged 88.2%; the supply side reduction average was 93.7%.

Almost all the seals (18 out of 22) achieved over 90% reductions from initial leakage.

One significant outlier was the return side of House # 6. It was extremely leaky, 1415 CFM25 on just the return side. The absolute reduction in duct leakage achieved was among the highest at 874 CFM25, however the percentage reduction was the lowest in the study, at 61.9%. It is not obvious where the remaining 541 CFM25 of return side leakage is.

			Return Side Only				Supply Side Only			
Home	Side	ACSize	PreCFM25	PostCFM25	CFM.Change	% Change	PreCFM25	PostCFM25	CFM.Change	% Change
Home-1	Return-only	2.5	634.1	43.5	590.5	93.1%				
Home-1	Supply-only	2.5					267.6	20.3	247.3	92.4%
Home-2	Return-only	3	917.0	52.2	864.8	94.3%				
Home-2	Supply-only	3					516.2	100.6	415.6	80.5%
Home-3	Return-only	3	831.3	60.3	771.0	92.7%				
Home-3	Supply-only	3					317.3	14.6	302.7	95.4%
Home-4	Return-only	3	855.5	52.6	802.9	93.8%				
Home-4	Supply-only	3					333.1	12.2	320.9	96.3%
Home-5	Return-only	3	397.0	48.1	348.9	87.9%				
Home-5	Supply-only	3					225.6	23.6	202.0	89.5%
Home-6	Return-only	3	1415.1	541.0	874.0	61.8%				
Home-6	Supply-only	3					92.3	0.2	92.1	99.8%
Home-7	Return-only	3	442.3	35.3	407.0	92.0%				
Home-7	Supply-only	3					165.3	12.8	152.5	92.2%
Home-8	Return-only	3	879.5	80.6	798.9	90.8%				
Home-8	Supply-only	3					540.9	6.4	534.4	98.8%
Home-9	Return-only	3	528.3	43.0	485.2	91.9%				
Home-9	Supply-only	3					214.8	3.4	211.4	98.4%
Home-10	Return-only	5	678.4	24.3	654.1	96.4%				
Home-10	Supply-only	5					298.1	7.8	290.3	97.4%
Home-11	Return-only	5	901.7	17.7	884.0	98.0%				
Home-11	Supply-only	5					360.8	7.8	353.0	97.8%
			8480.0	998.7	7481.3	88.2%	3332.1	209.8	3122.2	93.7%
	Averages (11)		770.9	90.8	680.1	88.2%	302.9	19.1	283.8	93.7%

Test Results – House Leakage

The average whole house leakage was 3045 CFM50 before duct sealing and 2697 CFM50 after. CFM50 leakage reductions average 11.4% or 348 CFM50. All 11 homes showed increased tightness, with CFM50 reductions ranging from -1.1% to -28.8%.

It became apparent that the seven two-story houses which had building cavity returns extending up to the second floor were initially significantly leakier than the other four houses (3 one-story, one a two-story with no building cavity return to 2nd floor). Before duct sealing, the seven “two-story” houses averaged 3667 CFM50 vs. 1956 CFM50 for the four “one-story” houses.

The two-story houses also achieved higher absolute and percentage reductions. House leakage reductions averaged 495 CFM50 (-13.5%) in the two stories vs. 90 CFM50 (-4.6%) in the single stories.

Exhibit 2 - Blower Door Tests					
First 4 Houses "Single Story", Next 7 "Two Story"					
		Blower Door CFM50			
	Cond Floor sq ft	**In**	**Out**	**Difference**	**% Reduction**
Home-7	3918	1312	1284	28	2.1
Home-4	2350	2050	1777	273	13.3
Home-5	3706	1236	1214	22	1.8
Home-11	2238	3225	3189	36	1.1
Avg. Single Story		**1956**	**1866**	**90**	4.6%
Home-6	2983	4393	3128	1265	28.8
Home-10	1647	3276	3023	253	7.7
Home-3	3494	2715	2440	275	10.1
Home-8	3515	2120	1953	167	7.9
Home-2	7000	6024	5135	889	14.8
Home-1	2748	1975	1795	180	9.1
Home-9	3572	5164	4725	439	8.5
Avg. Two Story		**3667**	**3171**	**495**	**13.5%**
Average All		**3045**	**2697**	**348**	**11%**

Interview Results - Selection of Homeowner Comments On Changes Observed

Ten of the eleven homeowners had lived in the homes before and after Aeroseal, and were interviewed about why they bought it, what their expectations were, and what changes they have noticed.

All of the homeowners said they noticed an improvement in comfort, specifically more even temperatures between rooms and levels. Some were extremely pleased. One specifically said the air was less humid/sticky in the summer.

Most said they "thought" their utility bills had dropped, however only one (House #9 – see quote below) knew exactly how much ($1584 per year) as she is on equal billing and had actually compared them. None of the others had done any form of utility bill analysis.

House #3 guessed that her bills had dropped from $300 to $200 month. We were able to conduct a degree day and baseload corrected analysis on her home, and concluded she was actually saving an average of $13.17 per month, or $158 per year.

Four of the ten said they definitely find their house to be less dusty, and can go longer between house cleanings.

- "The house is now much more comfortable. The second floor was always too hot in the summer. The central AC just didn't cool it enough, so we had to also use two window AC units upstairs. After the Aeroseal and the new AC the airflow upstairs increased and it is now much cooler. I don't have to use the window units anymore. My energy bills have gone down drastically. I'm on even billing. In 2012 it was $291 a month for gas and electric. Now in 2017 my monthly bill is $159, even though rates went up. I'm saving at least $1584 a year. Since I also replaced old equipment, I can't say how much is due to just the Aeroseal and not having to use the window units anymore, but I'm sure it's a major part of it." (House #9)
- "I noticed within a week or two that my house wasn't as dusty as it used to be. I used to dust the house and see the dust back on the furniture right away. Now I can go over two weeks without dusting."

- “The airflow in the house is better and the temperature difference between the upstairs and the downstairs is less. I have been able to raise the temperature on the thermostat in the summer months by three degrees from 70 to 73 and be as comfortable as I was before.”
- “The downstairs was cold as a meat locker during the summer because of the duct leakage. It has now evened out noticeably.”
- “Before we had the Aeroseal done, the temperature variations within the house were extremely uncomfortable. We used to have to adjust the thermostat significantly higher or lower depending on the season to compensate for the differences between the second level and basement.”
- “We had significant issues with the temperature regulation in a couple of our rooms. The Aeroseal has made a noticeable difference. We have also noticeable a considerable improvement in the amount of visible dust that accumulates in our home.”
- “After my wife and I had the Aeroseal done on our home, we noticed the system performance improvement right away. Our upstairs is easier to cool in the summer months and the temperature difference between floors is less noticeable.”
- “I found the house to be significantly more comfortable. The temperature of the whole second floor is much easier to regulate in the summer months. There was one bedroom in particular that was ice-cold in the winter and now the room is much closer to the temperature in the rest of the house.”

Measured & Estimated Impacts on Utility Costs

No real time energy/run time monitoring or sub-metering was performed before and after the Aeroseal processes were performed. As this study was done three to four years after the work was performed, we encountered numerous challenges documenting reductions in heating and cooling usage based on utility bills. One of the eleven homes turned out to be suitable for utility bill analysis.

(Of the others, four had had HVAC replacement within three months of the Aeroseal process, one had thermal envelope & renovation work done shortly after the Aeroseal process and second blower door test, one had an electric car charger installed, one had a change of ownership and records were unavailable, and three did not have utility bill records that far back and were unwilling to assist in getting them.)

House #3 Utility Bill Analysis

In this two story house, Aeroseal reduced the whole house leakage by 10% or 275 CFM50 (2715 to 2440). Two years before/two years after of “clean” utility consumption data were available.

After backing out baseload consumption (assuming the three lowest consumption months each year represented non-heating and cooling consumption rates), and adjusting for changes in degree days, the calculated annual savings were:

Gas: 312.5 CCF to 259.6 CCF = 52.8 CCF savings or 16.9% less

Electricity: 4756 kWh to 4039 kWh = 717 kWh savings or 15% less

At current 2018 utility rates, the savings total $158 per year.

Energy Modelling By GCEA

GCEA modelled the before and after effect of simultaneous reductions in the measured whole house leakage and duct leakage to outside in a representative average home. Their analysis predicted a $202 or 9.8% annual savings on heating and cooling.

4. Discussion Of Why The Houses Got Tighter

The blower door data indicates that the duct sealing also made the houses tighter. This has been routinely observed previously when sealing duct systems located outside the thermal and pressure boundaries (e.g. in ventilated attics, crawlspaces and garages). One early duct leakage measurement process known as the Blower Door Subtraction Test relied precisely on this phenomenon.

What is interesting is that this data showed the effect when the duct systems were "inside" the house. We propose two possible reasons why this happened.

Possibility #1: Direct Sealing Of Hidden Envelope Leakage On The Return Side

The reduction in house leakage in the homes in this study appears to primarily be a byproduct of sealing the leaks in building cavity returns from the inside using the Aeroseal process. The sealant finds and plugs the hidden shrinkage gaps and wiring holes – up to 5/8" across.

Figure 5 Typical Aerosealed Wall Cavity Return Top Plate and Wiring Hole

Background:

When hollow interstitial building cavities such as interior partition walls and panned floor joists are used to carry return air, air leaks are present where these "duct cavities" tie into the exterior pressure boundary/thermal envelope of the house. The partition walls used to carry return air seem to be mostly communicating to the attics; the floor cavities mostly into the perimeter exterior walls and band joist regions.

For example, due to the wood drying out in the first year, and the absence of any sealant applied during construction, every 2x4 top plate has a crack between the vertical 1.5" edges and the drywall. This crack is almost always wide enough for a business card or thin strip of steel to be slipped into. It is often over 1/8".

Many of these return wall cavities also have holes drilled through the top plates for wiring, and pipes such as whole house vacuums.

That these return cavities leak to outside has been routinely observed during whole house assessments. Over the last 35 years, negative pressure blower door tests in such houses, done with the furnace indoor blower off, have routinely – but not always - found that outdoor replacement air enters the home via the return grilles (discovered using hand-held smoke and thermal imaging).

Pressure pan testing has also often shown connections between the inside of the return system and outdoors. Pressure pan testing involves covering a return grille while the house is being blower door tested. If the pressure difference between the house and inside the duct is zero, it can be concluded that the duct does not communicate to outdoors. This testing routinely has measured pressures when the ducts are "inside".

Expressed another way, these hollow wall and floor cavities used to carry return air are "inside the house"; yet they are "connected to outside".

Since the Aeroseal sealant fog is injected via the duct system, for a reduction in whole house leakage to occur, there must be pathways from the inside supply or return duct system to leaks between the conditioned space and outdoors/buffer zones.

In most of the homes, it was possible to open high wall return grilles and look up to see where sealant had built up in the cracks as the fog worked its way out of the building cavity and up into the attic. In one home, it was possible to examine the return cavity top plates from the attic side. The rubbery sealant was found embedded in the loose fiberglass insulation directly over the top plate cracks, as well as in the cracks.

The fact that the two-story homes showed significantly greater reductions in house leakage than the one-story homes supports this overall hypothesis. Two story homes have significantly greater opportunities for communication to the outside via the building cavities used to carry return air.

The fact that an aerosol sealant can seal the building envelope has been proven by the relatively new Aerobarrier process, which intentionally seals envelope leaks by fogging the entire house under pressure. The results described here from Aerosealing the building cavities is in a sense a variation of the Aerobarrier process, applied to contained cavities.

Possibility #2: Contained Overspray From Hidden Supply Duct Leakage

Some envelope sealing may have also occurred due to sealant escaping during the sealing process from ducted supply leaks, which are contained in interstitial spaces. This sealant may then be finding its way to building envelope leaks.

Background:

When Aeroseal seals duct leaks, some of the sealant inherently escapes the ducts via the leaks, until the leak is sealed. This escaping air may also create a positive pressure in the interstitial space the duct is located in. The aerosolized particles will stay suspended for a period of time, and may continue travelling until they find another crack to be deposited in – this time in the pressure boundary of the home.

We know escaping supply air pressurizes wall and floor cavities to some degree, due to cases of wintertime condensation occurring where supply duct leakage has pushed air out at the band joist between the first and second floors in extremely cold climates like Minnesota.

Aeroseal typically creates much higher pressures in the ducts during sealing than is normally present. While a typical supply branch duct is well under 25 pa of positive pressure, Aeroseal routinely pressurizes the ducts being sealed to between 200 pa and 500 pa. The pressure inside the surrounding interstitial spaces is likely correspondingly higher as well. Whether the cavity pressure is high enough, and whether the flow rates are fast enough, for the overspray sealant to seal the envelope leaks is unknown.

In future studies, inserting another blower door test between sealing the two sides of the system, as well as monitoring the pressures created inside the surrounding wall and floor cavities, should answer this question.

Additional Observations and Discussion Points

Since we do not know the relative impact of the two possibilities described above, it is not apparent whether similar results would have been achieved if the return duct systems were hard ducted all the way from the furnace to the return inlet grilles. Further research is needed.

Earlier "basement duct" studies only addressed the impact of sealing duct leaks which were readily accessible for hand sealing – those in the unfinished basements. This data emphasizes the importance of evaluating the impact of sealing the hidden, inaccessible duct leaks – which routinely do leak to outside.

One unknown is whether "hand sealing" could have achieved remotely similar results. The author is skeptical. Aeroseal is uniquely capable of finding and sealing building cavities and concealed ductwork. While some of the leaks could be accessed by hand, most of the leaks which can conceivably leak to outdoors in this style of house are either inaccessible without removing drywall, or very difficult to access. Future research could attempt to quantify the relative effectiveness of hand sealing vs. Aeroseal. As pointed out by Blasnik, sealing accessible return leaks in the basement by hand, without sealing the hidden leaks or addressing increased static pressure, could conceivably increase duct leakage from outside.

While the Aeroseal process routinely seals supply ductwork by over 90%, some Aeroseal dealer contractors struggle to seal panned return systems as well as was done by the contractor in this study. Hader Solutions invested in the needed training and implementing the best practices needed, and had a crew with a high degree of motivation to achieve results. The author would like to commend the Hader duct sealing team for their dedication and ability to achieve significant reductions on the return sides. For Aeroseal to be eligible for any utility rebate program funding in this style of house, it will be essential that contractors invest in sufficient training and have the dedication to deal with sometimes challenging panned return issues.

The data shows that two story homes have greater likelihood of leakage to outside than single story homes. This needs to be investigated further.

As the blower door tests were never intended to be "research quality" there is inherently some uncertainty in the data accuracy. On the other hand, all of the houses showed a reduction in whole house leakage after sealing. Future work is planned to collect more and better data to reduce uncertainty.

5. Discussion of Other Energy Savings Potential

While this particular study did not control for all the possible factors which affect utility consumption, we identified a number of factors which should be kept in mind when trying to tease out energy savings from sealing "ductwork inside the conditioned space".

All 10 of the homeowners who had lived in the homes before and after sealing reported improvements in comfort. The most common comment was that the room to room and level to level temperatures where now more even.

In House #11, the homeowner had lived in the home for 30 years, and had historically kept the summer thermostat setting at 70 F. During the three summers after sealing, he found he had to raise the setting to 73 to be comfortable – 70 was now TOO cold. He attributed this to more even temperatures and to better humidity control (he is a retired engineer). The inspection and his recollections of the work done determined that two of the return floor cavities leaked significantly into a cantilevered bay window space. He recalled that the installers showed him cracks in the pine board soffit through which he could see the driveway. It stands to reason that the reduction in summertime air infiltration also reduced humidity infiltration.

Due mostly to the time which had passed (4 to 5 years) the other homeowners couldn't recall changing their thermostat habits once temperatures were evened out. Many had different thermostats which came with new furnace/AC. Different thermostat settings is nonetheless a fairly common result of such improvements and should be tracked better in future studies.

(The author recently investigated a separate case in Minnesota where the homeowner used to have to keep their thermostat on the main floor at 64 degrees in the summer to keep the 2nd floor bedrooms from exceeding 80. After the duct renovation they are now able to keep the main level at 70 and the bedrooms don't exceed 72.)

Another possible beneficial result from evening out temperatures is less use of auxiliary plug-in heaters, window AC units or use of constant circulation fan. One homeowner (House #9, comments in Section 3 above) used to have to use two window AC units on her second floor as the central AC did not cool it enough. She now longer uses them. Part of her substantial energy savings is likely due to no longer using relatively inefficient window AC units.

One other unknown is the extent to which the duct sealing positively affected internal pressure imbalances. One fairly common observation in this style of home is that dominant return leakage in the basement causes negative pressure WRT outside. This in turn increases infiltration levels. As the standard Aeroseal process tends to bring basements back to neutral pressure, this is another factor which should be investigated.

Future studies should measure and document before and after thermostat settings, humidity levels, use of supplementary heating/cooling, building pressures and constant vs auto fan setting.

Finally, the impact of the "recapture effect" which is known to be a factor when estimating the effects of sealing supply duct leakage inside the thermal envelope needs to be re-examined in regards to summertime air conditioning. While warm air escaping from supply ducts in basements does rise and help warm the house above (especially if there is no basement ceiling insulation and the basement walls are insulated), escaping air conditioning in the summer falls, creating a pool of cold air at the basement floor which in the author's opinion has close to no re-capture effect. (It does however cause the often mentioned "basement cold as a meat locker effect".) Surveys of supply airflow before and after Aeroseal in sheet metal systems consistently show 25% to 35% increases in delivered AC cfm's to the main living areas. It stands to reason that this causes less AC electrical consumption. Further research is needed.

6. Conclusions and Next Steps

The data indicates that in this style of home, especially the two-story models, with panned returns, ducts inside the house can leak significantly to outside.

At this time, while the blower door testing and limited utility bill analysis supports the potential of saving energy by sealing duct leaks "inside the house", insufficient data is available to draw firm conclusions. The author believes that sealing duct systems by 90% or better, in two-story homes of this construction style, has the potential to achieve heating and cooling savings of between 5%-15%. Additional research is planned to address this issue.

The results of this study are tantalizing, yet not conclusive. We are currently drafting a research protocol for possible future work, where more data can be collected with greater confidence. Improvements over this initial study would include:

- Ensuring that the blower door tests are of research quality (e.g. recent calibration, testing on same day as sealing by same operator, automated multipoint testing, wind restrictions, well documented preparation).
- A third interim blower door test taking place between sealing the supply and return sides of the systems.
- Duct leakage to outside and pressure pan testing.
- Other tests as budget permits, such as tracer gas infiltration, series pressure diagnostics and thermal imaging of the interstitial cavities during the sealing process, static pressures and airflows before and after, long term monitoring of thermostat setpoint, temperatures/relative humidity and particulates.
- Intentional control/monitoring of all variables which affect before and after energy consumption and utility billing records, use of supplementary heating/cooling, building pressures and constant vs auto fan setting.

The study was conducted by Comfort Institute, an international indoor comfort research, training and consumer education organization, with support and assistance from the Greater Cincinnati Energy Alliance, a nonprofit organization with a mission to facilitate investment in energy efficiency and renewable energy projects for the purpose of reducing carbon emissions.

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