Field Test of Aerosol-Spray and Best-Practice Duct-Sealing Approaches

Mark P. Ternes, Oak Ridge National Laboratory
Ho-Ling Hwang, Oak Ridge National Laboratory

ABSTRACT

A field test of an aerosol-spray duct-sealing technology and a conventional, best-practice approach was performed in 80 homes and five states to determine the efficacy and programmatic needs of the duct-sealing technologies as applied in the U.S. Department of Energy Weatherization Assistance Program. The study found that, compared with the best-practice approach, the aerosol-spray technology is 16–60% more effective at sealing duct leaks and can potentially reduce total labor time and repair costs for duct sealing by 30%. A pilot test of full-production weatherization programs using the aerosol-spray technology is recommended to develop approaches for integrating this technology with other energy conservation measures and minimizing impacts on weatherization agency logistics. Application testing of the aerosol-spray technology in mobile homes is also recommended.

Introduction

Within the Weatherization Assistance Program administered by the U.S. Department of Energy (DOE), the current approach taken by weatherization agencies to reduce air leakage in duct systems is to quantify the leakage and identify the leakage sites using a combination of blower-door testing and duct pressure measurement, and then manually reconnect ducts and seal identified leakage sites using sealants and other materials. In this field test, two advanced approaches to sealing ducts were studied: a conventional, best-practice approach using manual sealing augmented by advanced diagnostics, and an approach using an aerosol-spray technology. The field test was performed to determine the efficacy and programmatic needs of these technologies as applied in Weatherization Assistance Program homes and to support the U.S. Department of Housing and Urban Development's Partnership for Advancing Technology in Housing (PATH) in speeding the widespread use of the advanced duct-sealing technologies in the nation's housing.

Field Test Design

The field test of the advanced duct-sealing technologies was performed in the winter of 1999–2000. The field test involved 80 homes eligible for the DOE Weatherization Assistance Program in five states: Iowa, Virginia, Washington, West Virginia, and Wyoming. The five weatherization agencies participating in the field test were knowledgeable in and experienced with duct sealing and had the ability to use advanced diagnostic equipment.

Pre-retrofit space-heating energy use was measured in the first half of the 1999–2000 winter starting in November 1999. Duct sealing was performed in January 2000, allowing post-retrofit space-heating energy use to be measured for the remainder of the winter, ending in March 2000. Duct sealing was the only measure performed on the houses during the field test.

Eight houses at each agency were assigned to receive duct sealing using the conventional, best-practice approach and the other eight houses were assigned to be sealed using the aerosol spray approach.

All the houses were single-family, site-built homes (no mobile homes) heated by a central forced-air gas or oil furnace. The average floor area of the houses was 1,299 ft^2. Most of the houses had either basements (46%) or crawl spaces (33%). A majority of the houses had just one above-grade floor (61%), with most of the remaining houses being either two-story (28%) or a story and a half (11%). The average age of the houses used in the study was 60 years. The average whole-house pre-retrofit leakage rate of the homes was 3,962 cfm50, or 18 ach50.

Ducts were predominantly located in basements, crawl spaces, and inside the homes, consistent with the types of foundations found in the homes. Houses with more than one story usually had some ducts located inside the home, presumably to supply conditioned air to the upper floors. Ducts in houses built on slabs were located primarily inside the house and to a lesser extent in the attic. Sheet metal ducts, flex duct, and panned floor joists were commonly found in the field test houses. Duct board was not a common duct material in these homes.

Conventional, Best-Practice Duct-sealing Technology

Currently, most Weatherization Assistance Program agencies that include duct sealing as a conservation measure use pressure pan and, less frequently, dominant duct leakage measurements to determine if duct sealing is needed, help locate and prioritize duct leakage sites, and provide feedback on progress. The leaks identified through these measurements as well as leaks identified from visual inspection of obvious or potential leakage sites are sealed manually.

In this field test, this basic approach was enhanced to form a best-practice approach by measuring the total duct leakage and duct leakage to the outside using a duct blower with the ducts pressurized to 25 Pa. Including these measurements with the conventional approach is a powerful tool when combined with the other diagnostics and the weatherization crew's experience. Crews can use the initial direct measurements to help determine when duct sealing is warranted, rather than relying on indirect or anecdotal information from pressure pan and dominant duct leakage test. The magnitude of the duct leakage can also forewarn crews that big leaks in the system may be expected. Measuring the duct leakages at the end of the sealing work allows crews to decide if the system has been sufficiently tightened.

Aerosol-Spray Technology

The aerosol-spray technology was developed by Lawrence Berkeley National Laboratory (LBNL) with funding from DOE, the Environmental Protection Agency, and others. The University of California (which manages LBNL) was granted a patent in 1999 on this technology. Aeroseal, Inc., now holds an exclusive license to use this technology on residential and small commercial buildings.

The aerosol-spray technology involves a solid sealant (a vinyl acetate polymer) that is suspended in an aerosol spray. This is sprayed into the ducts, where it seeks out and seals cracks that are ½ inch or less, although larger leaks can be sealed if given enough time. Only about 10–20 ounces of sealant (costing \$15 to \$20) is used in a typical home. In addition to the sealant mixture, the technology consists of an injector (Figure 1), large-diameter flexible plastic tubing to connect the injector to the duct system (Figure 2), foam plugs to temporarily seal registers and protect heat exchanger surfaces in the indoor air handler unit, and computer software to operate the equipment.

The aerosol-spray equipment can be connected to the duct system through a large hole (20–24-inch diameter) cut in the supply or return duct near the air handler equipment (see the hole cut in the supply duct at the top of Figure 2), to the air handler unit itself (as shown in Figure 2), to the ends of the supply and return ducts after the air handler unit has been removed, and, if needed, to supply and return registers (although this is the least preferred method).

Once the aerosol-spray equipment is connected to the duct system and all registers are sealed with the foam plugs or by other means, the total duct leakage of the entire system (both supply and return) is measured using the aerosol equipment. Before the sealant is sprayed in, the heat exchangers in the air handler unit must be blocked off with the foam plugs, cardboard, or other materials so that sealant does not gum up these surfaces. This effectively isolates the supply ducts from the return ducts: only one-half of the duct system can be sealed before the equipment must be removed and connected to the other half of the duct system. The duct leakage is continuously monitored as the sealing occurs so that operators can gauge progress and determine when sealing should be stopped. When both the supply and return ducts are sealed, the heat exchanger is unblocked, and a final duct leakage measurement of the entire system is made. The aerosol-spray equipment is then removed. The final steps are to remove the foam plugs from the registers and air handler unit, cover and seal any holes cut in the ducts with sheet metal and mastic, reinstall fans and covers, and reinstall any air handler units that were removed.

Figure 1. The Aeroseal Injector

Figure 2. The Aeroseal Tubing Connection

It is important to note that the aerosol-spray technology still requires manual sealing of major duct leakage sites, which may have to be done before aerosol sealing rather than at the same time depending on the severity of the leaks. In addition, to improve effectiveness and to ensure timely sealing of larger leaks (¼ to ½ inch in size), it is recommended that 15–30 minutes be spent sealing these larger leaks by hand at the same time the aerosol-spray equipment seals the rest of the duct system to help the process along. In a duct system with a short return or one in which it is difficult to connect a portion of the duct system to the equipment, it can be more effective to seal an isolated part of the duct system by hand while the aerosol-spray equipment seals the rest of the system automatically. The foam seals used to block off the registers during the sealing process are placed inside the ducts; thus, the junction between register boots and wall and floors must be sealed by hand before or after the aerosol-spray sealing process.

The operation of the aerosol-spray equipment is controlled by a Windows-based software program operating on a portable personal computer. The software was developed by Aeroseal for private-sector heating, ventilating, and air-conditioning (HVAC) contractors to market, diagnose, and perform duct sealing using the aerosol-spray technology. As part of Aeroseal's licensing arrangements with its HVAC contractors, data collected by the contractors must be transferred to Aeroseal on a periodic basis for quality control reasons or the software will fail to function. Only portions of Aeroseal's software were needed for this field test. In addition, the data collection needed for this field test required a nonstandard use of the software. Nevertheless, this software was used because there was insufficient funds to develop a customized version.

Results

Duct Leakage Measurements

Four different measurements of duct leakage were made in each house before and after ducts were sealed. In these measurements, the duct leakage of the entire duct system (supply and return) was assessed — separate measurements of supply leakage and return leakage were not performed. Both total duct leakage and duct leakage to the outside were measured, and each measurement was made in two ways (with the duct blower or Aeroseal equipment installed in the same location for all four measurements). The total duct leakage and duct leakage to the outside were first measured by monitoring the duct pressure in the supply duct and pressurizing it to 25 Pa (allowing the return pressure to float), and then additional measurements were made by monitoring the duct pressure in the return duct and pressurizing it to 25 Pa (allowing the supply pressure to float). These measurements can differ considerably if a major leak exists in either the supply or return.

The measurements of duct leakage to the outside in basement houses were made with the basement isolated from the rest of the house and open to the outside in all cases, whether or not the basement might be considered conditioned or not. These values are reported (rather than assuming duct leakage to the outside was zero if the ducts were located in a conditioned basement) because the primary intent of the field study was to determine the difference in sealing capabilities of the two approaches.

Table 1 summarizes the results of the duct leakage measurements made in the field test houses. The study found that duct leakage problems in homes eligible for the Weatherization Assistance Program are prevalent and perhaps worse than in the general population of homes. The average values of the four duct leakages (total duct leakage and duct leakage to the outside, with both measured by pressurizing the supply and then the return ducts to 25 Pa) ranged from

Table 1. Average Duct Leakage Results as Measured in the Field Test Houses

Parameter	Total duct leakage[a]				Duct leakage to the outside[a,b]			
	Supply		Return		Supply		Return	
	Best-practice	Aerosol	Best-practice	Aerosol	Best-practice	Aerosol	Best-practice	Aerosol
Number of houses[c]	35	35	34	34	28	29	28	29
Pre-retrofit (cfm25)	862	364	642	626	692	309	534	489
Post-retrofit (cfm25)	444	122	352	166	279	115	245	140
Reduction (cfm25)	418	242	289	460	413	195	289	349
Percent reduction	41%	63%	38%	67%	50%	60%	49%	63%

[a] "Supply" and "Return" indicate where the duct pressure probe was inserted in making the measurements.
[b] Measurements of duct leakage to the outside were made in basement houses with the basement isolated from the rest of the house and open to the outside in all cases, whether the basement might be considered conditioned or not.
[c] Averages are based on fewer than 40 houses per group (the number of houses initially included in the field test) due to normal attrition associated with moving, illnesses, and emergency repairs required to the space-heating systems. Other houses were eliminated from the data set because measurements were not made or because measurements were determined to be unreliable.

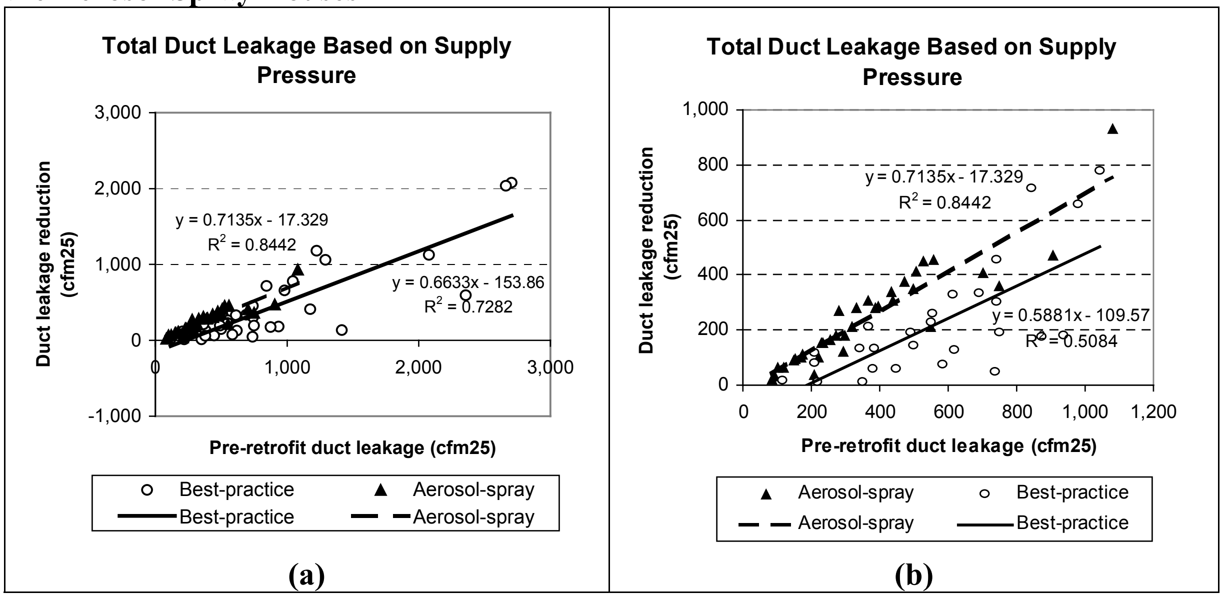
534–862 cfm25 in the best-practice homes and from 309–626 cfm25 in the aerosol-treated homes. These are generally larger than the average duct leakage of 150–400 cfm25 found in many other studies of non-low-income homes (Davis and Robinson 1993; Davis, Baylon, and Houseknecht 1998; Kallett et al. 2000; Kinert et al. 1992; Kolb and Ternes 1995; and Vigil 1993). The presence of a large number of basement houses in the field test, which often have leaky duct systems, may be one factor contributing to this observed difference.

Table 1 clearly indicates the positive impact duct sealing had on reducing duct leaks in the field test houses. Depending on which of the four duct leakage measurements one considers, the average duct leakage reduction was between 289 and 418 cfm25 (38% and 50%) in the best-practice homes and between 195 and 460 cfm25 (60% and 67%) in the aerosol-treated homes. The reductions in leakage were all statistically different from zero at the 95% confidence level.

The average reductions in duct leakage measured in this field test are all greater than the 75–171 cfm25 reductions reported in other studies using conventional approaches (Cummings et al. 1990; Davis and Robinson 1993; Davis, Baylon, and Houseknecht 1998; Kinert et al. 1992; and Kolb and Ternes 1995). The percentage reductions for the best-practice approach are consistent with the reported percentage reductions of 30–74% for these other studies. The percentage reductions for the aerosol-spray technology are in the upper end of this range and consistent with a 78% reduction obtained from another study of the aerosol-spray approach applied to non-low-income homes in Florida (Modera et al. 1996) and an 81% reduction found in a utility-based program in California (Kallett et al. 2000).

A typical new construction standard used by some states, utilities, and other agencies is that duct leakage in units of cfm25 should be no greater than 5% of conditioned floor area. For the average field test home, this would be about 65 cfm25 — significantly lower than the average post-retrofit duct leakages achieved in the best-practice homes (245–444 cfm25) but only about 50% lower than the average post-retrofit duct leakages achieved in the aerosol-treated

Figure 3. Comparison of Duct Leakage Reductions to Pre-Retrofit Duct Leakages Using: (A) All the Houses with Available Data (35 Houses in Each Group), and (B) A Subset of the Best-Practice Houses (27 Houses) with the Same Relative Range of Initial Duct Leakages as the Aerosol-Spray Houses



homes (115–166 cfm25). Thus, opportunities for greater reductions may remain, especially when the best-practice technologies are used.

Comparing the results of the best-practice homes to the aerosol-treated houses must be done cautiously because the initial duct leakage characteristics of the houses receiving the aerosol-spray treatment were not the same as the houses sealed using the best-practice technology (even though houses were assigned to the two groups randomly after considering key house characteristics to try to make sure the two groups were equivalent). The pre-retrofit duct leakage of the best-practice homes was about the same as the aerosol-treated houses when the total duct leakage and the duct leakage to the outside were measured by pressurizing the return duct to 25 Pa, but were significantly different when the measurements were made by pressurizing the supply duct to 25 Pa. Pressure pan measurements as described below also indicated that the two groups of houses had different initial duct leakage characteristics.

Models relating duct leakage reduction to pre-retrofit duct leakage values were developed to factor out the influence of the difference in initial duct leakages between the two groups of houses so that the two groups of houses could be compared on an equal basis. Figure 3 exemplifies such models using total duct leakage based on supply pressure, where Figure 3a used all the houses in both groups and Figure 3b used only houses with the same range of pre-retrofit duct leakage (i.e., pre-retrofit duct leakage <1200 cfm25). After ensuring that the models were not overly influenced by the best-practices group of houses having higher pre-retrofit duct leakages than the aerosol-treated houses, the models based on using all the houses were used with the pre-retrofit duct leakages measured in each house to predict the duct leakage reductions (and hence the post-retrofit duct leakages) that would have occurred for each house in the field test as if it had first been treated using the conventional best-practice approach and then by the aerosol-spray technology. These are the duct leakage reductions provided in Table 2.

Table 2. Average Duct Leakage Results for Simulated Set of Best-Practice and Aerosol-Sealed Houses

Parameter	Total duct leakage[a]				Duct leakage to the outside[a,b]			
	Supply		Return		Supply		Return	
	Best-practice	Aerosol	Best-practice	Aerosol	Best-practice	Aerosol	Best-practice	Aerosol
Number of houses	70	70	68	68	57	57	57	57
Pre-retrofit (cfm25)	613	613	634	634	497	497	511	511
Post-retrofit (cfm25)	350	193	338	168	229	185	234	144
Reduction (cfm25)	263	420	296	466	268	312	277	367
Percent reduction	43%	68%	47%	74%	54%	63%	54%	72%

[a] "Supply" and "Return" indicate where the duct pressure probe was inserted in making the measurements.
[b] Measurements of duct leakage to the outside were made in basement houses with the basement isolated from the rest of the house and open to the outside in all cases, whether the basement might be considered conditioned or not.

The results presented in Table 2 clearly indicate that the aerosol-spray technology combined with manual sealing of large leaks is more effective at sealing duct leaks compared with use of the best-practice approach alone. Average reductions in duct leakage for the aerosol group are higher than those for the best-practice group by 44–170 cfm25, a 16–60% improvement depending on which of the four duct leakage measurements being considered.

As exemplified by Figure 3, duct leakage reductions were more consistent and more predictable in the houses receiving the aerosol-spray treatment than in those receiving best-practice duct sealing alone. In addition, the model results (regression lines) predict that no reduction in duct leakage will be achieved in houses with a pre-retrofit duct leakage less than about 200 cfm25 using the best-practice approach and less than about 25 cfm25 using the aerosol-spray technology. This indicates that the aerosol-spray technology is able to seal houses with moderate duct leakage, whereas use only of best-practice approaches would have little impact on these houses.

Pressure Pan Measurements

In each house, the pressure pan readings (supply and returns) were added together to obtain a total value for the house. The average pre-retrofit value of the total pressure pan readings was 50 Pa in the aerosol-treated homes and 71 Pa in the best-practice homes, with both groups achieving a reduction of about 63%. The difference in pre-retrofit values supports the findings based on the duct leakage measurements that the two groups of houses were not entirely equivalent prior to duct sealing. Despite the lack of equivalency between the groups, other analysis of the pressure pan readings indicate that the aerosol-spray approach provided an improved performance. Although the distributions of the total pressure pan readings were about the same for the two groups of houses before duct sealing, 70% of the houses treated with the aerosol-spray technique had total readings following duct sealing that were less than 10 Pa, compared with only about 30% of the houses treated using the best-practice approach. Similar results were obtained when the average pressure pan readings for each house were examined.

Pressure pan readings of ≥1.0 Pa are often interpreted to mean that a sealable leak probably exists behind that register, whereas a value of <1.0 indicates that the measured portion of the duct system is relatively tight. The percentage of houses with no more than one register with a pressure pan reading ≥1.0 Pa increased dramatically in the aerosol group following retrofit, from 14 to 54%, while only limited improvement was observed in the best-practice homes (from 6 to 17%).

Houses with three registers ≥1.0 Pa are often considered good candidates for duct sealing. The percentage of homes with three or more registers with a pressure pan reading ≥1.0 Pa dropped markedly in the aerosol group (from 84 to 38%), while a much smaller drop occurred in the best-practice group (from 94 to 69%).

Repair Time and Cost

As seen in Table 3, the average elapsed time to perform repairs (defined as the time from the start of duct sealing, after the equipment was set up and all diagnostics were performed, until all duct sealing work was completed and before equipment was packed up) in the aerosol-spray houses was 98 min, an average time that was also reported in another study of the aerosol-spray system (Modera et al. 1996). This elapsed time was about 67% of the elapsed time needed to seal ducts in the best-practice houses (147 min).

Table 3. Average Repair Times and Costs for the Best-Practice and Aerosol-Spray Approaches

House type	Number of houses[a]	Elapsed repair time (min)	Crew-time for manual sealing (min)	Crew-time per elapsed time	Material costs for manual repair
Best-practice	35	147	330	2.2	$50
Aerosol-spray	24	98	66	0.7	$19

[a] Data was unavailable or improperly recorded for 17 houses in the sample; hence, the averages include only 59 houses.

Significant labor savings are indicated from use of the aerosol technology. The average crew-time needed to perform manual air sealing in the aerosol houses was 66 minutes (the total time spent by the crew manually sealing the ducts and not including any time spent working with the aerosol equipment), which again is very consistent with an average time of 65 minutes reported by Modera et al. (1996). This time to perform manual sealing in the aerosol houses was 20% of the average crew-time needed in the best-practice houses (330 minutes), or 264 crew-minutes (4.4 crew-hours) less. In the best-practice houses, crew-time was typically the number of crew members at the house times the elapsed time spent duct sealing. The crew-minutes spent manually sealing ducts in the best-practice houses was greater than 720 minutes (12 crew-hours) in about 15% of the homes (spread across three weatherization agencies). For comparison, the greatest amount of labor spent manually sealing ducts in the aerosol houses was 360 crew-minutes (6 crew-hours).

Considering both the elapsed time and crew time, a total of 98 minutes would typically be required for one person to operate the aerosol-spray equipment to seal leaks automatically and perform the necessary manual duct sealing once the aerosol-spray equipment is set up. By contrast, 330 crew-minutes would typically be required to seal ducts manually — or 232 crew-minutes (3.9 crew-hours) more than would be necessary with the aerosol approach.

Setup, tear-down, and diagnostic times must also be considered in determining the overall or total labor costs associated with a particular duct-sealing technology. These times could not be determined from the field test because crew members were performing these tasks while other diagnostics were performed. Two agencies reported setup times of 1½ to 2 hours by multi-member crews on the first houses where they used the equipment, with one agency saying that setup times decreased to 30 minutes on the last houses once they had become familiar with the equipment. Assuming a two-person crew, these times are consistent with times reported by Modera et al. (1996) in another study of the aerosol-spray technology; these researchers found that 3 person-hours were required for setup for the first 21 houses used in their study and 1.9 person-hours for the next 17 systems. The crew-hours required to perform setup, diagnostics, and tear down are probably greater for the aerosol-spray technology than for the conventional, best-practice technology. However, the additional time for these activities is probably much less than the four additional crew-hours needed to seal the ducts under the best-practice approach.

As shown in Table 3, average material costs associated with the manual portion of duct sealing were greater for the best-practice houses than for the aerosol houses ($50 and $19, respectively). However, including the average material cost of $15 to $20 per house for the aerosol-spray sealant, the total material costs associated with both methods are about the same.

Economics

The economics of duct sealing, as with most conservation measures, are usually highly house-specific. For duct sealing, economics depend on many variables, such as the initial energy use of the house, fuel costs, the location and extent of duct leaks, the degree of duct sealing achieved, and the costs incurred in sealing the ducts in the house. Because of the large variability in energy savings measured in individual houses, economic calculations for three groups of houses were performed and presented in Table 4 to provide some indication of the overall, average economic viability of the duct sealing performed rather than focusing on house-specific analyses:

- all houses (representing sealing ducts in all homes encountered in a weatherization program),
- houses with some ducts outside the conditioned space of the house (representing sealing ducts just in those homes that might most benefit from this work), and
- houses with all ducts in the basement (representing a class of homes with perhaps the least potential for energy savings from duct sealing).

The energy savings measured for each group (Ternes and Hwang 2001) were converted into cost savings by assuming $0.72 per therm, which was the average cost for natural gas in the year 2000. To be conservative, the same energy savings were assumed for sealing ducts using

Table 4. Average Economics for the Best-Practice and Aerosol Approaches

House type	Energy savings		Conventional, best-practice approach			Aerosol-spray technology		
	Therms	$	Installation costs ($)	Simple-payback period	Savings-to-investment ratio[a]	Installation costs ($)	Simple-payback period	Savings-to-investment ratio[a]
All houses	65	47	260	5.5	2.1	189	4.0	2.9
Some ducts outside	107	77	260	3.4	3.4	189	2.5	4.7
Ducts just in basement	23	17	260	15.3	0.8	189	11.1	1.0

[a] Calculated using a uniform present value of 11.59 based on a discount rate of 3.4% for the year 2000 and assuming a 15-year life, natural gas as the fuel, and a U.S. average (Fuller and Boyles 2000).

the aerosol-spray technology and the conventional, best-practice approach even though the larger reductions in air leakage measured in the homes using the aerosol-spray technology would be expected to translate into higher energy savings compared with the homes using just the best-practice approach. No conclusions could be drawn concerning energy savings differences between the two duct-sealing methods based on the field test energy measurements because the scatter observed in the savings for individual homes (and hence the statistical uncertainty in the calculated group means) was too great to reach any statistically valid conclusion, the groups were not equivalent with respect to initial duct leakage characteristics, and no correlation could be established between the reduction in duct leakage and energy savings.

Installation costs for the conventional, best-practice approach were estimated assuming 330 minutes (5.5 hours) of labor to make repairs (based on Table 3); 1.5 hours of labor to set up, tear down, and perform diagnostics; $50 in material costs (based on Table 3); and a labor rate of $30 per hour. The total estimated cost of $260 is consistent with an average cost of $293 ($41 for materials and $252 for labor) reported by Jump, Walker, and Modera (1996) in another field test. The total estimated crew-time of 7 hours is also consistent with an average crew-time of 10.3 hours reported by Modera et al. (1996) for conventional duct sealing in a Florida field test.

Similarly, installation costs for using the aerosol-spray technology were estimated assuming 98 minutes (1.6 hours) of labor to operate the aerosol-spray equipment and manually seal major leaks during operation of the equipment; 3 hours of labor to set up, tear down, and perform diagnostics; $50 in material costs; and a labor rate of $30 per hour. The total estimated crew-time of 4.6 hours is consistent with an average crew-time of 4.4 hours reported by Modera et al. (1996) to perform aerosol-spray duct sealing in another field test once crews became familiar with the duct-sealing equipment. Equipment costs were not included for either method.

In Table 4, the simple-payback period and the savings-to-investment ratio (SIR) confirm that, on average, duct sealing as performed in the field test can be a very economical energy conservation measure if the assumptions made in the calculations are reasonable. If these assumptions are different for a particular house or program, then duct sealing may become economically unviable. For example, if average costs for sealing ducts with the aerosol-spray technology are $1,009, as reported by Kallett et al. (2000) for a utility-based program in California, then the duct sealing as performed in this field test would not be economical. The economics are especially favorable in houses that can most benefit from duct sealing (e.g., houses with ducts located outside the conditioned space rather than in a conditioned basement), suggesting that weatherization programs might want to target these types of houses to receive duct-sealing measures. Higher SIRs and lower simple-payback periods result for the aerosol-spray technology because of its lower estimated installation cost, even without considering its potentially higher energy savings.

Weatherization Agency Input

Weatherization staff from four of the five agencies participating in the field test provided input on the performance and use of the advanced duct-sealing technologies. In general, these four agencies were impressed with the aerosol-spray technology, its hardware, and the duct sealing that could be achieved from its use. Although impressed, the agencies pointed out that the aerosol-spray method is not a practical tool for all applications, such as simple, small, and accessible duct systems that could be sealed easily by hand.

These four weatherization agencies also reported difficulty in using the software, especially because it is designed for private-sector HVAC work rather than for use in the Weatherization Assistance Program. For use in the Weatherization Assistance Program, two agencies recommended that the software be considerably retooled and simplified to focus just on pre- and post-retrofit duct leakage testing and on controlling the sealing operation because other information is routinely collected during initial weatherization audits.

The agencies generally felt that both the aerosol-spray technology and measuring duct leakages with a duct blower would be useful tools for use in their agency and would recommend their adoption within the Weatherization Assistance Program. One agency disagreed because they felt that "a well-trained weatherization technician can achieve reasonable, cost-effective duct-sealing results with a blower door and pressure pan."

Conclusions and Recommendations

Duct sealing using the best available method should continue to be a recommended weatherization measure, especially in homes with ducts located in unconditioned spaces, because of the favorable economics estimated for the work performed in this field test (SIRs greater than 3). The economics of performing duct sealing in homes with ducts located entirely in the basement was not attractive (SIRs between 0.8 and 1.0), suggesting that sealing ducts in these houses should be looked at critically.

Continued training on conventional, best-practice approaches is needed to achieve better duct leakage reductions and lower post-retrofit duct-leakage rates than those observed in this field test. Average post-retrofit duct leakages of 245 to 444 cfm25, as observed in this field test, indicate that major leaks are not being identified and sealed. Training should also promote more consistent results among agencies and perhaps faster installation times.

Compared to the best-practice approach, the aerosol-spray technology achieves 16–60% better air leakage reductions, ensures more consistent air leakage reductions among houses and agencies, and potentially reduces total labor time and repair costs by 30%. Based on these benefits, as well as the positive input received from the participating weatherization agencies, we recommend further study to encourage and promote use of the aerosol-spray technology within the Weatherization Assistance Program. The aerosol-spray technology could make duct sealing a more viable measure within the Weatherization Assistance Program by improving the cost-effectiveness of the measure and keeping total weatherization costs below program guidelines. We recommend a pilot test of the aerosol-spray technology in conjunction with full-scale weatherization to develop approaches for integrating this technology with other energy conservation measures and minimizing impacts on weatherization agency logistics. As part of this pilot test, a considerably scaled-down and simplified version of the software that measures duct leakage before and after duct sealing and operates the equipment during the sealing process should be developed.

Finally, application testing of the aerosol-spray technology in mobile homes is recommended. The Weatherization Assistance Program is serving more and more mobile homes each year, and mobile homes are the predominant house type served by many agencies. The aerosol-spray technology has been tested in mobile homes only on a very limited basis, and this field test addressed application of this technology to site-built, single-family homes only.

References

Cummings, J. B., J. J. Tooley, N. Moyer, and R. Dunsmore. 1990. "Impacts of Duct Leakage on Infiltration Rates, Space Conditioning Energy Use, and Peak Electrical Demand in Florida Houses." Pp. 9.65–9.76 in *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings,* vol. 9. Washington, D.C.: American Council for an Energy-Efficient Economy.

Davis, B., David Baylon, and Aaron Houseknecht. 1998. "Developing a Market-Based Utility Duct Sealing Program." Pp. 2.21–2.31 in *Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings,* vol. 2. Washington, D.C.: American Council for an Energy-Efficient Economy.

Davis, B. E., and M. Robinson. 1993. "Using the Pressure Pan Technique to Prioritize Duct Sealing Efforts: A Study of 18 Arkansas Homes." *Energy and Buildings* 20:57–63.

Fuller, Sieglinde K., and Amy S. Boyles. 2000. *Energy Price Indices and Discount Factors for Life-cycle Cost Analysis — April 2000: Annual Supplement to NIST Handbook 135 and NBS Special Publication 709*. NISTIR 85-3273-15 (Rev. 4/00). Washington, D.C.: U.S. Department of Commerce, April.

Jump, David A., Iain S. Walker, and Mark P. Modera. 1996. "Field Measurements of Efficiency and Duct Retrofit Effectiveness in Residential Forced Air Distribution Systems." Pp. 1.147–1.155 in *Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings,* vol. 1. Washington, D.C.: American Council for an Energy-Efficient Economy.

Kallett, Rick, Ed Hamzawi, Craig Sherman, and Janis Erickson. 2000. "SMUD's New Residential Duct-Improvement Program Using an Aerosol-Based Sealant." Pp. 2.163–2.174 in *Proceedings of the ACEEE 2000 Summer Study on Energy Efficiency in Buildings,* vol. 2. Washington, D.C.: American Council for an Energy-Efficient Economy.

Kinert, R. C., D. C. Engel, J. P. Proctor, and R. K. Pernick. 1992. "The PG&E Model Energy Communities Program: Offsetting Localized T&D Expenditures with Targeted OSM." Pp. 5.131–5.136 in *Proceedings of the ACEEE 1992 Summer Study on Energy Efficiency in Buildings,* vol. 5. Washington, D.C.: American Council for an Energy-Efficient Economy.

Kolb, James O., and Mark P. Ternes. 1995. "Investigation of Air Distribution System Deficiencies and Repair Benefits in Phoenix, Arizona." Pp. 379–87 in *Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings VI,* Clearwater Beach, Fla., December 4–8. Atlanta: ASHRAE Special Publication.

Modera, Mark P., Darryl Dickerhoff, Oddbjorn Nilssen, Holly Duquette, and Jan Geyselaers. 1996. "Residential Field Testing of an Aerosol-Based Technology for Sealing Ductwork." Pp. 1.169–1.175 in *Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings,* vol. 1. Washington, D.C.: American Council for an Energy-Efficient Economy.

Ternes, Mark P., and Ho-Ling Hwang. 2001. *Field Test of Advanced Duct Sealing Technologies within the Weatherization Assistance Program*, ORNL/CON-480, Oak Ridge National Laboratory, November.

Vigil, F. 1993. "Duke Power's Success." *Home Energy* 10, no. 5: 45–47.

Acknowledgments

The authors wish to acknowledge the U.S. Department of Housing and Urban Development for providing funding for this research as part of its Partnership for Advancing Technology in Housing (PATH) Program, and the U.S. Department of Energy's Office of Building Technology, State and Community Programs for also providing funds through its Weatherization Assistance Program. The authors are especially grateful to the weatherization agencies who participated in this field test: Community Action of South Eastern West Virginia, Virginia Mountain Housing, Inc., Iowa East Central TRAIN (Teaching, Rehabilitating, Aiding Iowa's Needy), Wyoming Energy Council, Inc., and The Opportunity Council (Bellingham, WA).