Residential Field Testing of an Aerosol-Based Technology for Sealing Ductwork

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Research over the past five years has indicated that a significant majority of the cost of residential retrofit duct sealing is in the labor required to find and seal those leaks. This paper describes the results of a field investigation of the performance and practicality of sealing residential duct leaks from the inside by means of a technique based upon injecting a fine aerosol spray into the duct system. The field results presented are from 47 houses located in Florida. The field measurements included estimates of the labor and costs associated with conventional sealing, minute-by-minute tracking of the aerosol sealing process, and a breakdown of the time required for the various aspects of the aerosol sealing procedure, including: 1) set-up, 2) aerosol injection, 3) supplementary conventional sealing, and 4) clean-up. These field tests indicated that this aerosol apparatus and injection protocol seals 60–90 cm^2 of duct leakage per hour of injection time in the first half hour of injection, depending on the type of duct system. This sealing rate decreases to 20–40 cm^2/h in the second half hour as the ducts became tighter, the pressures increased, and the duct velocities decreased. Overall, the technology was found to be capable of sealing approximately 80% of the leakage it encountered, assuming that catastrophic leaks such as disconnected ducts had been repaired. The entire sealing protocol, including supplementary conventional sealing, took an average of 5.5 person-hours for the entire sample. The injection process itself represented approximately 20% of this time, and thus the overall time required was found to decrease significantly as the set-up and clean-up procedures were improved.

INTRODUCTION

Over the past ten years, considerable interest has arisen with respect to the air tightness of residential ductwork (Cummings et al. 1990, Davis 1993, Modera 1993, Modera and Jump 1995, Parker 1993, Proctor et al. 1992). During that time a number of utility programs that attempt to seal these duct systems have gotten under way. The groups running those programs, as well researchers who have investigated duct leakage diagnostic/sealing techniques, have found that a significant majority of the cost of duct sealing is in the labor required to find and seal those leaks (Jump and Modera 1994). This paper describes the results of a field investigation of the performance and practicality of sealing residential duct leaks from the inside by means of a technique based upon injecting a fine aerosol spray into the duct system. The field results presented are from 47 houses located in Florida.

The use of aerosol particles to seal ductwork from the inside was brought to the proof of concept stage in 1994 by researchers at Lawrence Berkeley National Laboratory (LBNL) (Carrie and Modera 1994, Carrie and Modera 1995). In brief, this technology utilizes air laden with fine aerosol particles (2–20 μm) to pressurize a duct system, resulting in deposition of those particles at the leaks within that duct system.

METHODOLOGY

The basic methodology was to recruit homes in the service territory of Florida Power and Light (FPL) in Miami, Florida to have their duct systems sealed by means of a protocol centered on the aerosol-based sealing technology. The time required to seal those duct systems was compared with the conventional duct sealing time estimated by the standard FPL audit. The duct sealing procedure was tracked in terms of sealing performance and the time required for each task within the protocol, and the utility bills were compared for the summers on either side of the duct sealing.

Apparatus

This study was conducted using the first field prototype of the aerosol sealing technology. This prototype was designed specifically for residential-size systems. The apparatus utilized included: 1) a fan-powered aerosol generator/injector (including a compressor for the aerosolizing sprayer), 2) a set of rigid devices for temporarily sealing system registers, 3) disposable sheet-metal and cardboard for isolating heat exchangers and coils, and 4) plastic flexible ductwork and flanges for connecting the generator/injector to the duct system. The aerosol generator/injector utilizes three 15-amp 110-volt house circuits, one for the fan, one for an internal heater, and one for the compressor required for the internal aerosolizing sprayer (see Figure 1). Two types of rigid devices were used for temporary register sealing during the aerosol injection process: 1) rectangular Masonite plates with short wooden walls and closed-cell foam gaskets, which attach via metal "T-bars" that hook onto the backside of the grille vanes so as to hold the foam gasket against the wall around the register, and 2) several versions of gasketed rectangular plastic containers, including commercially-available "pressure pans," which were held against the wall surrounding the registers with telescoping painter's poles. The testing procedure also required the use of a hand-held digital manometer (The Energy Conservatory) for documenting the time history of the aerosol-injection process. The sealing apparatus installation is shown schematically in Figure 2.

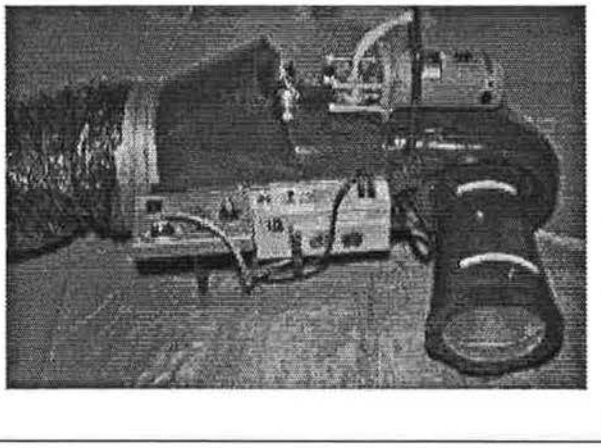
The aerosolized material used for this study was Ductseal (Puma Technologies), which is a vinyl acetate polymer suspended in water. For all of the houses sealed, the aerosolized liquid was approximately 15% solids, and was injected at 30 cc/min.

Procedure

The homes chosen to participate in this study were obtained by two means. First, a mailing was sent to 50 homeowners who had had their homes audited by Florida Power and Light (FPL) for duct leakage, but who had not yet had the sealing performed. Twenty three of those homeowners elected to participate in this study. The remaining participants were obtained on an availability basis from FPL staff and contacts.

The protocol used for each of the homes consisted of: 1) performing the standard FPL duct-system audit/estimate on

Figure 1. *Aerosol injection apparatus used for the field study.*



each house, 2) performing the entire aerosol sealing process on each house (including tracking the time required for each task in the process), 3) performing conventional mastic and fiberglass-tape repairs to large leaks and platform return plenums (including tracking the time required), and 4) minute-by-minute tracking of duct-system pressures and flows during the aerosol injection period. The standard FPL duct-system audit/estimate consists of a visual inspection of the duct system that is used to create a written analysis of the type of duct system (including a rough sketch), the type of sealing required, as well as time and materials estimates for the conventional sealing needs identified. This audit has been utilized in over 100,000 houses over the past four years, and has been calibrated against measured time requirements for sealing. The time required for the aerosol sealing process was broken down into six tasks, including: 1) aerosol injector set-up, 2) temporary sealing of registers, 3) temporary sealing of the heat exchanger and air handler, 4) aerosol injection, 5) supplementary conventional sealing, and 6) clean-up. The only change to the protocol over the course of the study, other than the increased efficiency associated with experience, was the gradual increase in the use of telescoping poles over "T-bar" hooks for holding temporary seals to registers.

RESULTS

FPL staff sealed a total of 47 duct systems with the aerosol sealing protocol during April, May and June 1995, however complete data sets are currently available for only 36 of those houses. In the vast majority of those houses (41 out of 47) only the supply side was sealed by aerosol injection. This stemmed from the fact that most of the systems had platform returns, which were more practically sealed with mastic and fiberglass tape.

Sealing Performance

The results of the aerosol injection processes in these houses are summarized in Table 1. The data in Table 1 shows that the average supply-side leakage in these systems prior to sealing was 70 cm^2, or 0.42 cm^2/m^2 of house floor area. This degree of leakage is comparable to what has been reported in the literature for similar duct systems (Modera, 1993, Proctor et al., 1992, Cummings et al., 1990). Table 1 also indicates that more than 80% of the supply-side leakage was sealed on average, and that an average of more than 80% of the return-side leakage was sealed by the aerosol in the 6 houses in which it was used on the return side.

The sealing results in Table 1 were obtained from the time-history plots that were produced based upon the minute-by minute data from the injection process. These time-history plots, examples of which are shown in Figures 3

Figure 2. Schematic of aerosol apparatus installation.

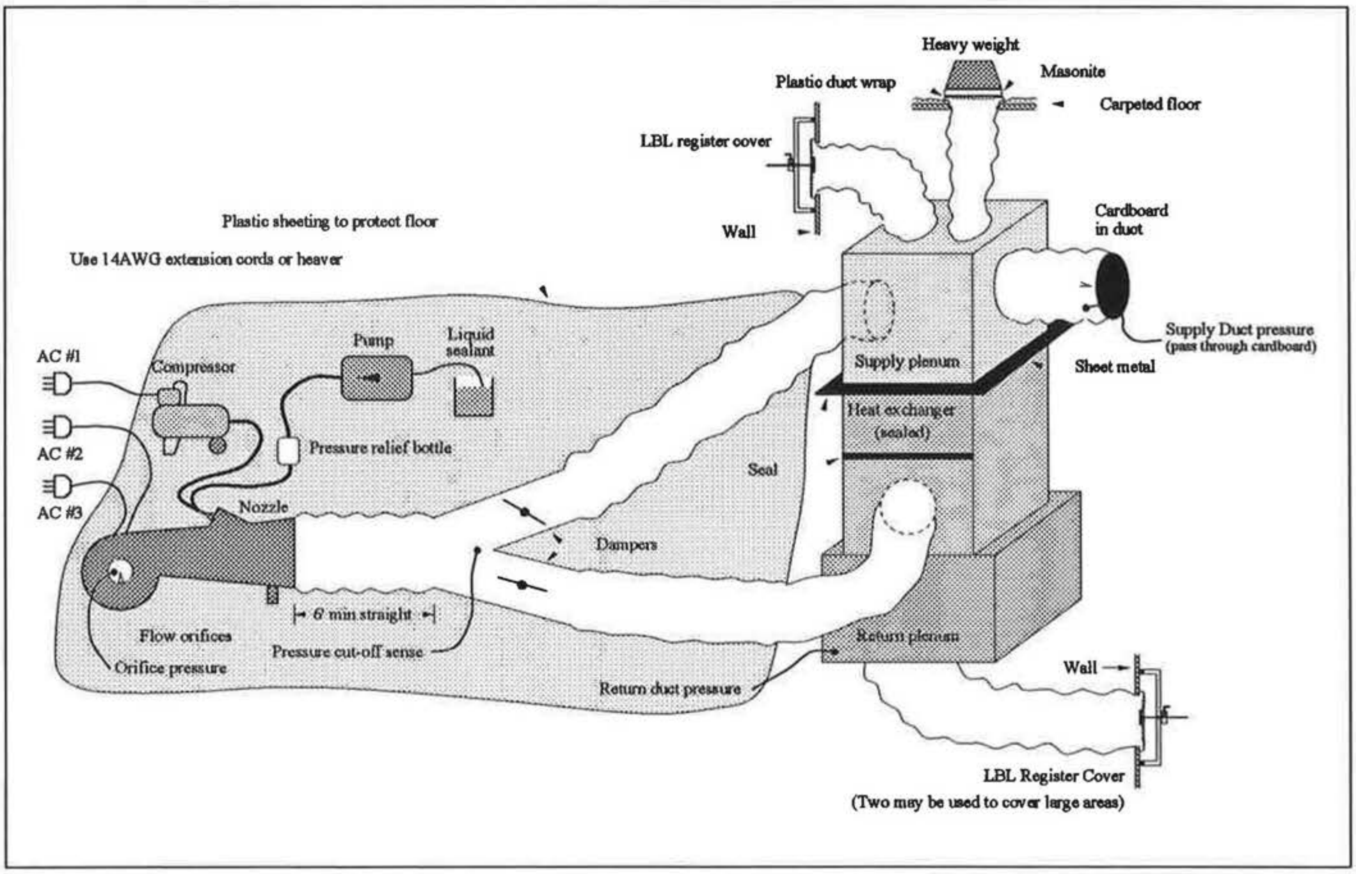
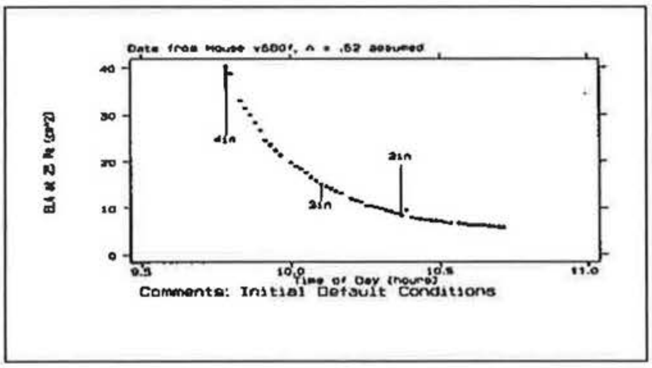


Table 1. Overall Sealing Performance of Aerosol Injection (36 houses)

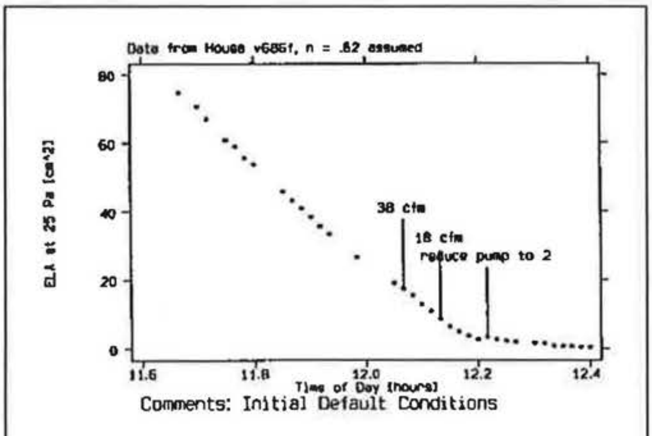
Sample	Number of Homes	Average House Floor Area [m²]	Average Pre-Retrofit Leakage [cm²]	Pre-Retrofit Leakage [cm²/m² floor area]	Fraction of Leakage Sealed [%]
Combined Supply and Return	6	167	95	0.59	86
Sheetmetal Systems	17 (1 combined)	172	62	0.36	87
Ductboard Systems	6 (4 combined)	163	90	0.56	77
Plastic Flexduct Systems	13 (1 combined)	152	62	0.43	67
Full Sample	36	165	66	0.42	78

Figure 3. Typical plot of duct system leakage as a function of time during the aerosol injection process that displays steadily decreasing sealing rate over the course of the injection (The pointers note the size of the inlet orifice to the injector).



and 4, were found to provide relatively unique "signature" descriptions of the sealing process, despite the fact that they all follow a similar pattern. The general pattern was that the sealing rate was highest at higher leakage levels, yielding leakage versus time curves with negligible or positive second derivatives. This result differs from what was predicted by theory and measured for a perfectly machined leak in the laboratory, in which case the sealing efficiency increased with time as the leaks were sealed, resulting in a negative second derivative (Carrie and Modera 1994). Three possible factors behind this difference between laboratory and field results are: 1) that in the field the smallest leaks are sealed first at a high sealing efficiency, leaving larger leaks to be sealed less efficiently, 2) that the reduction in flowrate during the sealing process results in less penetration of aerosol particles to the leaks, thereby reducing the sealing efficiency, and 3) that actual leaks in the field, which are not machined slots, do not have the same functional dependence on size as was derived and measured for machined slots in the laboratory.

Figure 4. Typical plot of duct system leakage as a function of time during the aerosol injection process that displays a relatively constant sealing rate over the course of the injection (The cfm pointers denote the calculated leakage flows at 50 Pa, and the pump pointer corresponds to a change in the liquid flowrate through the peristaltic pump).



The injection-process results were analyzed further to characterize the performance of the technology over the course of the injection, and as a function of the type of duct system. Figure 5 illustrates average absolute sealing rates for the first, second and third half-hour periods of aerosol injection for plastic-flexduct, sheet-metal, and ductboard systems. This figure illustrates the decrease in sealing rate and efficiency as the process proceeds, and also suggests that the sealing rate is highest for sheet-metal systems, next highest for ductboard systems, and lowest for plastic flexduct systems. The latter result merits more careful investigation to assure that it stems from the duct material, and not from other correlated characteristics of the systems (e.g., system size, leakiness, or design).

Figure 6 contains the same information that was presented in Figure 5, except in this case the leakage sealed in each half-hour period of injection is normalized by the leakage level at the beginning of aerosol injection. This normalization allows us to evaluate the fraction of the leakage sealed as a function of time, and illustrates that on average 40–65% of the sealing is completed within the first half hour. The fact that the percentage sealing rate is lower for ductboard systems despite their higher absolute sealing rate as compared to flexduct systems stems from the fact that the ductboard systems were somewhat leakier prior to injection.

Figure 5. Absolute leakage sealing rates for sheet-metal, fiberglass ductboard and plastic flexduct systems for the first three half-hour periods of aerosol injection. Error bars represent standard deviation. Numbers above error bars are the size of the sample used.

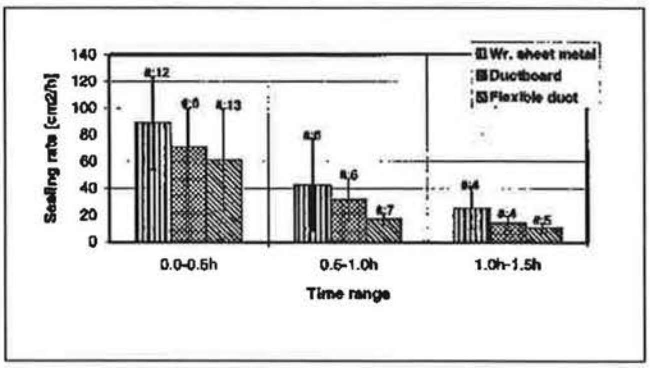
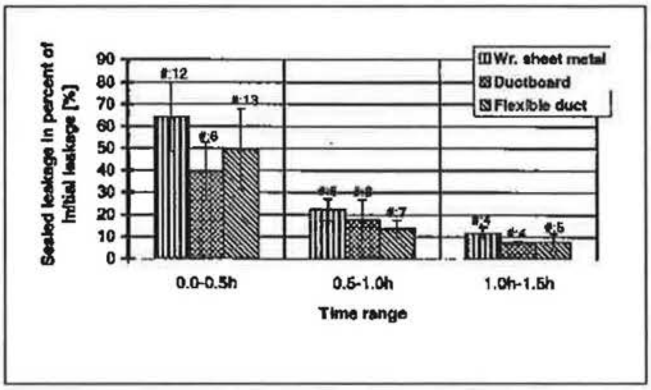


Figure 6. *Percentage of leakage sealed for sheet-metal, fiberglass ductboard and plastic flexduct systems for the first three half-hour periods of aerosol injection. Error bars represent standard deviation. Numbers above error bars are the size of the sample used.*



Time-Activity Analysis

The time-activity results for the aerosol sealing process are summarized in Table 2. The data in Table 2 illustrate that for the first half of the houses sealed, the aerosol-based protocol reduced the sealing time by approximately 35% as compared to the FPL estimates for conventional sealing protocols, whereas for the second half of the houses tested the aerosol-based protocol required 60% less labor. One other point worth noting about Table 2 is that the average aerosol injection time is slightly longer than 1.5 hours, but that the vast majority of the sealing is performed in the first hour (see Figure 6). This suggests that the protocol could be improved by developing cost-effectiveness criteria for stopping injection. On the other hand, there is no utility in shortening the aerosol injection period below the time requirements for simultaneous conventional sealing.

The sample-average data in Table 2 is broken down by the type of duct system in Figures 7 and 8.

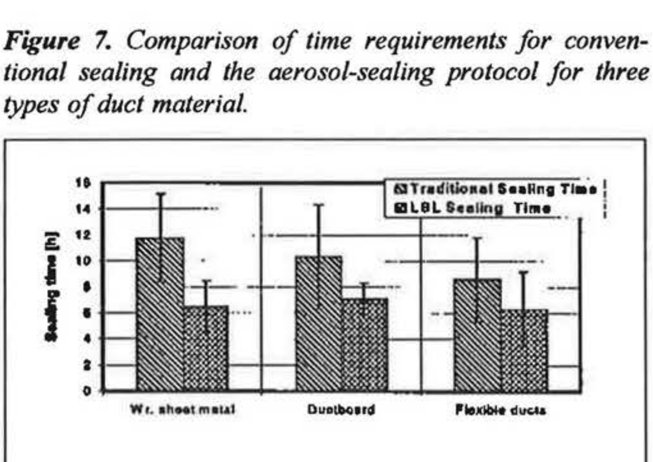
The data in Figures 7 and 8 indicate several differences in the time requirements for the sealing process stemming from the duct material for the system being sealed. First, it is clear that the time for conventional sealing of wrapped metal duct systems is considerably longer than that required for the other types of duct construction, particularly if you take into account that they had less pre-retrofit leakage (see Table 1). Figure 7 also suggests that the aerosol sealing protocol provides the most benefit when applied to wrapped sheet-metal duct systems. Figure 8 makes it clear that the aerosol injection time represents a larger fraction of the sealing process for ductboard systems, however it should

Table 2. *Time-Activity Results for FPL Field Test of Aerosol Protocol (38 houses)*

	First 21 Systems		Next 17 Systems	
Activity	Mean Time [person-minutes]	Standard Deviation [%]	Mean Time [person-minutes]	Standard Deviation [%]
Set Up	50		40	35
Register Sealing	90	82	44	
Heat Exchanger Sealing	40	45	32	66
Aerosol Injection	98	53	97	77
Conventional Sealing	70	40	58	66
Clean Up	88	51	52	
TOTAL[a]	**366**		**265**	
Conventional Estimate	**567**		**689**	

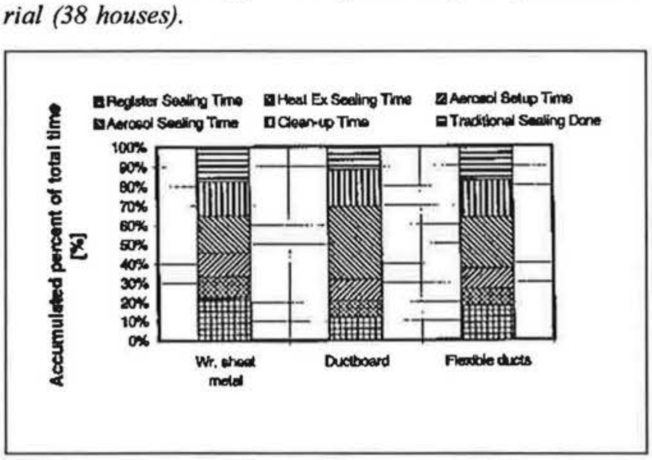
[a]Assuming that conventional sealing is performed during the aerosol injection process.

Figure 7. *Comparison of time requirements for conventional sealing and the aerosol-sealing protocol for three types of duct material.*



NOTE: The aerosol sealing times assume that the conventional sealing associated with the aerosol protocol is not performed during aerosol injection (38 houses).

Figure 8. *Breakdown of time requirements for each activity in the aerosol-sealing protocol for three types of duct material (38 houses).*



be noted that those systems were considerably leakier than the other types of systems (see Table 1).

Utility-Bill Analysis

A relatively crude analysis of the utility bills for the summers before and after sealing was performed. In this analysis, the total electricity use for 37 of the houses whose ducts had been sealed (those for which the full data set was available) was compared for the summers directly before and after sealing, as were the cooling degree days for the two periods. The result was that the average electricity consumption for July, August, September and October for the 37 houses was reduced by an average of 100 kWh per house, whereas the integrated cooling degree days for the post-retrofit period was 2297°F-days, as compared to 2143°F-days for the pre-retrofit period. Assuming that 60% of this electricity consumption was due to air-conditioning, the electricity consumption for the post-retrofit period should have been approximately 400 kWh higher. Thus our best estimate of the average energy savings associated with the retrofit is approximately 500 kWh, or 10% of the average electricity consumption for air conditioning. More detailed analysis of this data taking into account the variability in the degree of sealing, and utilizing cooling-degree-day data and electric consumption data on a finer scale is underway.

CONCLUSIONS

Several conclusions can be drawn based upon the field study results presented in this paper. The first and most significant conclusion is that the aerosol-based sealing technology can be used to seal residential ductwork on a production basis. The average time required for the complete sealing protocol, including conventional sealing (mostly of return platforms) was 5.5 person hours per house (assuming that conventional sealing is performed on the return side while the unit is sealing the supply side). Moreover, when choosing to seal platform returns with conventional mastic and fiberglass tape, the aerosol was capable of sealing approximately 80% of the leakage it encountered within approximately 1–1.5 hours of aerosol injection. For comparison purposes, residential duct sealing programs using conventional sealing generally seal 60–70% of the leakage encountered.

The second conclusion to be drawn from this field study is that the aerosol technology can significantly reduce the time required for sealing, while at the same time providing verification of that sealing. For the first half of the houses tested, the aerosol protocol required an average of 6 person-hours versus an estimated 9.5 person-hours for the conventional-only sealing protocol, whereas for the second half of the houses, the numbers were 4.7 and 11.5 hours respectively, representing a 60% reduction in labor. Moreover, the aerosol protocol yields a verification of the sealing (and could provide "signature" plots of the sealing process), whereas the extra time required for testing in and testing out was not included in the conventional-only protocol. As the material costs for the aerosol protocol are also lower than the material costs for conventional sealing, the overall cost for the aerosol sealing protocol could be significantly lower than conventional sealing costs (possible differences in the required degree of skill and training of the installers makes it premature to draw definitive conclusions on overall costs).

The third conclusion is that the aerosol can be used to seal systems constructed of most common duct materials encountered in residences, including sheet-metal, plastic flexduct, or ductboard. These field tests indicated that for the first half-hour of injection, the aerosol technology sealed 90 cm^2

of duct leakage per hour in sheet-metal systems, 70 cm^2/h for ductboard systems, and 60 cm^2/h for plastic flexduct systems. These rates were reduced to 45, 30 and 18 cm^2/h respectively for the second half hour of injection time. These results require further analysis to ascertain whether the observed differences are due the duct material, or stem from other differences between the houses/systems. Such analyses should also be made to explain the large observed variability in observed aerosol-injection times.

The final conclusion to be drawn from this study is that a significant majority, approximately 75%, of the time associated with the aerosol sealing protocol employed was not associated with injecting aerosol, but rather with set-up and clean-up. This suggests that future efforts should focus on those aspects of the process. At least for houses with platform (or other short easily-accessible returns), the time associated with conventional sealing, which could be performed simultaneously with aerosol injection, is comparable to the length of the aerosol-injection period.

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