SMUD's New Residential Duct-Improvement Program Using an Aerosol-Based Sealant

Rick Kallett, Ed Hamzawi, Craig Sherman, and Janis Erickson
Sacramento Municipal Utility District

ABSTRACT

The Sacramento Municipal Utility District (SMUD) initiated a program in June 1999 to stimulate the local market for residential duct-improvement services. Considerable evidence collected over the last 10 years indicated significant potential for energy savings by improving duct efficiency of forced-air distribution systems.

SMUD chose to implement its program around a newly commercialized aerosol-applied vinyl-polymer sealant that is injected into pressurized supply and return ducts. Developed by Lawrence Berkeley National Laboratory (LBNL), the technology was licensed for commercialization in 1997. Field testing by several utilities and contractor franchises established around the country have demonstrated the technology's performance.

To help jump-start the Sacramento market, SMUD contracted with the LBNL licensee to sell and maintain four contractor franchises in the utility's service territory and to train contractor sales staff and technicians. SMUD is also offering financial incentives to participating contractors and customers, providing customer leads to contractors, publicizing the program, and educating customers about the benefits of duct sealing.

This paper describes the program and discusses findings thus far with respect to specific program objectives.

Introduction

This paper describes the first large-scale utility program that promotes residential duct sealing specifically using a sealant injected into forced-air distribution systems of existing homes. The Sacramento Municipal Utility District (SMUD) hopes to stimulate the local market for residential duct-improvement services in general and sees this new technology as an opportunity to pursue its goal. SMUD is a public-power electric utility serving the more than 500,000 customers in California's capital city.

The aerosol-applied sealant is a non-toxic vinyl polymer injected into pressurized supply and return ducts. With all registers sealed, adhesive particles 2-20 μm in diameter are kept in suspension by a blower. As the pressurized air is forced out through leaks, the sticky particles deposit along the leaks' edges, eventually building up across and sealing leaks as large as 1.6 cm (⅝-in.) in diameter (Modera & Carrie, 1995; Bourne & Stein 1999). Developed by Lawrence Berkeley National Laboratory with funding from the California Institute for Energy Efficiency, U.S. Environmental Protection Agency, Electric Power Research Institute, and U.S. Department of Energy, the technology was licensed for commercialization in 1997.

SMUD chose to implement a residential duct-improvement program based on the aerosol technology because it appeared to offer several advantages over conventional duct-sealing methods. *Faster process:* Field tests demonstrated significantly less time for sealing

than conventional methods. *Measured verification:* The aerosol-technology protocol includes an initial, measured diagnostic test and pre- and post-sealing measurements, all of which are displayed on a lap-top computer and printed out on-site. *Inaccessible leaks:* The aerosol technology provides the only method by which to seal ducts in wall cavities and other inaccessible locations. *Greater savings:* As field testing found, the aerosol-sealant technology was more effective than conventional sealing methods. *Unique, valuable customer service:* In addition to duct sealing and repair, the protocol offers consumers measurable verification and safety testing.

Duct leakage is a significant waste of energy because a significant fraction of the heated or cooled air being delivered is lost to unconditioned space. In Sacramento, duct leakage of 24 existing homes was found to average 18% of supply fan flow and 17% on the return side (Jump, Walker & Modera 1996, 1.151). Neme, Proctor, and Nadel (1999) listed 19 studies, both measured and modeled, of existing and new homes conducted since 1992. These studies found duct losses representing HVAC energy-savings potential of 15-20%. Reviewing six of these same studies, Bourne and Stein (1999, 2-3) concluded that, on average, about 18% of HVAC energy usage is wasted by leaky ducts.

The aerosol-sealant technology was field tested in several locations. The first field prototype was applied to 47 homes in Florida (Modera et al. 1996). Duct leakage was reduced an average of 80% within 1-1½ hours of sealant injection, compared to 60-70% leak reduction from conventional sealing methods (visual inspection, mastic and fiberglass repair of large leaks in ducts and plenums). Researchers also found significantly less time required to seal ducts compared to conventional methods. The aerosol-technology protocol included manually repairing large leaks and measuring before and after leakage; the conventional protocol did not include measurement. A second field study of 23 Northeastern and Midwestern homes had similar results (Modera, Dickerhoff & Wang 1997).

This field research suggests that the aerosol technology may be less costly than conventional sealing methods—because of less time required to seal ducts—and is more effective. Unfortunately, research allowing direct cost comparison between the two methods is limited, in part because protocols and sample characteristics vary. For example, Lerman (1998, 2.120-21) reported an average contractor cost of $450 for sealing ducts of 194 centrally heated homes using conventional methods in a Tacoma pilot program. Costs varied widely, with the average cost reflecting some utility cost-control oversight. In Sacramento, researchers found the range of contractor costs was $335 to $1,069, averaging $635, for conventional duct sealing plus duct insulation in 24 homes of varying size and heating and cooling equipment (Jump, Walker & Modera 1996, 1.154). By comparison, cost of the aerosol technology was estimated at $400-$700, but included other duct diagnostics (Modera 1998, 3-72). Duct-sealing is part of California's Residential Contractor Program (RCP). RCP's duct sealing is independent of sealing method, but requires pre- and post-sealing leakage measurement, and offers a future opportunity for comparing benefits and costs of duct-sealing methods. However, savings and cost data are not yet available (Spivey 2000) for proper comparison nor is a comparative study the purpose of SMUD's program or this paper.

Program Description

SMUD introduced its duct-sealing program in June 1999 for the purpose of encouraging a residential duct-improvement-services market in Sacramento. The program's

objectives were to (1) develop a sustainable contractor base that provides duct-improvement services, (2) develop customer awareness of and sustainable interest in such services, (3) identify and track any changes in the cost of duct improvements, (4) quantify duct leakage in participating homes before and after improvements are made, and (5) determine energy savings due to the improvements. The last objective will be assessed after a full year's worth of electric bills have accumulated.

SMUD contracted with the aerosol-sealant licensee to sell and maintain franchises in SMUD's service area and to train contractor sales staff and technicians. After introducing the aerosol process (sealant equipment, computer program, and installation process) in a meeting of interested local contractors, the first four franchises were established. Contractors entered into a participation agreement with SMUD, enabling them to offer customers a reduced rate for a set of diagnostic tests and a customer rebate for recommended sealing work. SMUD covers $50 of the diagnostic tests and the customer pays $25. Customer rebates of $400 were available for the first 11 months of the program and then reduced to $200 for the remainder of 2000. The four contractors also received a 50% discount on the $20,000 franchise fee and a guarantee from SMUD for payment of franchise royalties in the event a specified activity level was not maintained for the first six months. SMUD is providing contractors with leads and marketing the program.

Interested customers call SMUD and are then referred to contractors on a rotational basis to schedule diagnostic tests. A contractor's sales person conducts five tests: duct-leakage analysis, register-temperature test, room air-flow test, return-air performance test, and combustion air-pressure safety test. A report is printed from a lap-top computer, identifying problems and indicating potential causes and solutions. The customer then receives a contract proposal and cost estimate.

If the customer approves the contractor's proposal, a second visit is needed to do the work. A two-person repair crew sets up the aerosol-injection equipment, consisting of a variable-speed fan, high-pressure pump to atomize the sealant, and electric heater to evaporate moisture from the sealant particles, all controlled by the same or similar lap-top computer. The crew connects the aerosol-injection equipment to the distribution system through a hole cut in a plenum, temporarily blocks off all registers, pressurizes the system, and measures total existing leakage (supply, return, equipment, and boots). Supply and return registers are then sealed with foam plugs and the coil and air handler are isolated before injecting sealant. Manual duct repairs are also made, as necessary, before or during the aerosol sealing. All boots are also manually sealed. As sealant is injected and leakage decreases, the computer measures the resulting increase in pressure and graphs the declining leakage over time in units of cfm. When sealant injection is complete, total leakage is again measured. The customer is then presented with a certificate of completion and a document showing the amount of leakage before and after sealing. A rebate application is completed by the customer and contractor and submitted to SMUD for payment.

Even before SMUD could begin marketing the program, a news report appeared in the regional newspaper. Describing differences between the aerosol and manual types of duct sealing, costs and SMUD rebates, and the value to the customer, the article generated several hundred leads. As appointments were scheduled and the backlog thinned, SMUD more formally introduced the program with a press release, following this with a direct-mail piece targeted to high-use customers, an article in the utility-bill newsletter, and booths in regional home-improvement shows. An on-site demonstration was also staged at a

customer's home, providing additional press coverage that included local television and radio stations. Targeted direct mailing is used to maintain a generally consistent flow of customer interest and leads. Intermittent contractor marketing also contributes as needs arise.

Progress to Date

This section describes the program's progress to date in terms of meeting the first four objectives, each of which is defined by several indicators.

Sustainable Contractor Base (Objective 1)

Facilitating a sustainable base of contractors to market and provide duct-improvement services is a long-term objective for which it is too early to draw conclusions. We are, however, monitoring several conditions that suggest progress toward this goal.

Number of participating contractors. As mentioned in the previous section, the program began with four contractors in June 1999. Three more contractors expressed an interest in participating, and paid the full franchise fee. Several of the seven contractors have purchased additional equipment and expanded their service to two sales people and even two installation crews. SMUD's program budget for 2000 limits participation to seven contractors. According to the distributor's Web site, there were 14 other franchises around the country, three of which were in California, as of May 2000 (Aeroseal 2000).

Contractor activity. As sales and installation personnel gain experience, contractors become more efficient at delivering the service, and customer demand increases, we would expect to see sustained if not increasing levels of activity. Applications submitted for diagnostics and sealing rebates are shown in Figure 1. Although jobs were completed in June 1999, rebate applications were not received until the following month. Additionally, time lags resulted from sealing jobs occurring sometimes weeks after the diagnostics were performed, and some contractors delayed in turning in their applications for the diagnostics rebate. Time lags notwithstanding, Figure 1 shows a steadily increasing level of activity. Through April 2000, contractors completed diagnostic tests in 1,323 homes, of which 593 have so far resulted in sealing jobs. Even as three contractors were added in January, sealing jobs completed per contractor each month increased from an average 8.6 over the first seven months to an average of 21.3 in the following four months (January-April). Similarly, the ratio of aerosol duct-sealing jobs per diagnostic test increased from an average

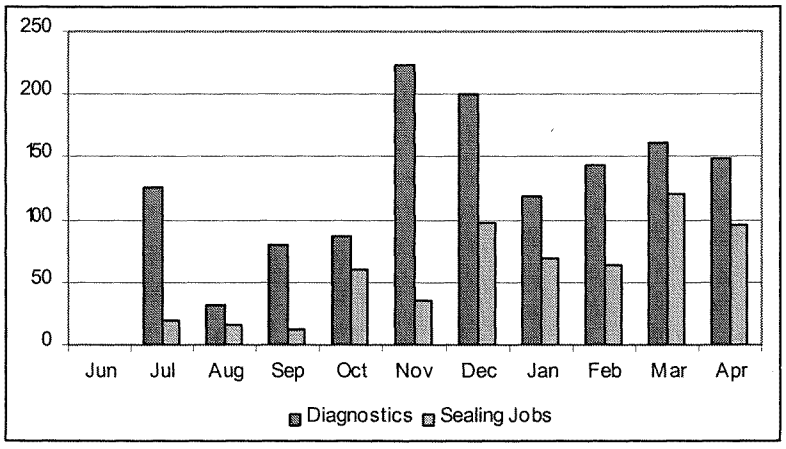

Fig. 1. Number of Diagnostic Tests and Sealing Jobs Completed in the Program's First 11 Months, 1999 -2000

of 32% over the first seven months to 61% in January-April. In sum, total activity and activity per contractor increased over the program's first 11 months.

Significantly, some contractors have been using the duct-sealing service as an opportunity to sell additional services. Table 1 lists additional work not directly related to duct sealing that contractors have sold along with the 593 total aerosol-sealing jobs.

Table 1. Additional Services Sold by Contractors to Aerosol Duct-Sealing Customers, June 1999 – April 2000

Additional Services	*Jobs*	*Additional Services*	*Jobs*
Clean ducts	187	New thermostat	43
New HVAC system	82	New S/R duct system	23
Electro-static filters	78	New supply ducts	23
HVAC-system service	46	Miscellaneous	200+

Contractor marketing. The ability of contractors to obtain their own leads is a clear sign of a sustained contractor base. Although SMUD is initially supporting contractors with marketing and soliciting customer leads, this support will eventually end. Frequent conversations with contractors and an informal survey of contractors during the last week of February indicated that most contractors were supplementing SMUD leads and marketing with their own efforts. For the majority of contractors, SMUD leads comprised 85% or more of their appointments for diagnostic testing. For some contractors, leads were generated from their service crews, company Web sites, and Yellow Pages listings. Some tried telemarketing and door hangers. One contractor reported 90-95% of leads were self-generated using a variety of techniques. Nearly all have plans for future marketing, including telemarketing, direct mail and calls to their customer bases, and recommending sealing when service crews replace furnaces and air conditioners.

Contractor profit. Obvious evidence for a sustained contractor base is whether the contractor is grossing enough revenue to offset the original franchise costs as well as day-to-day operational costs. In our informal contractor survey in February, all contractors reported making progress toward paying off their original investment. Indeed, it appears that they are incorporating the sealing process more into their overall business, in that aerosol sealing of ducts is being sold increasingly along with central heating/cooling system replacement.

Effect of reduced rebates. Eventually, SMUD will eliminate the contractor rebate for diagnostics-tests and consumer rebate for sealing. How well contractors will be able to sell this service without SMUD's financial support is a significant question in terms of a sustained market. Unfortunately, the answer will not be known at least until later this year, after consumer rebates are reduced to $200, or later when they are eliminated.

Customer Awareness and Interest (Objective 2)

Surveys and program records were used to monitor several indicators of customer awareness of and interest in duct-improvement services and the aerosol-sealant technology.

Customer awareness. In Fall 1999, we conducted a survey among the first 140 program participants, of whom 96 (69%) responded. The purpose of this telephone survey was to obtain early customer feedback on program awareness and satisfaction. Note that there were only four contractors at this point in the program.

One question asked customers whether they had concerns about their homes' duct efficiency before they were aware of the SMUD program. Concern was expressed by an unexpectedly high 72% of respondents. It was likely that these initial participants called for the diagnostic test because of their greater awareness and concern compared to the general population. A second participant-awareness survey will be conducted in Spring 2000 and again at one or more later dates to monitor changes.

Response to solicitations. Just as the program was beginning, several news articles in the local press resulted in nearly 250 unsolicited requests for diagnostic tests, keeping contractors busy through August. A September mailing to the 6,300 highest-usage customers netted a response of 3.7%, a rate more than double most SMUD-program direct-mail solicitations. Supplemented by interest generated from an October utility-bill newsletter, an earlier press release, and radio and television coverage, contractors' schedules were subsequently filled through December. A second promotional mailing to the next tier of 10,200 high-usage customers resulted in a response rate of approximately 2.4%, although at this point it becomes difficult to clearly distinguish the impact of previous and supplemental marketing. SMUD promoted the program at several home shows during January and February, and a bill insert was mailed to all residential customers during March, providing leads well into the summer. Direct mailings will continue to be used to sustain customer interest and to supplement the contractors' own leads through the rest of the year. Thus far, customer interest and response has been sufficient to generally maintain contractor work.

Customer satisfaction. A positive interaction between the contractor and consumer is a key to sustained customer interest and a sustainable business for contractors. The survey asked participants for their reactions to the contractor representative conducting the diagnostic tests. Figure 2 suggests that participants were moderately to very satisfied with their contractor in terms of knowledge and experience, how adequately things were explained, courtesy and professionalism, and honesty. The data indicated no significant distinction between the four contractors. Follow-up surveys will query customer satisfaction with the sealing work and longer-term results.

An important aspect of the contractor-customer relationship and the aerosol-technology protocol is on-site use of the lap-top computer to demonstrate visually the measured extent of leakage. The survey asked for participants' impressions of the printed report they received after the diagnostic tests were completed. As shown in Figure 3, the computer-generated diagnostics report was well-received by participants.

Acceptance of recommendations. The Fall 1999 survey also asked participants what the contractor recommended to them as a result of the diagnostic tests. For the 90 respondents to this question, sealing supply and/or return ducts were recommended in 53% of the homes. In 22% of the cases, repair and/or improvements other than sealing, such as replacing existing ducts, replacing the entire heating/cooling system, or installing a CO detector, were recommended. No work was recommended in 25% of the homes.

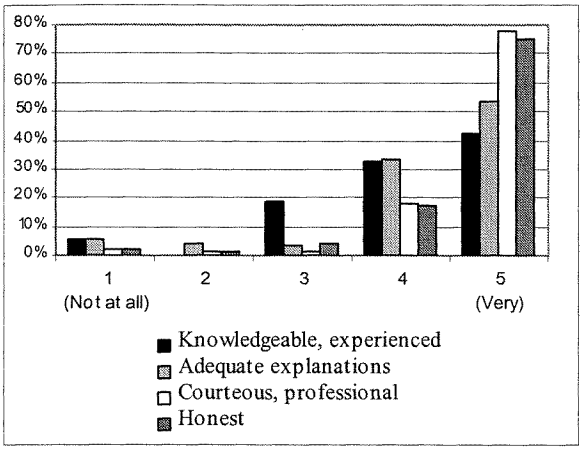

Fig. 2. Participants' Assessment About the Contractor Who Conducted the Diagnostic Tests On Their Home

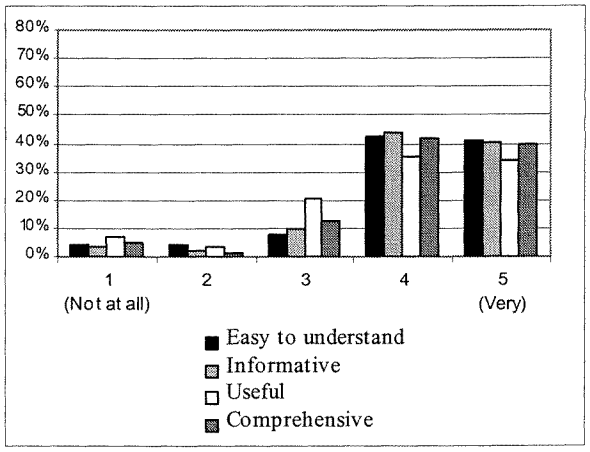

Fig. 3. Participants' Impressions of the Diagnostic-Tests Report of Their Home

Survey respondents were asked whether they proceeded or planned to proceed to have some or all of the recommended work done. Of the 67 respondents to this question, 60% stated that they did or will have the work done. The survey also asked for their reasons for proceeding or not proceeding with the work (multiple reasons were possible). Figure 4 indicates the frequency of reasons for customers accepting the work. Clearly, comfort ("increased comfort," "better airflow") and energy use ("more efficient system," "use less energy") were the prime drivers of this initial group of participants. Of those survey respondents who chose not to proceed with the recommended work, a large majority (65%) stated that it was too expensive.

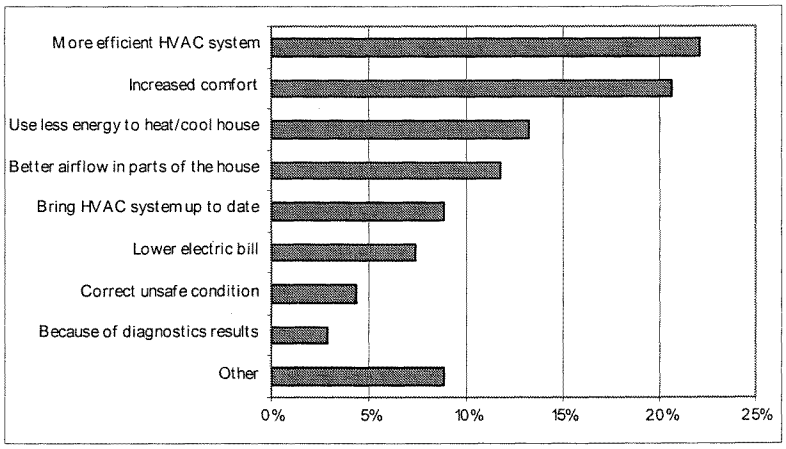

Fig. 4. Reasons for Participants' Decision to Proceed With the Recommended Work

Expectation of costs. Clearly, customer cost as a function of the value received is a significant determinant in establishing and sustaining customer interest. Although limited in its scope, we asked a series of questions that probed at this relationship. After they were reminded that SMUD was paying a portion of the cost for the diagnostic test (they also may have remembered from news stories that SMUD was paying $50 of the $75 cost), in addition to their $25 cost, participants were asked how much they would be willing to pay if they had to pay the full cost of the diagnostics test. Their response, shown in Figure 5, indicates that

57% of respondents would be willing to pay more than the current $25 charge for the diagnostic test, and that 16% perceived the value of the test to be more than the $75 cost.

Two other questions asked participants for the amount of their contractor's job estimate and how this estimate compared to their expectations. Figure 6 compares contractors' job estimates with participants' expectations. To most survey respondents (63%, n=55), job estimates were higher than expected. As with the diagnostics-test cost, participants were aware of expected pre-rebate duct-sealing costs; the June news article, for example, cited $600-$1,000 and SMUD marketing claimed $800-$1,200. Many of the job estimates, however, included other work, such as entire duct and even central-system replacement, which explain the values at the high end of Fig. 6. Still, as indicated earlier, 60% of survey respondents to whom contractors provided estimates chose to have the work performed.

Cost of Improvements (Objective 3)

Consistent tracking of costs has been difficult because each contractor records job estimates differ-

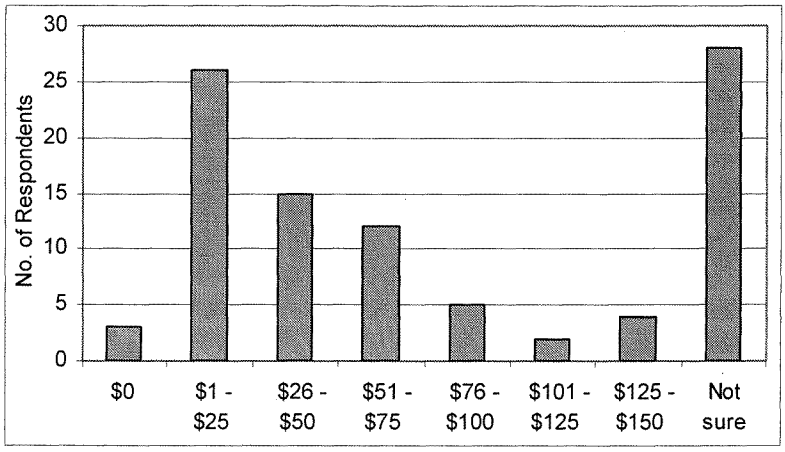

Fig. 5. The Full Cost Participants Would Be Willing to Pay for the Diagnostic Test

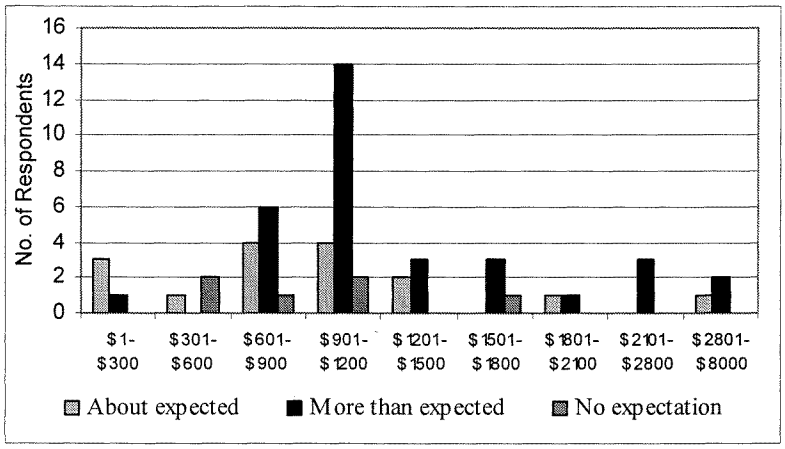

Fig. 6. Participants' Expectations of Their Contractors' Cost Estimates (includes improvements other than sealing)

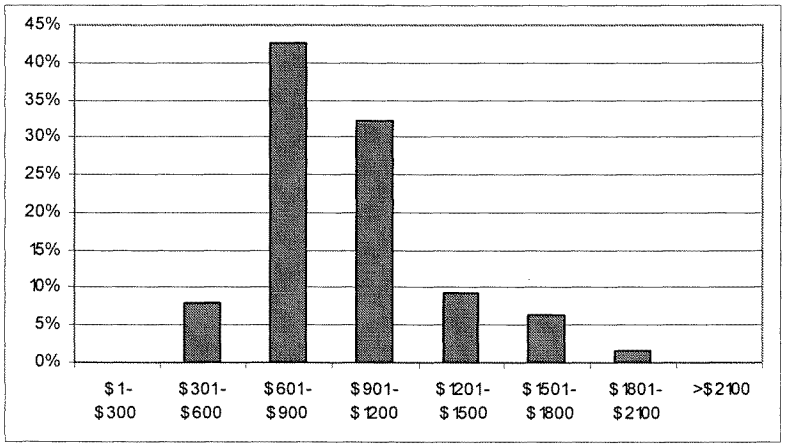

Fig. 7. Aerosol Duct-Sealing Costs, June 1999 – March 2000 (mean = $1,009, median = $900)

ently. For example, in their job estimates, contractors do not always separate cost of sealing from other work, such as installing duct insulation, electro-static filters, or heating/cooling-system replacement. Nonetheless, through March 2000, there were a sufficient number of jobs with cost data on the sealing portion of each job that the sample size is relatively large (n=127). Overall aerosol-sealing costs are shown in Figure 7. Average job cost was $1,009; a few jobs included more than one air-distribution system. Average cost for each of the four contractors for whom we have the most cost data varied from $872 to $1,119.

Average monthly aerosol-sealing job costs rose over the first six months of the program, as shown in Figure 8, and then leveled. One possible reason for this is that customer rebates were increased from $200 to $400 effective September 1, which may have induced contractors to increase their prices. Although rebates were reduced back to $200 as of May 1, 2000, data are not yet available to conclusively identify long-term trends in job costs and potential effects from rebates; this will continue to be tracked.

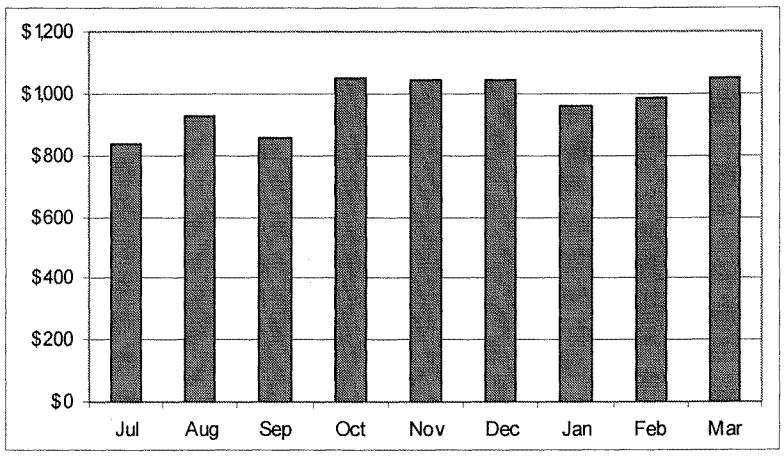

Fig. 8. Average Cost of Aerosol Duct Sealing, All Contractors, 1999 - 2000

Duct Leakage (Objective 4)

Measuring duct leakage before and after sealing is an important element of this program, in terms of verification for SMUD and the customer as well as a "sales tool" for the contractor. Pre- and post-sealing leakage measurements are stored in each contractor's lap-top computer and periodically downloaded to a central database at the licensee's offices and subsequently shared with SMUD program staff. To quantify leakage before and after aerosol sealing, data covering the first eight months of the program were evaluated. These data provided complete information on pre- and post-sealing leakage rates, supply-register airflow measurements, and air-conditioner tonnage for 121 sites.

Within this sample, total pre-seal leakage varied widely, from 53 to 564 cubic feet per minute at 25 Pascals air pressure (cfm_{25}). Mean leakage per site was 220 cfm_{25} and the average leakage weighted by system capacity was 230 cfm_{25}. The wide variation in pre-seal leakage is partly the effect of varying system capacities, which ranged from two to six tons and averaged 3.6 tons. Adjusting for system capacity and using a typical design airflow rate of 400 cfm/ton, total pre-seal leakage averaged 16% of design airflow across the evaporator coil. Actual airflow, however, has been found to be less than design airflow due to installation, system configuration, and operating conditions. Using 320 cfm/ton (Parker et al. 1997) to represent more typical airflows, total pre-seal leakage averaged 20% of airflow. These values were still far less than identified in previous studies; for example, Jump, Walker, and

Modera (1996) found 18% average leakage in just the supply side and another 17% in the return.

Both the variation in the pre-seal leakage values and the relatively low average leakage rate suggested inconsistencies among contractors in applying the aerosol-technology field-measurement protocols. It appeared that some contractors performed manual repairs to the system prior to running the tests, while others reported leakage for only the supply or return side but not the total during the pre-seal phase of the process.

To further examine this issue, we used supply-register airflow data measured by the contractors using a flow hood during the diagnostic tests. From these data we derived estimates of total supply cfm/ton for each site. Figure 9 summarizes these results and clearly shows that the vast majority of the systems performed at levels significantly below recommended design specifications. The average supply airflow rate of the systems was 242 cfm/ton. At 320 cfm/ton, the average supply-side-only loss (leakage) was 24%. This value was much higher than the average of the recorded total pre-seal leakage values, providing greater evidence that contractors were under-reporting the pre-seal leakage rates.

The data also revealed that contractors were not consistently measuring total remaining system leakage during the post-sealing phase of the process as well. This can result in overstating the total leakage reduction and in missing leakage in other portions of the system.

Figure 10 compares the recorded pre-seal and post-seal leakage for the 121 sites in order of decreasing pre-seal leakage. Despite overestimating pre-seal leakage and underestimating post-seal leakage, Fig. 10 graphically demonstrates the relative extent to which leakage was reduced as a result of the duct-improvement measures and the aerosol sealant. The average reduction in duct leakage for all sites was 81%, which appears to be in line with earlier studies. SMUD and the aerosol-sealant licensee have been working with the contractors to ensure consistent use of measurement protocol.

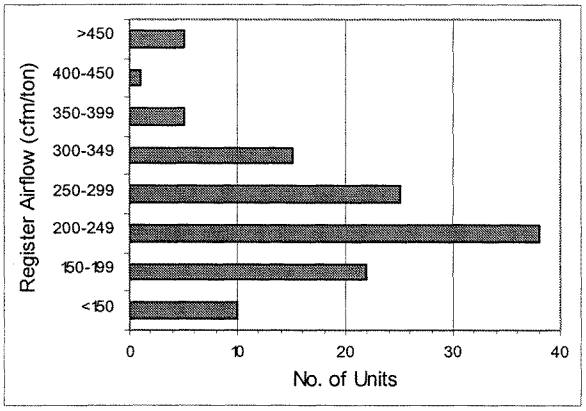

Fig. 9. Supply-Register Airflows Measured by Contractors at 121 Sites

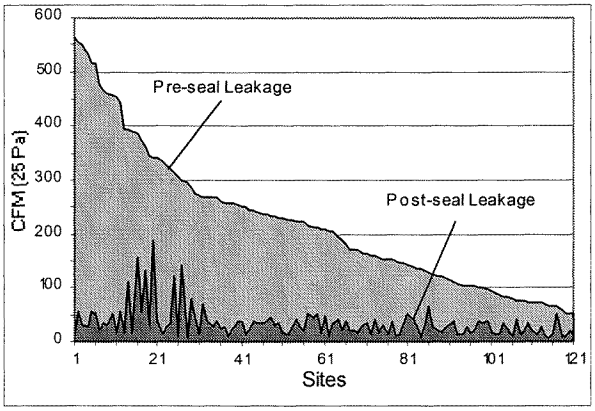

Fig. 10. Pre- and Post-Seal Leakage in Order of Decreasing Pre-Seal Leakage

Conclusions

SMUD's residential duct-improvement program appears to be off to a good start. The initial contractor base increased and is currently stable at seven. While the level of activity varies among contractors, all seven indicated progress towards recovering their initial

investment and a commitment to the technology and the process. Contractors increasingly incorporated the aerosol-sealing process into their overall business strategy and expanded their scope of services offered to their customers.

Responses to early press releases and information disseminated through the media and by direct mail indicated sufficient customer interest in the program. Customer satisfaction with contractors and the diagnostic report was very high. The majority of participants for whom the diagnostic test showed a need for improvement in their duct system proceeded with the aerosol sealing (and other repairs). Those who did not declined primarily because of cost considerations.

The average cost for the aeroseal process, $1,009, falls within the expected range ($800-$1,200). The average cost of an aeroseal job increased over the first six months of the program, possibly the result of an increase in customer rebates offered by SMUD.

Examination of the reported duct-leakage results before and after repair and sealing revealed inconsistencies in the data that resulted from contractors deviating from the established measurement protocols. Nonetheless, leakage reduction as a result of aerosol sealing and repair protocol appears to be significantly large.

In summary, SMUD is pleased with the progress that has been made to date in developing and implementing its residential duct-improvement program. Although several of the indicators of progress are based on preliminary data, the evidence suggests that the program is fulfilling the goals for which it was intended. Further monitoring and data collection activities are planned in the future to track the progress of the program and, in particular, measure energy savings, comfort, and other benefits to SMUD's customers.

Acknowledgments

The authors wish to thank the following individuals for their assistance in preparing this paper: Wim Bos, Mark Modera, and Carol Novak.

References

Aeroseal Inc. 2000. http://www.aeroseal.com/certifiedcontractors.htm. May 4.

Bourne, Dick and Jay Stein. 1999. *Aeroseal: Sealing Ducts from the Inside Out.* ER-99-16. Boulder, CO: E SOURCE, INC.

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." In *Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings*, 1.147-55. Washington, D.C.: American Council for an Energy-Efficient Economy.

Lerman, David. 1998. "Getting Our Ducts in a Row: Evaluation of the Tacoma Duct Sealing Program." In *Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings*, 2.115-26. Washington, D.C.: American Council for an Energy-Efficient Economy.

Modera, Mark. 1998. *Cited in* Steven Nadel, Leo Ranier, Michael Shepard, Margaret Suozzo, and Jennifer Thorne. *Emerging Energy-Saving Technologies and Practices for the Building Sector*. December 1998. Washington, D.C.: American Council for an Energy-Efficient Economy.

Modera, Mark and Francois Remi Carrie. 1995. "Aerosol-Based Duct Sealing Technology." *Center for Building Science Newsletter*, #5. Winter. Berkeley, CA: Environmental Energy Technologies Div., Lawrence Berkeley National Laboratory. (http://eande.lbl.gov/cbs/newsletter/nl5/duct.html)

Modera, Mark, Darryl Dickerhoff, and Duo Wang. 1997. *Field Testing of Aerosol-Based Sealing Technology*. LBL-39521. Berkeley, CA: Lawrence Berkeley National Laboratory.

Modera, Mark, Darryl Dickerhoff, Oddbjorn Nilssen, Holly Duquette, and Jan Geyselaers. 1996. "Residential Field Testing of an Aerosol-Based Technology for Sealing Duct-work." In *Proceedings of the ACEEE 1996 Summer Study on Energy Efficiency in Buildings*, 1.169-75. Washington, D.C.: American Council for an Energy-Efficient Economy.

Neme, Chris, John Proctor, and Steven Nadel. 1999. *Energy Savings Potential From Addressing Residential Air Conditioner and Heat Pump Installation Problems*. Washington, D.C.: American Council for an Energy-Efficient Economy.

Parker, D.S., J.R. Sherwin, R.A. Raustad, and D.B. Shirey, III. 1997. "Impact of Evaporator Coil Air Flow in Residential Air Conditioning Systems." FSEC-PF-321-97. Cocoa, FL: Florida Solar Energy Center. (http://www.fsec.ucf.edu/~bdac/pubs/PF321/PF321.htm)

Spivey, Keith. 2000. Personal communication. San Francisco, CA: Pacific Gas & Electric. May 19.