# Getting Our Ducts in a Row: Evaluation of the Tacoma Duct Sealing Program

*David Lerman, Tacoma Power, Tacoma, WA*

**ABSTRACT**

In 1995 Tacoma Power initiated a test of residential duct sealing to determine the feasibility of a full-scale program to improve the duct system in customer homes with central system electric heat. The Residential Duct Sealing Pilot Program was designed with six main goals: 1) determine the typical reduction in heating energy use attributable to eliminating or reducing duct leakage in residential customer central heating systems; 2) determine the cost-effectiveness of the program, including the cost of administration of the program and measure installation; 3) determine if local contractors were able to install duct sealing measures; 4) assess the level of customer acceptance of the program; 5) establish the relationship between reduction in duct leakage and heating energy use reduction; and 7) determine if there is a difference between weatherized and non-weatherized homes in their heating energy use reduction under the program.

Energy Services staff at Tacoma Power performed an evaluation of heating energy use reduction patterns for program participants and a comparable group of non-participants. Weather-adjusted changes in consumption between pre- and post-participation periods were calculated using the Princeton Scorekeeping Method (PRISM).

Staff also conducted an analysis of program costs from program records. Finally, Energy Services commissioned a telephone survey of program participants by a local market contractor to obtain participant ratings of the program.

Integrated results of these three studies form the basis of the present report.

## Introduction

In homes with central heating systems, air heated by a furnace or heat pump passes through a series of metal or composite plastic/metal ducts to deliver conditioned air to living spaces[1]. Either through faulty construction when the system was installed or through deterioration over time, this duct system develops leaks, resulting in a loss of system efficiency: a portion of the heated air never reaches its intended destination. All ducts exhibit some degree of leakiness, but most furnace systems are able to compensate for small leaks by operating for longer periods, making it unlikely that the house occupants will notice the leaks. This compensation by the heating system results, of course, in higher heating costs, but most homeowners have no ready means to determine the extent to which their duct systems are leaking heated air.

In the past ten years new techniques have emerged which make it possible to easily identify and remedy leaky duct systems. The remedies consist of plugging holes in the ducts using mastic compound or long-life duct tape, or reconnecting portions of the system which have become disconnected over time or were never properly connected in the first place. Much of the early work in duct sealing was carried out in the southeast part of the United States, where central cooling is

[1] This condition applies to both heating and cooling systems. Research covered in this report deals only with central heating systems because residential central cooling is relatively uncommon in the region where Tacoma is located, the portion of the Pacific Northwest west of the Cascade Mountains.

relatively common and energy reductions from improvements to the duct system can be derived from both the heating and cooling modes of the systems.

Tacoma Power has been weatherizing customer residences and inspecting new homes for Energy Code compliance since the early 1980s. Program staff has reported serious shortcomings in customers' duct systems, even in newly constructed homes. Based on these reports and on information on duct sealing programs from other utilities, Tacoma Power determined that very little information was available on actual reductions in energy use which resulting from improvements to duct systems.

In early 1995 the Conservation Section[2] at Tacoma Power implemented a test of a residential duct sealing program. This test, referred to in the present report as the Residential Duct Sealing Pilot Program, was carried out in 1995. The test was run to gather the following information: 1) determine the level of energy savings from duct sealing; 2) determine cost-effectiveness of the measure and administrative costs of the program; 3) determine if local contractors were able to install duct sealing measures; 4) assess the level of customer acceptance of the program; 5) establish the relationship between reduction in duct leakage and energy savings; and 6) determine if there was a difference in the energy use changes for weatherized versus non-weatherized homes. This last goal of the program could only be attained if sufficient numbers of both types of homes participated in the pilot program.

In the period during which the Pilot Program operated, 194 homes were treated. Staff visited a total of 400 homes in the course of the program. Participants were screened on several criteria prior to the field visit: 1) central electric heating system with ducts in unheated and accessible spaces; 2) no combustion appliances[3]; 3) single family dwelling, mobile/manufactured homes excluded; and 4) owner-occupied.[4]

During the period that the Pilot Program operated the cost of the measures and program administration was subsidized wholly by Tacoma Power. No financial contribution was required of program participants.

## Program Description

The Energy Services Office maintains a database of homes which have been weatherized under the utility's Residential Weatherization Program. Dust Sealing Program solicitation letters were mailed to customers on this list. The solicitation letter described the duct sealing process and requested that those interested call the utility for information and to schedule an appointment for a staff visit. Non-weatherization customers were recruited for the Pilot Program through a single newspaper ad in the Tacoma News Tribune and through promotion by the utility's field representatives. Interest in the program was also generated through a News Tribune article describing the program. Of these approaches the News Tribune article produced the most customer calls about the program.

Initial screening for Tacoma Power customer status and central electric heat was carried out by the Energy Services receptionist. Customers passing the initial screen were entered into the Duct Sealing Program tracking system, the customer was assigned to a Residential Field Representative, and a visit to the home was scheduled.

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[2] The functions of the Conservation Section were incorporated into the new Energy Services Section in October 1996. For the sake of consistency the unit is referred to as Energy Services throughout the present work.

[3] Initially this was interpreted to mean no wood heat and no gas water heaters. This criterion was ultimately relaxed so that those with infrequently used wood stoves and fireplaces and those with gas water heaters in garages were allowed to participate,

[4] This criterion was introduced to increase the likelihood of continual tenancy during the test period. It was subsequently relaxed to allow condominium residents to participate.

On the first visit to the home the Field Representative first determined that the residence indeed had central electric heat and that the major portion of the duct system was located in an unheated space. If these criteria were met a check was also made for the presence of combustion appliances. Having satisfied all of the requirements for participation, the Field Representative then carried out series of measurements to determine the leakiness of the duct system. These tests consisted of first depressurizing the house with a blower door, using a Pressure Pan test to screen for initial leakiness, and then measuring the air leakage of the duct system with a unit known as a Duct Blaster. Those houses with leakage above 200 cubic feet per minute (at 50 pascals) were deemed eligible for participation in the Duct Sealing Pilot Program.

A number of other tests were conducted on this first visit, tests which were specific to the Pilot Program and which would not be a part of an operational program. These additional tests posed demands on program staff which would be eliminated in actual implementation of the program.

The Field Representative explained the workings of the program to potential participants and the customer indicated a willingness to proceed. Initially each contractor was assigned five to ten customers who had expressed an interest in participating, and pertinent information on each assigned house, collected on a standardized reporting form was sent to the contractor. As Field Representatives continued to qualify homes the homes were placed on a list, and as soon as a contractor completed a job satisfactorily, he/she received a new work assignment from that list. This provided an incentive for the contractors to complete work on a timely basis.

All contractual arrangements were between the customer and the contractor, with the utility having no formal standing in the customer/contractor relationship. Once the contractor submitted a bill for work performed to Tacoma Power, the Energy Services Office arranged for an inspection of the job. If the work was deemed satisfactory Energy Services arranged for payment to be made to the contractor. As a part of the post-treatment inspection by Energy Services a second measurement of duct leakiness was made using the same equipment and procedures as were used in the pre-installation tests.

The four contractors participating in the program signed agreements with Tacoma Power which detailed methods, material specifications and procedures for the Duct Sealing Program. They were also required to attend utility-sponsored training conducted by Washington State Energy Office staff. Specifications for materials and procedures were patterned after those used in an earlier residential energy efficiency building code project sponsored by the Bonneville Power Administration, the Residential Construction Demonstration Program.

## Methodology

Tracking records for the program included customer name, address and account number, limited characteristics of the residence (square footage, furnace and thermostat characteristics), pre and post duct pressure and blower door measurements, contractor name, labor and materials costs, and whether or not the residence had been weatherized by Tacoma Power.

Approximately one year after all work had been completed on all 194 participants, energy consumption records were assembled for each house in the program. Daily average temperatures for Tacoma[5] were also collected.

[5] Tacoma Power has daily high and low temperatures from the weather station at the its Energy Control Center for the period August 1978 through the present.

Energy Services designed an instrument to measure customer satisfaction with the Duct Sealing Pilot Program and to assess customer expectations for the program and their hypothetical willingness to pay for a similar program. The questionnaire was developed by in-house staff and was administered as a telephone survey by a local market research firm to all 186 program participants who continued to reside in the homes on which the duct work had be performed. Of those 186, fully 125 completed the telephone survey, for a completion rate in excess of 67%.

With data on changes in heating system leakiness, changes in energy consumption, and customer assessments of the Pilot Program, all that was necessary for a comprehensive evaluation of the program was consumption information for a sample of comparable non-participants. This sample was selected from participants in Tacoma Power's 1990, 1992 and 1996 Residential Customer Characteristics Surveys. Billing histories were collected for those survey participants living in single family residences with electric furnaces. The 223 houses so selected were identified as a comparison group for the study. Electricity consumption for this group of homes would be compared to the pre- and post-consumption of the program participants to see how much the participants likely would have consumed had they not participated in the Duct Sealing Pilot Program.

## Findings

### Changes in Energy Use: Participants

Of the 194 participants in the Duct Sealing Pilot Program, 181 had a sufficient number of pre- and post-treatment electric bills to conduct an analysis of energy consumption. The houses which were not included in the analysis had too few meter readings in either the period before or the period after duct sealing. Only those houses with at least four readings in both the pre and post periods were included. With Tacoma Power customer meter readings occurring every other month, this meant that those houses included in the study had to have at least eight months of consumption data.

Meter readings for these 181 homes were subjected to a PRISM[6] analysis in order to be able to compare energy consumption for different time periods. PRISM is a straightforward tool for adjusting billing histories, and its workings and theoretical basis will only be briefly sketched here. PRISM uses heating degree days to adjust annual energy consumption so a particularly mild or harsh winter - in the case of studies of heating energy consumption - in either the pre- or post-treatment year will not distort the results of the savings analysis. All consumption is adjusted to what a particular house would have used in a *normal* weather year, normal being defined as the long-term average for a given locality. The resulting consumption is termed Normalized Annual Consumption, or NAC.

PRISM, in addition to calculating the NAC for each house in the study, also indicates how well the house's energy consumption follows the outside temperature. As the temperature falls, energy consumption should rise if the metered consumption is the only source of heat for the home under observation. PRISM uses heating degree days (HDD), the difference between a reference temperature, 65 degrees F, and the local average daily temperature, as a measure of the severity of the weather. The

[6] PRISM is an acronym for PRInceton Scorekeeping Method and is a method for accounting for the effect of annual temperature variations on energy consumption analyses. The tool was developed by the Center for Energy and Environmental Studies at Princeton University in the early 1980s. The Advanced Version used in the present study was co-funded by the Electric Power Research Institute (EPRI) and was released in April 1995. A useful bibliography of PRISM-related research is included in the PRISM documentation for the Advanced Version. A good introduction to the theoretical and practical underpinnings of PRISM is found in the 16 papers collected in Energy and Buildings, 9, #1-2, 1986, edited by Margaret F. Fels.

agreement between energy consumption and heating degree days is taken as a measure of the degree to which the house can be said to be well-behaved in PRISM terms. Houses whose consumption does not track well with heating degree days - e.g. houses whose consumption is relatively constant despite marked drops in outdoor temperature - cannot be examined using PRISM and are traditionally dropped from the analysis.

The 181 houses with sufficient bills for analysis were analyzed with PRISM, and it was determined that seven houses had changes in annual consumption in excess of 10,000 kWh. Of the seven, three saw a decrease in consumption greater than 10,000 kWh and four saw an increase. These were dropped from the analysis, along with an additional 12 houses whose consumption did not track with heating degree days.[7] This left 162 participant houses in the analysis set.

The average, or mean reduction in energy use for these 162 participants was 750 kWh per year. It should be pointed out that the variation in reduction was extraordinarily large. Energy use change in the analysis set ranged from a low of -9,890 kWh (i.e. this house used 9,890 kWh more after duct sealing than before) to a high of 9,247 kWh. In statistical terms, the standard deviation for change in energy use was over 3,000 kWh, four times the mean.

**Changes in Energy Use: Participants**

In order to assess what the participants would have done had they *not* participated in the program, we set out to create a comparison group of customers who were roughly equivalent to the participants but who had not taken part in the Residential Duct Sealing Pilot Program. In traditional evaluations of weatherization program savings, the use of non-participants has allowed researchers to estimate the impact of non-programmatic factors on energy consumption. These factors have typically included changes in general economic conditions, changes in utility rates, and broader societal trends, any of which might have an impact on energy consumption. The comparison group also serves as an additional weather-adjustment tool.

Because of a lack of housing characteristics for Tacoma Power customers at large, the Energy Services staff turned to residential customers who had responded to the utility's Residential Customer Characteristics survey in either 1990, 1992 or 1996. These surveys were administered to a random sample of Tacoma Power's residential customer base and included a range of questions on housing and demographic characteristics, including housing type, heating fuel and heat source.

In the three survey cohorts (1990, 1992 and 1996) there were 223 houses which were roughly comparable to the group of homes that participated in the Residential Duct Sealing Pilot Program. These houses were single family structures and were heated by a central electric furnace. There was no item in the survey which indicated whether the duct system was in a heated or unheated space, but it was assumed that this was not critical for the purpose of constructing a comparison group.

Attrition for the non-participant group was higher than for the participants, hardly surprising given the fact that seven years had passed since some of the survey respondents had last been contacted. Of the 223 homes initially selected for inclusion in the comparison group, 171 had sufficient billing history data in both the pre and post[8] periods for PRISM analysis.

[7] If the association between normalized annual consumption and heating degree days was less than .75, the houses were dropped from the study.

[8] Of course, there was no true "pre" or "post" period for the non-participants since they had not participated in the duct sealing program. For the purposes of this analysis 1995 was considered the "pre period and 1996 the "post" period for the non-participants. This corresponded roughly to the pre and post periods for the participants.

Non-participants were subject to the same screens for extreme changes in consumption and for poor association between heating degree days and consumption as the participants. This reduced the size of the comparison group to 138 houses.

Non-participant houses displayed the same large variation in pre to post annual changes in consumption as the participant group. After dropping extremely high and low cases and eliminating those houses whose consumption did not roughly follow heating degree days, changes still ranged from roughly -7,700 kWh to almost 8,300 kWh. Mean energy use change for the non-participant was -757, indicating that the average annual consumption for this comparison group actually *increased* by more than 750 kWh in 1996 compared to 1995 after adjusting for weather differences.

**Net Energy Use Change**

The table below compares the change in annual electric energy use for program participants and non-participants. In each group there are many whose consumption increased in the period after participation in the program[9], but the trend that emerges from the data is that more of the participants enjoyed reduced energy consumption, i.e. positive savings, than was the case for the non-participants: the participants reduced consumption by an average of 750 kWh per year, while the non-participants as a group increased consumption by roughly the same amount, or 757 kWh per year. The conventional interpretation of these two figures is that the participants would have increased their average consumption by the latter amount, had they not been involved in the program. In other words the net change for the Residential Duct Sealing Pilot Program is the difference between their change in consumption and the change for the non-participants.

**Table 1.** Changes in Pre- and Post-Program Energy Consumption

| Group | Size | Mean kWh Change | "Savings" Range (kWh) |
|---|---|---|---|
| Program Participants | 162 | 750 | -9,890 to 9,247 |
| Non-Participant Sample | 138 | -757 | -7,700 to 8,300 |
| Net Savings | | 1,507 | |

The net figure is derived by subtracting the average change for the non-participants from that for the participants:

$$[\text{Change}_{\text{participants}}] - [\text{Change}_{\text{non-participants}}] = \text{Net Change}$$
$$[750 \text{ kWh}] - [-757 \text{ kWh}] = 1{,}507 \text{ kWh}$$

**Cost Effectiveness**

Contractors charged an average of $450.73 to perform all tests and seal the ducts for all of the houses that participated in the program. Costs ranged from a low of $41.84 to a high of $1,263.51.

The single job at the low end of the cost spectrum is an anomaly and represents a house where very little work was performed. The higher cost jobs, those more than double the average cost of $450, either had significant repair costs included in the total cost of the work done on the house, were very

[9] In this and the discussions that follow we will continue to refer to 1995 and 1996 as the "pre" and "post" periods, respectively, even though there was no event for these non-participants which served as a reference for pre and post.

large homes with extensive duct systems, or were participants relatively early in the program when staff cost-control oversight was less stringent.

Interestingly, there does not appear to be any correlation between the cost of duct sealing on a particular house and the energy savings. The correlation between contractor cost and energy change is less than .03, where 1.0 would represent a perfect association between these two variables. Another way of expressing this relationship, or lack thereof, is to say that knowing how much money was spent on sealing the ducts in a particular house does not help at all in predicting how much reduction in energy use that house would enjoy.

The cost of conserved energy under the Residential Duct Sealing Pilot Program was calculated based on zero measure contribution by the utility, with Tacoma incurring costs only for the administration of the program and the *theoretical* cost of money for a zero-interest loan to the customer.[10]

Recalling that the mean job cost under the Pilot Program was approximately $450, we can calculate the cost of a zero-interest loan to Tacoma. The following discussion assumes that the cost of capital to Tacoma is 6% per annum, that the duct sealing work has a lifetime of ten years, and that the minimum loan payment is $20 per 2-month billing period. In order to simplify calculations we will calculate the cost of money to Tacoma based on a $480 loan with a term of 48 months. We then calculate the cost to Tacoma of a $960 loan with a capital cost of 6% per annum and a term of 96 months. The final calculation will be for a loan of $1,500 with the same cost of capital and a term of 10 years.

In addition to the capital cost of a zero interest loan to cover the contractor costs for each participant, Tacoma incurs costs in the form of staff and management hours for each job. An analysis of the costs of administering the Residential Duct Sealing Pilot Program revealed loaded staff costs of approximately $250 per house. Eliminating the extensive testing carried our to support the evaluation of the pilot would reduce the staff cost in an operational program to approximately $160 per participant.

Table 2 below shows the derivation of the levelized cost for duct sealing jobs of varying contractor costs, with administration costs assumed to be $160 per job. The Total Program Cost is the sum of the cost to Tacoma of the zero interest loan and administrative costs.

**Table 2.** Levelized Cost of Zero Interest Loan and Program Administrative Costs

| Measure Life (years) | Loan Amount | Loan Term (years) | Cost of Capital | Tacoma Loan Cost | Tacoma Admin Cost | Total Program Cost | Annual Savings (kWh) | Lev. Cost (mills) |
|---|---|---|---|---|---|---|---|---|
| 10 | $480 | 4 | 6% | $61 | $160 | $203 | 1,500 | 18.8 |
| 10 | $960 | 8 | 6% | $207 | $160 | $367 | 1,500 | 34.9 |
| 10 | $1,500 | 10 | 6% | $423 | $160 | $583 | 1,500 | 56.0 |

The high levelized cost for the largest loan is the result of the increased loan amount and the length of the loan. In order for this size and length of loan to meet the utility's cost-effectiveness

[10] There was no zero-interest loan under the Pilot Program since the utility covered all program costs. The calculations of levelized cost in this section assume that the operational program will include a zero-interest loan to cover the contractor costs on the customer's behalf. The administrative cost of the loan is found under "Tacoma Admin Cost" in Table 2.

criterion, some means of reducing either the amount or the length of the loan would have to be found. Alternatively, the participant could pay something toward the cost of the loan, thereby reducing the utility's costs. For example, a 4 percent loan (instead of 0%) would reduce the loan costs to the utility to $137, which when added to the administrative costs yields a total cost of $297, or just under 27 mills.

## Assessment of Contractor Performance

In the course of the pilot Tacoma Power enlisted the services of four contractors to implement duct improvements in customer homes. All four contractors participated in the Washington State Energy Office training offered through Tacoma Power, and all were able to perform satisfactorily under the guidelines and specifications established under the Pilot Program. Table 3 is a comparison of contractor participation, average cost and average energy reduction for those homes which were suitable for inclusion in the PRISM analysis[11].

**Table 3.** Contractor Activity and Performance

| Contractor | Number of Houses | Average Cost | Average Energy Reduction (kWh) |
|---|---|---|---|
| A | 63 | $487 | 843 |
| B | 51 | $402 | 685 |
| C | 32 | $531 | 179 |
| D[12] | 14 | $259 | 1,909 |
| All Contractors | 160 | $449 | 753 |

Based on this segmentation of a none too large total sample, it would not be prudent to draw overly confident conclusions about comparative contractor performance. For example, the apparently low cost and very high energy reduction figures for Contractor D are based on a very small number of cases. The relatively high cost and poor performance for Contractor C are likewise to be interpreted somewhat tentatively. It should be noted, however, that the cost levels for jobs by Contractor C were the subject of concern on the part of program management relatively early in the program and prompted discussions with that contractor and warnings that their costs were too high.

The conclusions of program staff and management at the end of the Pilot were that there was sufficient local expertise in duct sealing to warrant continuation of the program if other program success criteria were met.

## Change in Energy Use versus Duct Leakage

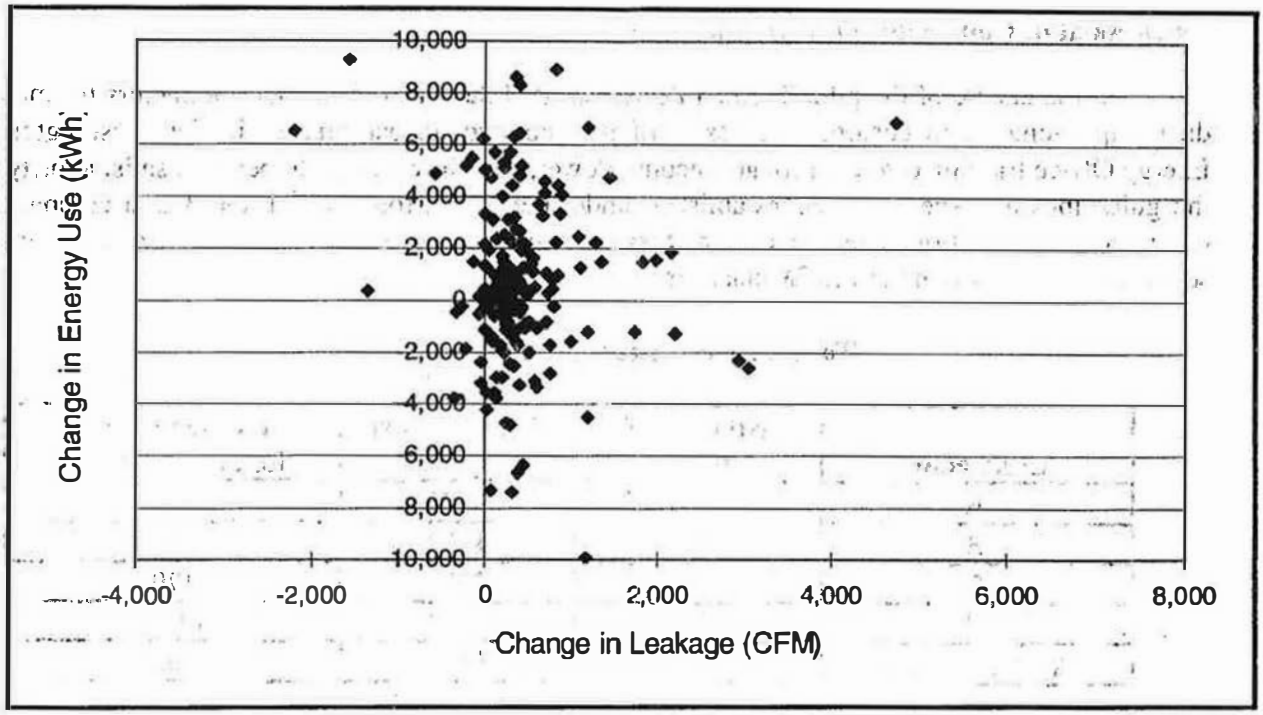
If we compare the results of the test of the duct system before any work was done on the house with the results of the same type of test conducted after the duct work was completed, we have two measures of leakiness expressed in cubic feet per minute. The difference between these two test results

[11] Incomplete cost data for one job reduced the sample size to 160, compared to 161 for the PRISM analysis.

[12] We should note that Contractor D, in addition to being the lowest cost contractor with the best energy results, was also the only contractor with zero customer complaints

is the change in leakiness. We can then correlate this change in leakiness with the change in energy consumption, i.e. the energy savings. We would expect that houses with large changes in leakiness would also tend to show large energy savings. Figure 1 below suggests that this is not the case.

**Figure 1.** Change in Energy Use versus Change in Duct Leakage




This initial impression is reinforced when we derive the statistical relationship between change in duct leakage and change in energy use. The correlation between the two measures is close to zero and is, in fact, slightly negative at -0.06. For the houses in the Pilot Program, at least, larger energy changes tend to be associated with smaller amounts of improvement in the duct system, although the association is very close to zero.

## Weatherized versus Unweatherized Homes

The original research design called for an examination of the differences in energy savings from duct sealing for houses which were previously weatherized versus those which had not been weatherized. It was thought that previously weatherized houses might present lower savings opportunities from duct sealing since convection and conduction leakage from the house shell and glazing was small relative to unweatherized houses. The following discussion is based on a comparison of savings figures from 73 unweatherized houses and 88 weatherized houses.

The expectation that weatherized houses would exhibit smaller changes in energy use than unweatherized homes was borne out by the data on the houses in this study, with those living in unweatherized homes realizing almost twice the average change as those living in weatherized homes. Mean weather-adjusted change in energy use for the weatherized homes was 534 kWh, while non-weatherized homes changed by an average of 1,012 kWh annually.

The cost of duct sealing in these two groups of homes was nearly identical, $448 for the unweatherized cohort and $447 for those which had been previously weatherized. This should not be particularly surprising given the earlier finding of essentially no relationship between job cost and energy use reduction.

Although this already modest sample of homes in the Pilot Program is even further reduced when segmented into weatherized and unweatherized subgroups, the magnitude of the difference between the two cohorts is surprisingly large and suggests that it is not an artifact of sampling.

**Customer Acceptance of the Program**

In order to determine what participants thought of the Residential Duct Sealing Pilot Program, TPU staff designed a telephone survey which would assess participants' reasons for participating in the program, their level of satisfaction with the work done on the house and with the contractor who performed the work, and with the program overall. Items were included which tapped participant expectations for the program and attempted to determine what changes to the house which might affect energy consumption had been made since the duct work was completed.

Survey interviewers were able to contact 125 of the 196 program participants. Of these 125 who completed the telephone survey 103 had usable billing histories after PRISM analysis. The annual consumption of these 103 households which participated in the program and completed the survey was compared to the 59 program participants who had usable bills but did not complete the survey. Table 4 below shows the comparison between program participants who completed the survey and those who did not and reveals that survey respondents enjoyed smaller savings than non-respondents.

**Table 4.** Pre- and Post-program Energy Consumption for Survey Participants versus Non-participants

| *Completed telephone survey* | Pre-program consumption PRENAC (kWh) | Post-program Consumption POSTNAC (kWh) | Annual Change in Energy Use DNAC (kWh) |
|---|---|---|---|
| Yes | 27,494 | 27,026 | 468 |
| No | 25,386 | 24,142 | 1,243 |
| Total | 26,726 | 25,976 | 750 |

(In the discussions which follow it should be kept in mind that the subgroup which completed the survey had a smaller mean change in energy use than those who did not take part in the survey.) We asked what participants in the program had hoped to accomplish by having work done on their duct systems. Virtually everyone who answered this question responded that they hoped to use less energy to heat their homes. Forty percent said they wanted to lower their heating bill; 27 percent wanted "More efficient heating;" 14 percent wanted to bring their heating system up to date; 10 percent cited energy conservation; and one percent wanted better insulation of their heating system. Only 5 percent listed "increased circulation" as the reason for having work done on their duct systems, and an additional 4 percent did not know why they participated or they refused to answer.

When asked how well the program did what they hoped it would do, 68 percent of the telephone respondents replied that they thought the program did either "Extremely well" or "Very well." An additional 23 percent thought the program did "Pretty well," while nine percent thought the program did "Not so well" or "Not at all well."

Table 5 shows the mean energy change for the three groups of respondents to the survey. There appears to be little relationship between participants' evaluation of how well the program met their expectations and actual change in energy use: the group with the lowest average change gave the program the highest ratings. This apparent paradox may be partially explained by the fact that the change in energy consumption, while measurable and significant when considering an entire year may not be particularly noticeable on a given utility bill. For a participant whose consumption decreased by 1,000 kilowatt hours on an annual basis, the change on a single two-month bill may be only 200 or 300 kilowatt hours. This might represent a percentage change of less than 10 percent for the typical participant and could very well be overlooked. In addition, the number of heating degree-days in 1996 was approximately 10 percent higher than the number in 1995, further obscuring the apparent impact of the program for the participants. It is therefore not particularly surprising that participants are not able to accurately gauge the impact of the program on their energy consumption.

**Table 5.** Perception of How Well Program Performed versus Measured Change in Energy Use

| *How well did duct program meet expectations?* | Mean Change in Use (kWh) | N | Std. Deviation |
|---|---|---|---|
| Extremely well/Very well | 320 | 64 | 2,825 |
| Pretty well | 852 | 22 | 2,522 |
| Not so well/No at all well | 769 | 10 | 2,019 |
| Total | 488 | 96 | 2,673 |

Realizing that this was a program without cost to participants, we investigated participants' feelings about a program with some cost to those participating. When asked whether they would recommend the program if the program were no longer free to participants, 76 percent replied that they definitely or probably would, 13 percent said they probably or certainly would not, and ten percent said they did not know. When asked how much they thought people would be willing to pay to have the work done on their duct systems, assuming that the money would be loaned to participants through a zero-interest loan, the majority of our survey respondents, fully 70 percent, did not know what others might be willing to pay. Of the 30 percent of the survey respondents who would estimate the extent of people's willingness to pay for duct sealing, almost half thought the price would be less than $200. Another 31 percent thought people would be willing to pay between $200 and $500. It will be recalled from the Cost Effectiveness section that contractor costs for the program ranged from less than $100 to more than $1,200.

## Conclusions

The lessons from the pilot program are quite straightforward:

1. Reducing leaks in heating duct systems results in net reductions in energy use. Average energy use reduction per participant is approximately 750 kWh per year. Taken together with increases in consumption for comparable non-participant homes yields a net reduction of approximately 1,500 kWh per year.

2. The cost of these improvements to the duct system represent a energy resource to Tacoma Power with a levelized cost of approximately 17 mills, depending on the type and length of financing.
3. The change in consumption for participants in the Pilot Program ranged from an annual increase of nearly 10,000 kWh to a decrease of 10,000 kWh.
4. Homes which had not been previously weatherized yielded decreases in energy use nearly twice that of homes which had been weatherized.
5. There appears to be little association between the cost of the duct sealing work and the magnitude of the change in energy use.
6. Sufficient expertise is available in the local area to implement a duct sealing program on an operational basis.
7. Participant satisfaction with the program is not related to their level of energy use reduction.
8. Overall satisfaction with the Residential Duct Sealing Pilot Program was very high, with 80 percent of participants saying that they would definitely recommend the program to a friend or neighbor.
9. Most participants were not willing to estimate how much they thought others would be willing to pay for the services which they themselves had received without cost.

Based on the present research we offer the following recommendations:

1. Do duct sealing at the same time as weatherization to reduce administrative costs and to meld the cost of energy savings from duct sealing into the higher savings from weatherization.
2. Target unweatherized homes first to maximize program impact
3. Manage contractor costs and place cap on total job cost
4. Institute cost-sharing for higher cost jobs such as non-zero interest loan for these participants.
5. Monitor administrative cost to keep total program costs down
6. Reduce dry hole percentage through stricter qualification by intake staff.
7. Stress "improvement to heating system" and "comfort" rather than energy savings in program promotions.

## Acknowledgments

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