Savings from an Expedited Duct Sealing Program for Mobile Homes

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ABSTRACT

This paper documents the energy savings observed for a program operated by the Eugene Water and Electric Board which provided duct sealing for mobile and manufactured homes as its principal measure. Billing data and associated mean outdoor temperature data on more than 400 participants for one or more years pre and post was used as the basis of the savings estimate. The observed savings were used along with site treatment costs to estimate a levelized cost of savings of 12 mills/kWh exclusive of utility management costs.

Clear evidence of a mean gross pre-post Normalized Annual Consumption (NAC) savings of 1258 kWh/yr. was observed with an error of +-150 kWh/yr., at 95% confidence. This study included 80% of the participant population. Although the amount of savings were small relative to overall consumption, they could be clearly demonstrated in a plot of cumulative distributions.

The savings analysis was based on the fitting of a single break point function to both the pre and post billing data vs. temperature, i.e., PRISM® heating mode only. Results were normalized for conditioned area at each site to allow for an area weighted aggregation of results. Results were presented as NAC savings in the city of program activity and in the form of a temperature function which allowed the results to be estimated for other climates. Results were equivalent to about a 13% improvement in duct delivery efficiency.

The contractor used site pressure diagnostics (blower door and pressure pan) during the sealing process to detect sealing opportunities and to confirm job completion. The diagnostics played a key role in expediting program cost effectiveness by detecting at the outset sites with limited savings potential.

Introduction

Eugene Water & Electric Board (EWEB) initiated a unique program in January 1995 which focused on residential duct sealing. The new program, called Comfort S.E.A.L.™ (Stop Expensive Air Leaks), operated with simplified field protocols designed to identify duct sealing opportunities quickly and reduce cost. The program provided services at no cost to mobile and manufactured homes, a housing sector historically ignored, and, often, the housing sector of low-income residents. EWEB chose to design and fund its own program, rather than participate in the mobile home weatherization program offered by Bonneville at that time. EWEB found that in this housing stock Comfort S.E.A.L.™ provided higher savings at a cost substantially lower than could be achieved through weatherization. EWEB developed a unique and highly effective approach to marketing, delivering, and administering the program, which required no audit, no report, and no bid. Currently 20% of the homes are inspected. During the pilot phase, work was observed and inspected by trained EWEB staff in 100% of the homes.

Since the completion of the Impact Evaluation in Oct. 1997, more than 2000 manufactured and mobile homes have participated in the program. It has provided a useful pilot for other parts of the residential housing market, and has since evolved to a fee based service for site built homes.

The objective of this program was to achieve cost effective savings by sealing duct air leaks in manufactured homes with electric heating systems. The duct sealing effectiveness was verified on site by immediate pre- and post-retrofit blower door tests. The use of the blower door as a diagnostic tool provided an immediate "cost effectiveness meter" by which the contractor judged the efficacy of his duct sealing efforts in an expedited manner. This led to a cost effective retrofit for the contractor because the blower door measurements established the point at which most of the duct sealing had been accomplished. Beyond that point only marginal air leakage savings were possible and at a steeply increasing level of effort.

Recommended program procedures gave precedence to indoor air quality. No residence was treated if there could be an adverse effect on interior moisture retention, or any backdrafting of combustion appliances.

EWEB had two primary reasons for development of this program. In the immediate term, EWEB was responding to customer need as expressed in high bill complaints and requests for energy efficiency audits. EWEB's second reason for program development took a longer term perspective. EWEB hopes to leverage the program development effort by franchising the mature program.

To determine the effectiveness of EWEB's immediate efforts, the most important research questions in the Impact Evaluation were: (1) Did the program achieve cost effective savings? And (2) Did the program respond to the customer needs? To assess the value of the program to the customers, we determined the magnitude of the energy savings, and estimated a levelized cost of savings from billing data and from site inspection data which substantiated and estimated measure life. Responding to the longer term perspective, we expressed the program savings as a temperature function so that savings in other climates could be confidently estimated. We also looked at screening criteria based on site diagnostics or prior billing history which might be used to increase overall cost effectiveness of the work.

Analysis Methodology

Billing Analysis Methodology

We used the PRInceton Scorekeeping Method (PRISM®) (Fels, Kissock & Maurean 1995) to weather normalize the consumption data to remove 'noise' due to the weather which could influence consumption before or after treatment. The difference between consumption before and after treatment represents the energy savings due to the program.

Review of the initial model results demonstrated that PRISM® was not robust with regard to disaggregation of components. That is, the normal variation of customer behavior introduced considerable "noise" into the regression model. In selecting the best regression equation, PRISM® can easily chose to change the balance temperature in order to accomplish minor improvements in the regression fit. In a few cases, random noise in the data would lead PRISM® to specify a model with illogical amounts of space heating. Although PRISM® provides a good comparison of NAC, the estimates of baseload and space heating components were poor.

According to building physics, one would not expect that the Comfort S.E.A.L.™ treatment would affect the balance temperature. If the thermal shell of the building is not treated and the occupant behavior does not change, the balance temperature should not change. Energy savings from the treatment should be apparent as savings in the space heating component. In a few exceptional cases, the Comfort S.E.A.L.™ treatment may have decreased the amount of passive infiltration by repairing large air leaks. In these cases, one might expect the balance temperature to change.

We determined that there was a logical range for the balance temperature. Accordingly, we constrained the PRISM® models and manually reviewed the first 120 plots and output to assure that PRISM® supplied a reasonable consumption model.

Programmatic impact on consumption was evaluated using a traditional quasi-experimental design. The design compares the participants to a similar but untreated group. The non-participants were drawn from a pool of future program participants to reduce self-selection bias that may affect estimated savings. Use of future participants offered another benefit since the building audits or site characteristics collected in a later year could be applied to the comparison group in an earlier year. To confirm similarity of the comparison group to the treated group in the baseline (pre-treatment) year, we examined the cumulative distributions of consumption parameters for both groups, and found them to be similar.

The analysis used a standard pre/post cross sectional consumption (billing) analysis. The weather normalized annual consumption (NAC) before the treatment established a baseline, which was then compared to weather normalized consumption after the treatment. The difference in consumption determined gross savings. That is: Gross savings = NAC(pre) - NAC(post).

Gross savings were determined for the comparison group in the same way. The participant savings could then be corrected for any consumption change apparent in the comparison group. The results represented net savings attributable to the program. This difference of differences approach is traditionally used in DSM evaluation to "net out" savings due only to the treatment. Results were reported in terms of the average savings per dwelling unit.

We reviewed regression results for all cases with a poor regression fit ($R^2 < .7$) or outlying results and defined outliers as those cases exceeding two standard deviations based on annual savings per square foot. The review included removal of atypical billing points and rerunning the regression fit. The resulting cleaned cases represented the physical data set.

To visualize the change in consumption due to the program, we aggregated results while normalizing to savings per square foot. The methodology normalized for three factors: average power; building size; and weather. (West et al. 1996) Since the individual building models were normalized to a form of watts/ft^2 vs. temperature, the models for all the buildings in a group could be aggregated into a single model, which described performance of the whole group in terms of watts/ft^2 vs. temperature. The result was shown as a temperature-dependent model of energy consumption pre- and post-retrofit. The aggregation preserved the temperature dependency of the savings and allowed extrapolation of the results to other climates.

Gross and Physical Data Sets

If the savings are roughly the same size as random variations, the signal-to-noise ratio may make it difficult to quantify the savings. Therefore, we investigated the savings using two procedures. First, we aggregated the entire data set (referred to as the Gross Data Set) and second, we aggregated a physical case subset. The physical case model examined with statistic al rigor a dataset from which occupancy changes and obvious outliers were removed.

Both approaches have respective advantages but address different questions. The overall or gross approach includes all homes, without detailed data cleaning, and asks "What were the savings for the overall program?" This approach is consistent with the inclusion of all homes in the cost effectiveness analysis. When individual cases are reviewed, the standard data quality procedures often eliminate 25-50% of the homes. Therefore, the individual case model asks the questions "What were the savings for the homes with clean data?" When only clean or well behaved homes are included, the strategy is to exclude the noise in the data in hopes of discerning the underlying impact of the measures.

Sample Disposition

The intent of the evaluation was to analyze consumption for all participants. Due to incomplete data and occupant changes a full sample is never possible. However, we analyzed approximately 80% of program participants, including 387 cases out of the first 475 participants. *Table 1* shows savings results, statistically adjusted for a finite population.

Results

Site Inspection Results

Site inspections of four sites chosen from the first 50 sites retrofitted were conducted approximately 18 months after measure installation. The sample of inspected sites was too small to be statistically significant. It was designed to obtain detailed observations on: (1) the durability of the sealing techniques, (2) air quality or moisture problems, and (3) customer perspectives. Mastic showed no degradation after 18 months. No moisture problems were found. Customers perceived the program very positively.

Participant Group Impact Results

Statistically, the strongest savings were found in the difference in pre- and post-retrofit Normal Annual Consumption (NAC). We estimated average savings of 1258 kWh/year for the participants. Savings for all the heating-related variables were statistically significant. There were significant savings in the heating slope or temperature dependency of the home and in the computed amount of annual space heating. While these two variables were closely related, the annual space heating savings included additional change due to a reduction in the balance temperature for each house. Savings were also normalized for size (NAC per square foot). These savings were significant as well, but did not show improvement in statistical confidence.

Results were consistent with expectations. Most of the savings were expected to manifest as an improvement in the heating plant efficiency or savings in the heating slope. In some cases, the decrease of passive infiltration may have improved the balance temperature and contributed additional savings.

The aggregation approach in *Figure 1 Aggregate Temperature Model* aggregates the individual NACs and the square footage, normalizing to a form of watts/ft^2 vs. temperature, into a group performance model. The group performance model is the area weighted average of all the individual building performance models, and it is algebraically equivalent to the use of the individual models in computing the savings for the group.

The average change in consumption for the aggregated sample, *Figure 1*, shows there was little change when weather averaged greater than about 60 degreesF. Because manufactured housing is of similar construction, savings apparent in the change in the heating slope will hold for other climates. Using *Figure 1*, savings during the heating season can be computed for other climates. These estimated savings, measured by the change in kWh, represented about 6% of the total annual energy consumption or about 13% of space heating consumption. Thus, the duct sealing appeared to provide about a 13% improvement in heating delivery. That is, if the duct delivery was usually 70% efficient, the duct sealing increased the efficiency to about 80%. This figure included savings due to reduced passive infiltration as well as savings due to improved delivery of heated air. These results were close to those reported from co-heating tests of a small sample. (Ecotope 1997) In those tests, average delivery efficiency was increased from 69% to 82%.

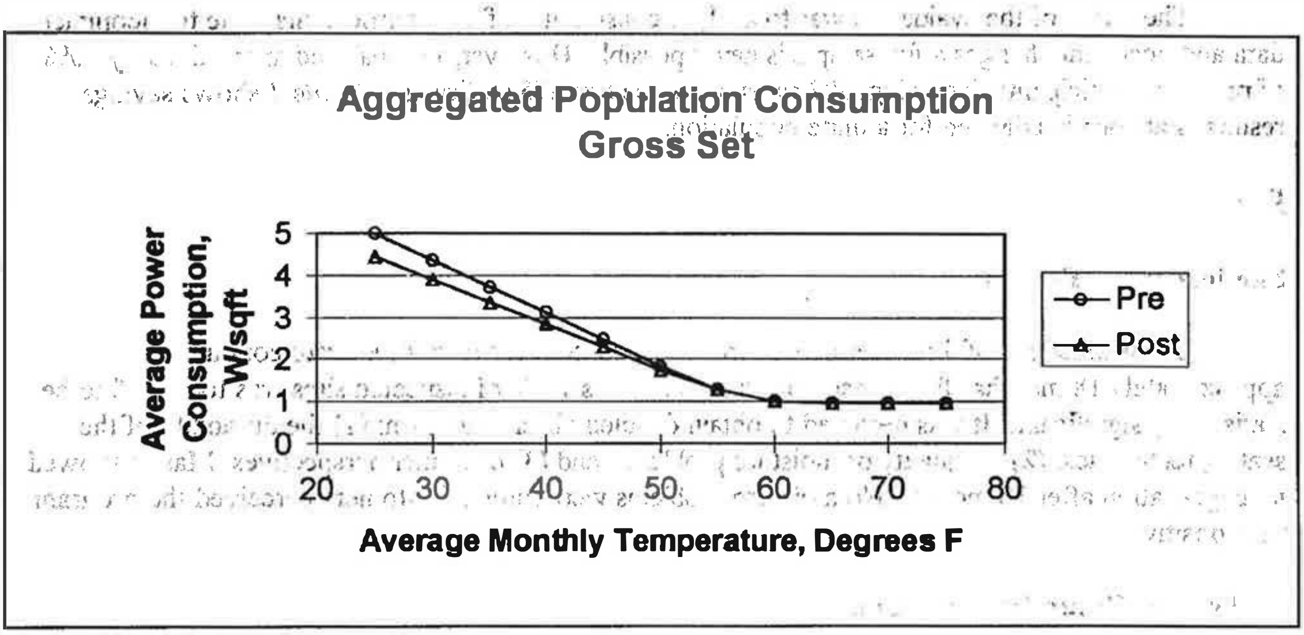

Figure 1 Aggregate Temperature Model

Oftentimes, a difficulty in viewing savings is that the customer's behavior is not necessarily consistent from year to year. Changes in family size or consumption habits interfere with direct observation of the savings. That is, a small savings signal buried in a large amount of noise is difficult to see in a normal frequencies plot. One approach we used to minimize the effect of behavioral "noise" was to observe the distribution of pre- and post-retrofit NAC as shown in *Figure 2 Pre/Post Distribution Treatment Group*. While average savings were still the basis for savings in this graph, individual cases were normalized for square footage of the home and sorted by consumption level. This compensated for random variation in behavioral consumption. The resulting plot showed a clear distinction between the pre- and post-retrofit distributions of consumption, thus providing a visual demonstration of average change.

Comparison Group Impact Results

A similar treatment of the comparison group is shown in *Figure 3 Pre/Post Distribution Comparison Group*. Note that the pre- and post-retrofit distribution of consumption was very similar for this group. That is, there were no savings. This demonstrated that the estimated savings for the participants were not due to factors outside the treatment.

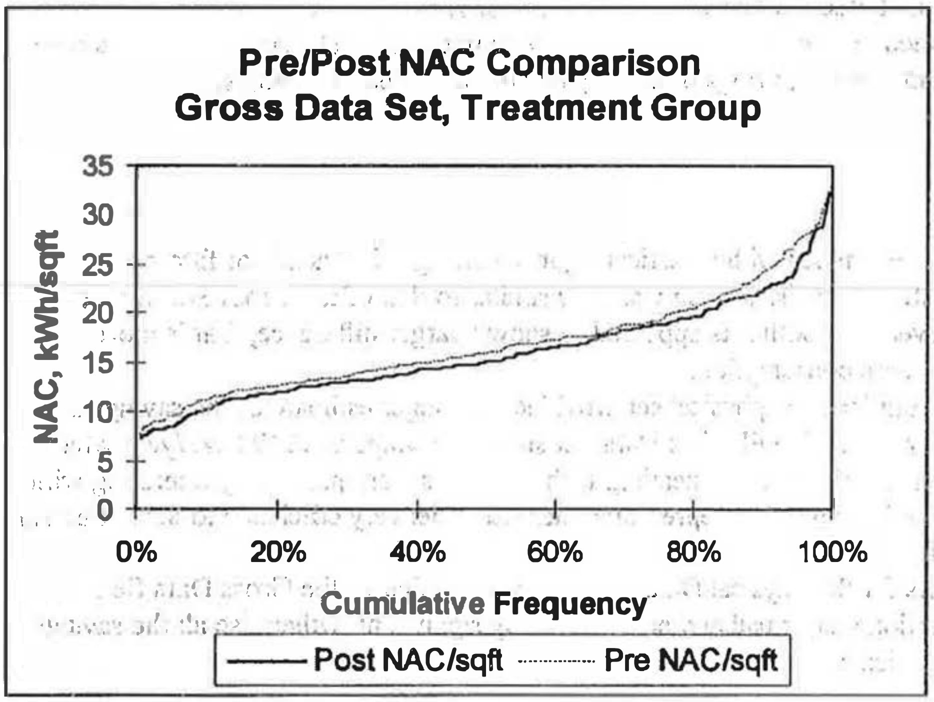

Figure 2 Pre/Post Distribution Treatment Group

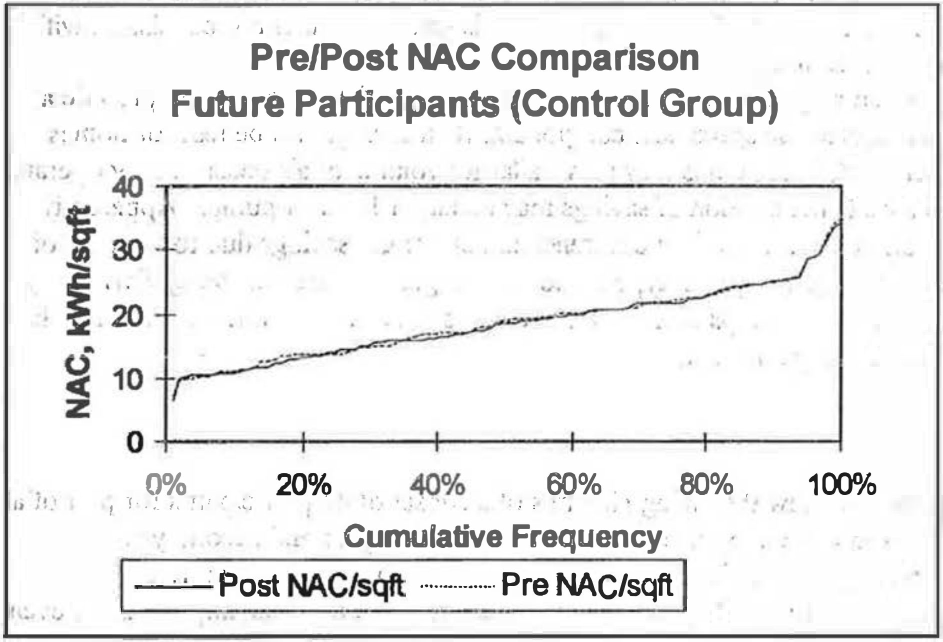

Figure 3 Pre/Post Distribution Comparison Group

Gross savings for this group showed a small but statistically significant amount of savings. These results were, however, due to a small group of outliers where family changes had evidently taken place during the study period. These outliers were removed to provide the results shown in *Figure 3*. The overall differences between pre-and post-retrofit NAC were not statistically significant. Based on these results, we felt confident that the savings of participants did not need to be adjusted for any background effects.

Physical Data Set

The Physical Data Set examined with statistical rigor the changes in "clean" or filtered observations for individual sites. This distribution was very similar to that of the Gross Set. It was interesting to observe, however, that both sets appeared to show a larger difference, that is more savings, for participants with high consumption.

In removing extreme outliers, the physical set provided a stronger estimate of the savings as indicated by the higher t-test results. The Physical Data Set showed savings of 1249 kWh/year which was 7% of total consumption or 15% of space heating. If the furnaces were previously operating with a delivery efficiency of 70%, the improvement represented increasing delivery efficiency to 82%. Such an improvement seems plausible.

Overall savings results for the Physical Data Set were very similar to the Gross Data Set. Savings in baseload consumption were small and not statistically significant. Otherwise all the savings comparisons were highly significant.

Heat Pumps

We examined the consumption of heat pump versus electric resistance furnaces for the Physical Data Set group (210 cases -- 68 heat pump and 142 resistance furnace). The ratio of space heating consumption suggested an effective annual COP of about 1.2. This was rather low but consistent with the similarity of savings for both system types.

The type of heating system may affect the programmatic savings. If the duct repairs provide a constant fraction, say 10%, savings of the space heat component, then savings will be less for homes with heat pumps. On the other hand, heat pumps may move a larger volume of air because they operate at a lower temperature. In this case, the fraction of savings may be larger for heat pumps. Apparently these factors tend to cancel out. We observed little difference in duct repair savings due to the type of heating system. Distribution of savings by system type is shown in *Figure 4 Distribution of Savings by System Type*. It would appear that heat pumps reduce extreme cases at both ends of the distribution but otherwise savings were not appreciably different.

Persistence Of Savings

We had the opportunity to review the billing histories of a subset of 43 participants for part of a second year. This exercise allowed the comparison of savings for the first year and second year following the retrofit. These billing histories included only about five months of the second post-retrofit year. Thus, the second year results were highly preliminary. These results show consumption at an even lower level during the second year. In both cases, the same pre-retrofit consumption was used to compute savings. Based on these results, we concluded that there was no evidence that savings decreased. However, given the small sample and a fractional year for billing data, we do not believe that the analysis was sufficient to conclude that savings increased in the second year.

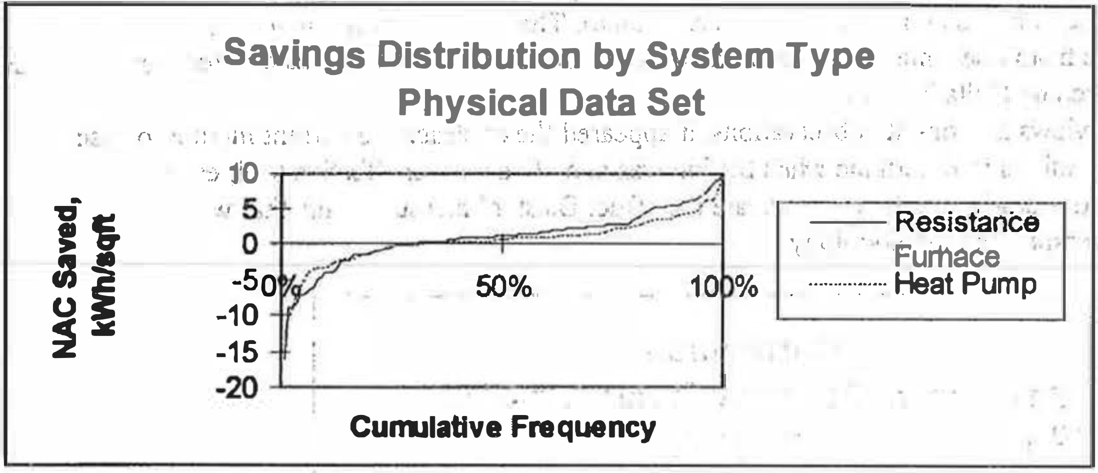

Figure 4 Distribution of Savings by System Type

Energy Savings And Historical Consumption

Ideally, a potential screening criterion, done prior to going into the field, would separate out those potential candidates with the most opportunity for savings. Candidates could then be grouped according to potential savings and targeted for various services. We found little relationship between estimated savings and the amount of pre-retrofit consumption. We set the usage criterion at 20,000 kWh/yr. Participants below that point averaged savings of 197 kWh/yr. and above that point averaged 2690 kWh/year. Most of the program's average savings occurred in high usage cases. However, the variation was large. There were still cases with lower consumption that achieved high savings. Ruling out low consumption customers would eliminate some opportunities to achieve useful savings.

Use of a more specific parameter might be expected to provide a better screen. An earlier proposal for such a parameter was to screen based on the heating slope per square foot. A similar lack of correlation was evident in the Physical Data Set shown in *Figure 5 Screening Criterion*. The vertical line in this figure represents a screen of 35 BTU/deg-hr/sqft or 0.12 W/deg/sqft. Savings averaged -0.1 kWh/sqft below and 1.43 kWh/sqft above the screen. Thus, this criterion is even better at identifying the homes where savings will average a high value. However, there was so much variability with individual results that the criterion is not useful for predicting results for a specific case. Moreover, use of this criterion requires knowledge of the square footage of the home. If this information is not readily available, this screening criterion cannot be computed.

Energy Savings and Field Measurements

In a similar fashion, we compared estimated savings against parameters measured in the field. The goal was to determine if any of the field measurements provided useful diagnostics to identify potential savings. Once again, the results were highly variable and did not show a strong correlation with field measurements. Based on these results, we do not have specific recommendations for field measurements as diagnostics to identify potential savings. The savings appear to have occurred with wide variability and little correlation to measured parameters. The field measurements of interest were:

(1) Total reduction in sum of pressure pan readings. This was considered a qualitative measurement.

(2) Reduction in whole-house infiltration. This was computed as seasonal ACH (air flow rate at 50 Pascals divided by 26 and divided by house volume). The factor 26 was a generic adjustment to extrapolate from one-time flow measurements to seasonal infiltration. It was derived from previous field research by Delta T, Inc..

Based on interviews and on-site observations, it appeared the contractor's current method of using pressure pan readings to determine when the job was complete was an effective tool; easy to implement. In this study, we did not replicate the "Duct Blaster" measurements that were used to develop the pressure pan methodology.

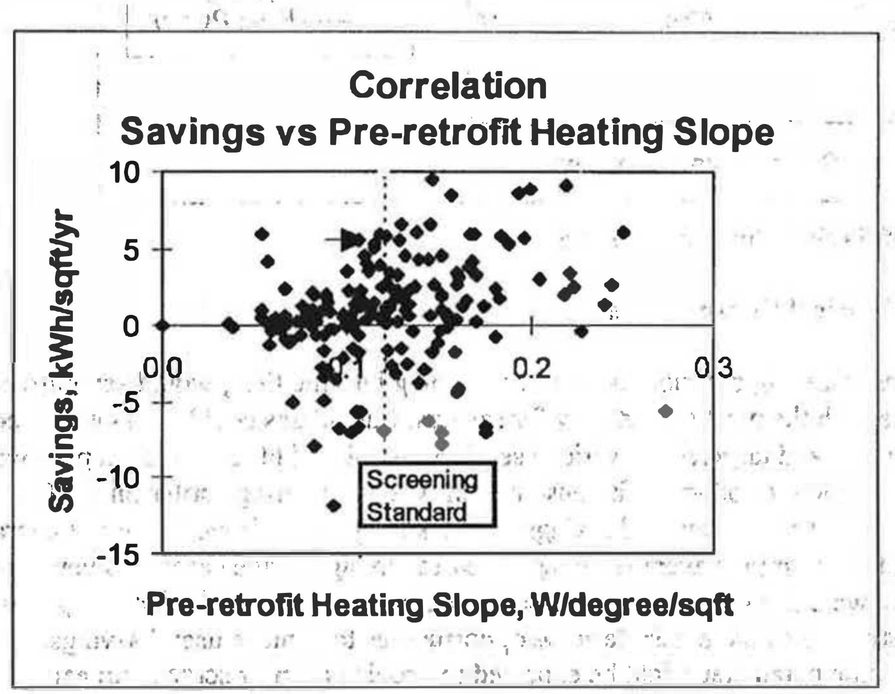

Figure 5 Screening Criterion

Program Cost Effectiveness

The aggregate measure life used for estimating the levelized cost of savings depends principally on two factors, (1) the life of the measures, and (2) the remaining life of the dwelling.

The life of the principal measure, the RCD mastic, has been investigated through accelerated age testing by RCD corporation. This testing supports a useful life of 30 years as reported by Oregon Office of Energy. (Hewes 1997)

The remaining useful life of the dwelling has been investigated by John McBride and Tom Hewes in a study of moisture and indoor air quality in manufactured housing retrofits. (Hewes & McBride 1996) This study identified that the metal outside shell was playing a significant structural role. The dwellings studied were currently in use and had a remaining lifetime expectancy of 30 to 50 years. The economic motivation for using a manufactured home is strong enough to keep it in use until it fails structurally; it will not become outdated. Therefore, a remaining useful life of 20 years is a conservative mean estimate for the stock treated in the EWEB program which consists principally of post 1975 vintage manufactured homes. A measure life of 20 years was applied to calculate the levelized cost of savings.

Overall Program Results

The Impact Evaluation was conducted in two phases, based on availability of data, and not on any programmatic change. Combined results for the two evaluation phases were calculated. Since billing analysis was conducted on a large (81%) portion of the participants, statistical results of the combined phases were adjusted for a finite population. That is, the statistical uncertainty was reduced to reflect the fact that most of the participants were included in the analysis and, thus, the average savings were fairly clearly known. See *Table 2 Combined Sample Savings Estimates*.

All of the savings measures were statistically significant for the combined sample, especially after adjusting the uncertainty for the finite population. Overall savings, based on NAC and NAC per square foot, were robust and demonstrated a large program benefit. Savings represented about 13% of space heating.

Program results were averaged for all the participants in *Table 1 Overall Program Results*. This table was based on averaging the total number of participants in both phases analyzed, and provided an estimate of the average impact for the overall program.

Gross Savings included turnover in the population and other factors which interfered with an accurate measurement. However, it represented the savings that could be expected "at the meter", given customer changes, partial vacancy and other real world factors. The Physical Set savings represented an attempt to clean the data and derive the best estimate of savings where customers were stable. These savings represented those that would be captured by an engineering analysis. They were in close agreement with the Gross Savings.

The average savings (including "dry holes") of 1258 kWh per year were delivered at an average cost of $226 or a levelized cost of 12 mills per kWh. This cost represented only the field delivery and did not include administrative costs incurred within EWEB. This cost represented a highly effective conservation resource.

Table 1 Overall Program Results

	Number of Participants	Net Savings per Customer kWh/yr.	Net Savings per Sift kWh/yr.	Average Cost
Gross Set Savings				
Phase1	114	1,782	1.92	$222.28
Phase 2	361	1,093	0.86	$227.39
Both Phases	475	1,258	1.11	$226.16
Physical Set Savings				
Phase1	86	1,600	1.67	
Phase 2	193	1,249	0.87	
Both Phases	279	1,357	1.12	

Table 2 Combined Sample Savings Estimates (387 Cases)
Adjusted for 80% Sample of Finite Population

Variable	Mean	Standard Deviation	Standard Error	95% CL Lower	95% CL Higher	t-test	Significance (2-tailed)
Baseload, Pre (kWh/day)	26.673	10.501	0.230				
Baseload, Post (kWh/day)	26.174	11.364	0.249				
Baseload Saved (kWh/day)	0.498	6.638	0.150	0.204	0.792	3.330	.000
Heat Slope, Pre (W/degday)	3.447	1.242	0.003				
Heat Slope, Post (W/degday)	2.957	1.111	0.003				
Heat Slope, saved (W/degday)	0.490	1.039	0.002	0.445	0.535	21.55	.000
Space Heat, Pre (kWh/yr)	8,736	3232	70.7				
Space Heat, Post (kWh/yr)	7,625	3253	71.2				
Space Heat, Saved (kWh/yr)	1,110	2400	52.5	816	1404	21.14	.000
NAC, Pre (kWh/year)	18,478	4940	108				
NAC, Post (kWh/year)	17,185	4780	105				
NAC, Saved (kWh/year)	1292	2595	56.8	1007	1577	22.77	.000
Pre-NAC/sqft, (kWh/sqft/yr)	17.95	5.96	.13				
Post-NAC/sqft, (kWh/sqft/yr)	16.68	5.59	.12				
NAC/sqft, Saved (kWh/sqft/yr)	1.27	2.63	.056	1.16	1.38	16.62	.000

Conclusions

- The Comfort S.E.A.L.™ program provided effective savings. The average savings including both evaluation phases was 1258 kWh/year.
- Savings were equivalent to about a 13% improvement in duct delivery efficiency.
- Program savings could be clearly demonstrated in a plot of cumulative distributions.
- With 475 participants during the study period, program savings were estimated to be 597,550 annual kWh.
- The savings estimate could be extrapolated to other climates using the temperature relationship shown in *Figure 1 Aggregate Temperature Model.*
- The contractor's field protocols appeared to be successful at screening sites for treatment. The average savings included 9% "dry holes" when duct sealing was not appropriate.
- Customers were highly satisfied with the program and their interaction with the contractor.
- The comparison group showed no significant change in energy consumption during the study.
- Savings for a persistence sample showed no reduction in savings during a second year of study.
- Evaluation Phase 2 participants appeared to consume less energy than participants in Phase 1 of the Evaluation. Projected savings for the future participants were expected to be about 1093 kWh using current results.
- The program was highly cost effective. Direct measure costs averaged $226 per site, including a few "dry holes". Levelized cost for the overall program was 12 mills/kWh.

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