Energy Trust of Oregon 2008 Existing Homes Gas Impact Analysis

Prepared by Brien Sipe
January 7, 2011

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Energy Trust 2008 Existing Single Family Gas Impact Analysis

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Executive Summary

The objective of this analysis is to estimate annual gas savings for participants in the 2008 Home Energy Solutions (HES) program, both at the household and measure level. As with previous impact evaluations, weather normalized annual consumption, similar to the PRInceton Scorekeeping Method (PRISM), is employed, allowing for more direct comparisons of results and exploration of trends in program savings over time.

Gas savings estimates from this and previous studies are used in Energy Trust's annual true-up process, as well as being used to inform future expected measure savings and to identify potential issues with implementation that may not be detected via field quality control inspections.

The following details highlights from the analysis, as well as a comparison of 2008 and 2006-2007 estimates relative to current deemed estimates, and savings from frequently installed packages of measures.

- Estimated average savings per household is 62 therms, or 8% of total household gas usage.
- Evidence from this study suggests gas savings for air sealing and duct sealing in 2008 are 0.
    - A high volume contractor, responsible for over half of duct and air sealing projects, consistently had poor quality control inspection results, and were subsequently removed from the program.
    - Three studies on air sealing during the 2006-2007 program years found negligible air sealing savings, given that no change in implementation practices occurred in 2008, the estimated 0 therm savings can be considered robust.
    - Contractors who actively performed duct sealing prior to 2008 achieved an average therm savings of 32, consistent with the savings estimate of 34 from 2006-2007 impact evaluation, however, these contractors accounted for only 30% of the duct sealing work in 2008.
    - **Recommendation:** Based on the above two bullets, predicted savings for duct sealing should remain at 34 therms.
    - **Recommendation:** 2008 air sealing savings are 0 therms per project.

- Duct insulation savings were in line with findings from 2007 (implementation issues in 2006 resulted in a 2006-2007 average of 16 therms), with average savings per project of 28 therms, compared to 2007's estimate of 33.
    - **Recommendation:** Predicted duct insulation savings should be in the 0.15/therms per lineal foot (average of 2007 estimate of 0.16 and 2008 estimate of 0.14 therms/lft).

- Ceiling, floor and wall insulation estimates of gas savings per square are slightly higher than estimates from the 2006-2007 study.

- **Recommendation:** Use average of 2006-2007 and 2008 estimates of therm savings per square foot of shell insulation:
    - Ceiling insulation: 0.052 therms/sqft.
    - Floor insulation: 0.046 therms/sqft.
    - Wall insulation: 0.059 therms/sqft.

- Estimates of window 'replacement', in gas heated homes are significantly less than current estimates of 'incremental' savings. This drop in savings will place an even higher importance on the quantifying of non-energy benefits for maintaining measure cost effectiveness. Estimates of per square foot therm savings (0.195 therms/sq ft) are consistent with the 2006 finding (0.190 therms/sq ft). Inconsistent savings were found during the 2007 program year with an estimate of 0.0339 therms/sq ft. of glazing, despite comparable sample sizes across all three program years.
    - **Recommendation:** Examine quality control reports for windows in the 2007 program year to explore the low savings estimate.
    - **Recommendation:** Use average of 2006 and 2008 windows savings per therms/sq ft. (0.190 and 0.195 therms/sq ft.)
    - **Recommendation:** Savings need to be 'de-rated' based on baseline assumptions to yield incremental savings to be used by the program. The Regional Technical Forum uses two tiers for replacement U values in single family homes, 0.85 and 0.50. Energy Trust U-value specifications in 2006-2008 were 0.32, with a baseline value of 0.35.

The following table details savings estimates from the 2008 analysis, as well as a comparison of estimated savings from the previous impact evaluation conducted in-house on program the 2006-2007 program years. For comparison purposes, all measures which treat varying areas (e.g., windows, shell insulation) average 2008 treated areas are used. Consistent estimates of savings are observed for the majority of measures, with the exception of windows savings in 2007 and duct sealing savings in 2008, for the reasons described above as well as in the body of this report.

Table 1 Single family estimated therm savings by measure (robust regressions)

Measure	Current estimates	2006-2007	2006 only	2007 only	2008
Air sealing	26	0	15	-25	5
Duct sealing	21	34***	32**	37**	6
Gas furnace	71	77***	75***	78***	68***
Windows† (per sqft)	44	28 (0.11***)	47 (0.19***)	9 (0.03)	50 (0.20***)
Ceiling insulation (per sqft)	101 (0.08)	65 (0.05***)	75 (0.06***)	59 (0.05***)	65 (0.05***)
Floor insulation (per sqft)	92 (0.08)	47 (0.04***)	43 (0.04***)	47 (0.04***)	59 (0.05***)
Wall insulation (per sqft)	99 (0.10)	56 (0.06***)	54 (0.05***)	61 (0.06***)	62 (0.06***)
Duct insulation (per lft)	12	15 (0.07***)	8 (0.04)	33 (0.16**)	28 (0.14***)

*** p<0.01, ** p<0.05, * p<0.1

†Deemed windows savings are based on 'incremental' savings, impact estimates in this table represent 'replacement' savings and are not de-rated to account for baseline assumptions. In addition, the combined savings estimate from 2006-2007 includes an anomalous estimate in 2007.

Introduction

The objective of this analysis is to estimate annual gas savings for participants in the 2008 Home Energy Solutions (HES) program, both at the household and measure level. This study follows on the 2006-2007 impact evaluation of gas weatherization and heat pump programs completed in January 2010. The analytical approach and modeling techniques build on the work conducted by Michael Blasnik & Associates (2005-2006 duct sealing and insulation, 2007-2008 air sealing duct studies) and Stellar Processes (2005-2006 duct insulation and sealing study) which targeted specific aspects of the 2005-2007 HES program years.

To provide flexibility in the data analysis, this study uses a weather normalized annual consumption approach, similar to the PRInceton Scorekeeping Method (PRISM). Utilizing a consistent modeling approach across studies allows for more direct comparisons of results and exploration of trends in program savings over time.

Gas savings estimates from this and previous studies are used in Energy Trust's annual true-up process, as well as being used to inform future expected measure savings and to identify potential issues with implementation that may not be detected via field quality control inspections.

Savings estimates are robust, and are in line with findings from the 2006-2007 impact evaluation, with the exception being duct sealing, where estimated savings appear to be negligible. The 2008 program year saw close to a 400% increase in duct sealing projects, accompanied by a large influx of new contractors with recently trained technicians. Most notably, one high volume contractor that performed over 60% of duct sealing projects in 2008 was removed from the program after being placed on probation due to persistently high quality control inspection failure rates.

Background & Methodology

Sample selection

Each sites pre and post treatment period consists of the full year prior to, and following, the year of program participation (2008 participant's pre and post years are 2007 and 2009, respectively). Participants who participated in either the pre or post year (repeat participants) were removed from the analysis to eliminate the effect of prior or subsequent participation from effecting 2008 savings estimates. In addition, observations with treatment dates within a billing period which straddled the beginning or end of the treatment year were dropped. This approach simplified the matching of the participant to comparison group, and aided in minimizing any weather related bias due to misalignment of the pre and post periods between groups.

Billing data cleaning

Energy Trust has developed a standardized procedure to 'clean' billing data prior to analysis. The major steps performed by the routine are:

- Estimated meter readings are added to next actual reading, to ensure meter begin and end dates accurately align with weather data.
- Sites with several consecutive estimates were removed if the number of observations in either the pre of post period fell below a minimum threshold.
- Excessively short or long readings are removed prior to weather normalization (less than 10 days, greater than 60).

- Sites with occupancy changes during the study period were flagged to allow an examination of influence, if any, on savings estimates (no significant changes were observed in the estimates when excluding sites with occupant turnover).

Comparison group selection

HES participants who installed measures resulting in gas savings during late 2009 and 2010, but in no other year, were used as a comparison group, with the intent being to control for secular changes in energy consumption. We assume that future participants share a similar propensity to participate in Energy Trust programs as the group of interest. While propensity to participant in voluntary programs such as HES can vary across time due to changing economic conditions and consumer preferences, utilizing future participants as a comparison group is standard industry practice in energy program evaluation.

To ascertain overall attributable program savings, the comparison group was stratified based on region and consumption to bring the pre-period usage between the two groups into closer alignment, again assuming that future participating households in close proximity and with similar energy usage to 2008 participants allows for a more comparable estimate of savings. Comparison group sites are stratified based on consumption quintiles and region are proportionately matched to participants using a technique similar to a Monte Carlo simulation to minimize random sampling error.

Weather normalization

Analysis was conducted using a method similar to the PRInceton Score-keeping Method (PRISM). The algorithm decomposes energy use into estimated heating, cooling and base load components. To do this, an optimum 'set-point' or reference temperature is found below (above) which energy use for heating (cooling) is detected. The reference temperature is a combination of consumer preference for thermostat settings, and the thermal integrity of the structure. Long-run average weather data is then used to calculate an estimate of annual energy use in an 'average' year.[1] Model specifications for weather normalization can be found in Appendix A.

Post weather normalization data screening:

- Sites were flagged if pre to post change exceeded 65%, changes that could signify other major alterations to the household unrelated to ECM installation.
- Gas sites were flagged if their pre or post normalized consumption model R2 < 0.7
- Michael Blasnik provided guidance on additional screens to verify adequate variation in the model to estimate heating/base loads. Site's are flagged when the sum of HDD's for observed billing periods were less than 40% of the long run average, or Max-Min HDD/Day were less than Average HDD/day. Prior screens, assessing number of observations and R2 tend to capture most of these sites.
- Sites with pre period consumption above the 99^{th} or below the 1^{st} percentile were removed.
  - o Non participant consumption was bounded based on the minimum and maximum participant consumption.
- Sites with less than 6 pre or post observations were flagged.

[1] Energy Trust uses TMY3 weather data to align with the Northwest Power and Conservation Council's Regional Technical Forum methods.

- This criteria resulted in a large amount of attrition due to the lack of readings with ‘0’ read values in Energy Trust’s utility database. Removal of these observations is due to an older data handling routine used prior to 2007. This could result in the heating related consumption being biased upward, but this bias, if it exists, is present for both participants and non-participants.

Savings estimation

Two approaches were used to estimate annual program and measure level gas savings. The first is a difference in differences model where the change in consumption during 2008 between the participant and comparison group are subtracted, yielding average household savings. This technique can also be used to ascertain average savings for various groups of commonly installed measures. These findings are indicative and help to provide more insight into trends in savings across measures and examine the efficacy of particular contractors.

The second approach relies on a multivariate regression to estimate average measure level savings within the program. Three modeling approaches are used to allow an examination of the influence of outliers. Ordinary Least Squares (OLS) is the standard multivariate approach, supplemented with Robust regression and DFBETA estimates, with the latter two techniques intended to reduce the influence of outliers on the measure level savings estimates. Outliers may come in the form of inordinately large projects (shell insulation performed in homes over 4,000 square feet, or homes that were only partially occupied during the year).

Study sample attrition

Sample attrition from various sources is presented in Table 2 below. As with prior impact evaluations, much of the attrition in this analysis stems from an inability to match usage data to program tracking data, this coupled with the dropping of repeat participants led to 32% of 2008 participating sites dropping out immediately. Subsequent attrition was due to the data cleaning steps described above in the methodology section of this report. Overall, just under half of the sites which received at least one gas measure were eligible to be included in the analysis.

Table 2 Gas site attrition

Attrition sources	2008 site attrition	Sample as a % of total 2008 program sites
Unique sites with gas savings	12,289	100%
Sites where bills were found and had no participation in pre-post period[2]	8,332	68%
Sites with at least 6 observations pre and post	6,851	56%
Sites with less than a 65%+ change delta Pre/Post	6,534	53%
Sites with therm consumption between the 1st and 99th percentile in pre-period	6,446	52%
Eligible participant sites with R2 > 0.7 & adequate weather variation	**5,859**	**48%**
Eligible participant sites after additional measure screens		
Final gas comparison sample*	**6,265**	**-**

[2] Current work on Energy Trust’s utility database in conjunction with the implementation of a integrated solutions initiative is expected to dramatically reduce this attrition source.

* Non-participants were screened using the same criteria.

Based on the site level sample attrition described above in Table 2, the following details the sample disposition of measures installed in 2008, and those included in the subsequent analysis. Measures which were infrequently installed were removed from the analysis, as well as those where fuel switching (e.g. customers replacing electric water heaters with tankless gas water heaters) is a known problem, were removed from the modeling. These measures will be explored in subsequent analysis to verify earlier impact findings.

Table 3 Sample disposition for 2008 gas weatherization impact analysis

Measure	2008 installs	2008 sample	Percent in sample
Air sealing	1136	636	56%
Ceiling insulation	1578	667	42%
Domestic hot water measures	4391	2180	50%
Duct insulation	443	191	43%
Duct sealing	1191	669	56%
Floor insulation	907	386	43%
Gas furnace	5488	2172	40%
Wall insulation	591	235	40%
Windows	361	143	40%

Findings

Difference in differences estimates

Results from the difference in differences approach are presented below in Table 5. Average estimated therm savings for the 2008 program year, net of the comparison group, is 62 therms. This figure is slightly less than the average savings from 2006-2007, estimated at 73 therms. Given that the matching technique for participant/comparison groups maintains the proportionality of all regions represented in the dataset, the comparison group is greatly reduced due to the few homes in the sample outside the Willamette valley. A second comparison of net savings for the Portland Metro area (where the bulk of program activity occurred) shows no difference in average program savings.

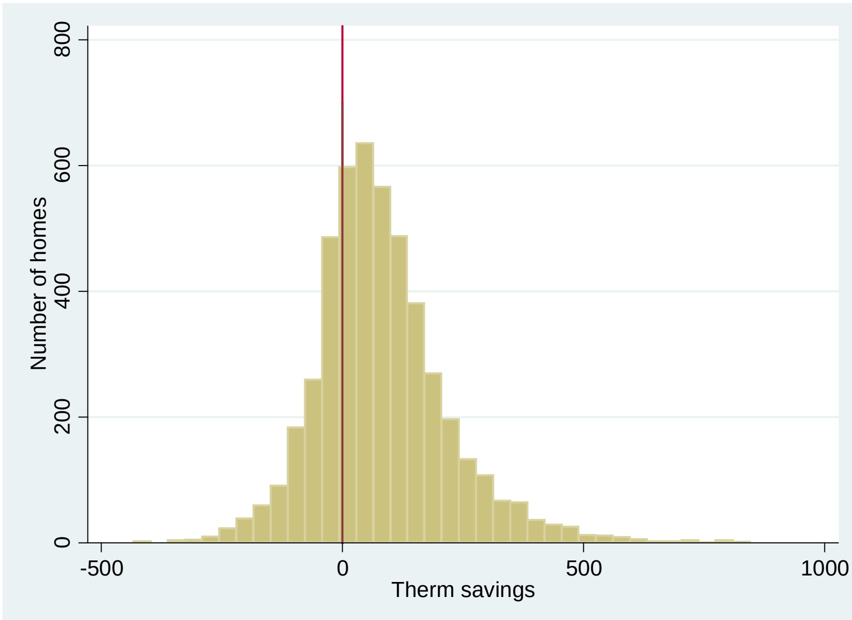
Table 4 2008 Average annualized pre-treatment therm usage and savings for program participants and comparison group

Cohort	N	Pre-period therm usage	Base load	Heating load	Therm savings	Savings net of comparison group	95% CI
2008 participant	4823	751	174	577	82	62	±7
2008 comparison group	910*	748	173	576	20		
2008 metro participants	4624	749	173	575	82	62	±4
2008 metro comp group	3205	747	172	576	19		

*Comparison N is substantially reduced from the N reported in Table 3. Due to the stratification approach employed. The method used forces comparison group strata (region and consumption quantiles) to be exactly proportionate to the participant strata's, resulting in small N's in outlying regions.

Figure 1 below shows the distribution of gross gas savings (not accounting for non-programmatic trends captured by the comparison group) across the study sample. While indicative, this graphic provides a more visual representation of program savings across all homes.

Figure 1 Distribution of therm savings



For frequently occurring measure or measure groupings (N>20), a difference in differences estimate was generated using a stratified comparison group. While these findings are indicative, they help to illustrate some of the trends observed in the multivariate models to follow. While N's are small, the comparison between standalone gas furnaces, duct sealing and the combination of the measure provide insights into an apparent lack of efficacy on the part of the majority of duct sealing projects conducted in 2008.

HVAC contractors performing both furnace installs and duct sealing together yielded an average of 50 therms over and above the standalone gas furnaces installations. Duct sealing only projects achieved savings which were not significantly different from that of the comparison group. Duct sealing only projects were primarily performed by a single high volume contractor, which was placed on probation for high failure rates in quality control (QC) inspections and was subsequently removed from the program. This trend is explored in more detail in Table 6.

Examining the gas furnace results also, average pre-treatment usage was slightly less than 800, of this an estimated 580 therms were used for heating, yielding average heating load savings of almost 14%. This finding is consistent with program tracking data which indicates the average efficiency of incented furnaces in 2008 was 94% with efficiencies of replaced furnaces averaging 80%.

Table 5 Therm savings estimates net of comparison by frequently combined measures

Measure category	Part N	Savings net of comparison group	95% CI	Participant pre-usage
Air sealing	81	24	±28	667
Ceiling insulation	282	78	±16	723
Ceiling and floor insulation	70	105	±32	721
Ceiling and wall insulation	36	126	±38	627
Ceiling insulation and windows	29	88	±50	670
Duct and floor insulation	29	76	±38	766
Duct sealing	98	18	±24	748
Duct and air sealing	371	18	±10	685
Duct sealing and gas furnace	29	130	±71	821
Floor insulation	80	74	±26	706
Gas furnace	1,983	80	±12	792
Wall insulation	90	93	±23	651

Air and duct sealing discussion

The 2008 program year saw a dramatic increase in air and duct sealing projects (air sealing projects went from a few hundred in 2007 to over 1,000 in 2008, duct sealing work increased nearly fourfold to nearly 1,200 projects). Much of this increase in sealing related projects was driven by a single contractor (contractor 'Z'). This contractor was responsible for the majority or air and duct sealing measures during 2008 (63% of air sealing and 61% of duct sealing). As mentioned previously, this contractor's trade ally status was revoked due to poor quality control inspection pass rates.

To explore the effect of this high volume contractor on estimated savings, a difference in differences approach was used similar to that above (Table 5) with and without contractor Z's projects included in Table 6 below. Removal of said contractor results (although with a significantly reduced sample size) in an estimated savings of 64 therms (statistically significant from the comparison group), compared to 18 therms with the contractor's projects included (not statistically different from the comparison group).

These findings point to the effectiveness of HVAC contractors as well as those contractors who were active duct sealers prior to the 2008 program year at sealing ducts, who represented 30% of the work performed in 2008.

A similar approach was used for air sealing, controlling for the effect of active duct/air sealing contractors in 2007, and examining the impact on air sealing savings in 2008. No significant difference was found between those active in 2007 and contractors who entered the air sealing market in 2008. As with prior work conducted by Michael Blasnik on a sample of 2006 to early 2008 air and duct sealing data which found no air sealing savings, the efficacy of air sealing as a measure capable of producing therm savings does not look promising under the implementation protocols used in the program through 2008.

QC inspection protocol calls for a blower door test to verify a contractor's test-out CFM numbers. This approach, however, has no way to validate a contractor's test-in CFM, as the work had already been performed. Given that the QC inspection followed the same guidelines as the air sealing protocol (no sealing of duct registers) QC inspections would yield no clues as to the efficacy of whether reported air sealing delta CFM numbers are simply contractors double counting reductions in duct leakage as air sealing reductions as well.

Table 6 Installer effects on duct and air sealing savings

Measure category	N	Savings net of comparison	95% CI	Participant pre-usage
Duct/air sealing without contractor 'Z'				
Duct sealing	35	**64**	±49	787
Duct and air sealing	16	6	±29	630
Duct sealing and gas furnace	29	130	±71	821
Gas furnace	1,982	79	±11	792
Duct/air sealing only contractor 'Z'				
Duct sealing	63	(8)	±21	726
Duct and air sealing	355	19	±10	687

Regression model estimates

Sites receiving shell and duct Insulation or glazing limited to cases falling between the 5th and 95th percentile of the area treated. Obvious data errors as well as trivial projects (e.g., less than 100 Sq. Ft. of ceiling insulation or a project indicating 11,000 Sqft. of glazing) were eliminated. A comparison of 2008 estimates to 2006-2007 impact estimates reveal nearly identical savings estimates. Given the maturity of insulation technologies and consistent implementation guidelines across program years, this finding comes as little surprise. As with prior impact work, robust regression estimates have been considered the most reliable, and are therefore used for program planning and true-up purposes.

Table 7 Regression estimates of savings

Variables	1 – OLS/SQ FT.	2 – Robust/SQ. FT.	3 – DFBETA/SQ. FT.
Duct sealing	14.62*	**5.559**	0.573
Air sealing	1.495	**5.193**	0.471
Gas furnace	77.51***	**68.20*** **	64.31***
Ceiling insulation (per Sqft.)	0.0498***	**0.0515*** **	0.0401***
Floor insulation (per Sqft.)	0.0549***	**0.0508*** **	0.0430***
Wall insulation (per Sqft.)	0.0645***	**0.0623*** **	0.0566***
Duct insulation (per Lft.)	0.125**	**0.137*** **	0.137**
Windows (per Sqft.)	0.181***	**0.195*** **	0.206**
Constant	24.48***	**21.62*** **	29.93***
Observations	4,689	**4,689**	3,999
R-squared	0.091	**0.115**	0.099

*** p<0.01, ** p<0.05, * p<0.1

Table 8 below provides savings estimates evaluated at the average treated area for the 2008 program year to give an idea of site level savings from these weatherization measures.

Table 8 Estimated insulation and glazing savings using average treated area

Measure	Average treated area	Estimated savings per installed unit (Robust estimates)	Estimated average savings per installation
Ceiling insulation (per Sqft.)	1,258	0.0515	65
Floor insulation (per Sqft.)	1,153	0.0508	59
Wall insulation (per Sqft.)	988	0.0623	62
Duct insulation (per Lft.)	201	0.137	28
Windows (per Sqft.)	256	0.195	50

Duct sealing contractor analysis Table 9 below shows the effect of contractors performing duct sealing in 2008 who were active in the program prior to 2008. The model uses dummy variables rather than the per sq ft. approach used above to avoid reducing the sample size of duct sealing observations and maintain adequate variance in the model. Duct sealing performed by contractors who became active in 2008 achieved negligible savings, whereas controlling for the pre-2008 contractor group yields an estimated savings of ~31 therms per project, in line with the 2006 and 2007 estimate of 34 therms. This finding lends additional evidence to support the conclusion that much of the work performed by the contractor performing the majority of duct sealing work in 2008 was ineffective.

Table 9 Regression estimates controlling for effects of active duct sealing contractors prior to 2008 program year

Variables	OLS	Robust
Duct sealing	9.420	-0.00457
Air sealing	2.193	6.998
Ceiling insulation	60.16***	60.33***
Duct insulation	19.26	21.88**
Floor insulation	57.67***	52.05***
Gas furnace	76.42***	66.71***
Wall insulation	57.73***	51.32***
Windows	42.82***	36.56***
Duct sealing Contractor before 2008	**30.87****	**32.32****
Constant	26.33***	23.95***
Observations	4,823	4,823
R-squared	0.093	0.112

*** p<0.01, ** p<0.05, * p<0.1

Conclusions

- Estimated average savings per household is 62 therms, or 8% of total household gas usage.
- Evidence from this study suggests gas savings for air sealing and duct sealing in 2008 are 0.
    - o A high volume contractor, responsible for over half of duct and air sealing projects, was removed from the program due to consistently poor quality control inspection results, and were subsequently removed from the program.
    - o Three studies on air sealing during the 2006-2007 program years found negligible air sealing savings, given that no change in implementation practices occurred in 2008, the estimated 0 therm savings can be considered robust.
    - o Contractors who actively performed duct sealing prior to 2008 achieved an average therm savings of 32, consistent with the savings estimate of 34 from 2006-2007 impact evaluation, however, these contractors accounted for only 30% of the duct sealing work in 2008.
    - o **Recommendation:** Based on the above two bullets, predicted savings for duct sealing should remain at 34 therms.
    - o **Recommendation:** 2008 air sealing savings are 0 therms per project.

- Duct insulation savings were in line with findings from 2007 (implementation issues in 2006 resulted in a 2006-2007 average of 16 therms), with average savings per project of 28 therms, compared to 2007's estimate of 33.
    - o **Recommendation:** Predicted duct insulation savings should be in the 0.15/therms per lineal foot (average of 2007 estimate of 0.16 and 2008 estimate of 0.14 therms/lft).

- Ceiling, floor and wall insulation estimates of gas savings per square are slightly higher than estimates from the 2006-2007 study.
    - o **Recommendation:** Use average of 2006-2007 and 2008 estimates of therm savings per square foot of shell insulation:
        - Ceiling insulation: 0.052 therms/sqft.
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- Estimates of window 'replacement', in gas heated homes are significantly less than current estimates of 'incremental' savings. This drop in savings will place an even higher importance on the quantifying of non-energy benefits for maintaining measure cost effectiveness. Estimates of per square foot therm savings (0.195 therms/sqft) are consistent with the 2006 finding (0.190 therms/sqft). Inconsistent savings were found during the 2007 program year with an estimate of 0.0339 therms/sqft. of glazing, despite comparable sample sizes across all three program years.
    - o **Recommendation:** Examine quality control reports for windows in the 2007 program year to explore the low savings estimate.
    - o **Recommendation:** Use average of 2006 and 2008 windows savings per therms/sq ft. (0.190 and 0.195 therms/sqft.)
    - o **Recommendation:** Savings need to be 'de-rated' based on baseline assumptions to yield incremental savings to be used by the program. The Regional Technical Forum uses two tiers for replacement U values in single family homes, 0.85 and 0.50. Energy Trust U-value specifications in 2006-2008 were 0.32, with a baseline value of 0.35.

Appendix A: Model specifications

Weather normalization and impact estimation model specifications

Normalized annual consumption (NAC) and measure level savings model specifications:

(1) Pre/Post heating and cooling model: $NAC_i = \alpha_{i1} + \beta_1 HDD_i(\tau_h) + \beta_2 CDD_i(\tau_c) + \varepsilon_i$

(2) Pre/Post heating model: $NAC_i = \alpha_{i1} + \beta_1 HDD_i(\tau_h) + \varepsilon_i$

(3) Multivariate measure level savings model: $DeltaNAC_i = \alpha_{i2} + \beta_m ECM_i + \varepsilon_i$

(4) Difference in differences estimation:

$DeltaNAC_p = (PreNAC_p - PostNAC_p) - (PreNAC_c – PostNAC_c)$

With the estimated standard error calculated using:

$SE(DeltaNAC) = (SE^2_{DeltaNAC,p} + SE^2_{DeltaNAC,c})^{1/2}$

Where:

α_{i1} = Estimated average daily use, the ‘base load’ in models (1) and (2)

α_{i2} = Savings not attributable to measures installed at participant sites in model (3)

NAC_i = Normalized annual consumption for site i

$DeltaNAC_p$ = Participant savings net of comparison group’s change in consumption

PreNAC/PostNAC = Pre/post normalized annual consumption (calculated for both participants and comparison group)

$HDD_i(\tau_h)$ = Model predicted heating slope at reference temperature τ_h

$CDD_i(\tau_c)$ = Model predicted cooling slope at reference temperature τ_c

ECM_{mi} = Vector of ECMs installed at site i

ε_i = Unexplained error term

Multivariate model descriptions

1. Ordinary least squares (OLS) estimate – Estimates coefficients by minimizing the sum of squared errors. This approach is susceptible to outliers.
2. Robust regression – model down-weights cases with large residuals to reduce the influence of outliers on estimated savings coefficients.[3]
3. DFBETA – Cases exerting a large influence on individual coefficients are screened out of the analysis.[4]

[3] Down-weighting occurs when a case’s absolute residual value exceeds a distance from the median absolute deviation from the median residual described by the literature. Extremely large outliers are given weights of 0.

[4] DFBETA values over $2/\sqrt{n}$ are considered by the literature to be an acceptable tolerance for deeming an observation as ‘influential’ (Belsley, Kuh and Welsch 1980).

Appendix B: Michael Blasnik and Associates 2007-2008 Duct and Air Sealing Impact Analysis

Billing Analysis of Air Sealing and Duct Sealing Impacts

Prepared for : Energy Trust of Oregon

Prepared by: Michael Blasnik, Michael Blasnik & Associates

Draft October 9, 2009

This study is designed to assess the energy savings produced by air sealing and duct sealing treatments in the Home Energy Solutions (HES) program using billing data analysis. The analysis focuses on participants from 2007 and part of 2008. A prior billing analysis of 2006 participants found savings of about 40 therms/year for duct sealing and 27 therms/year from duct insulation. Air sealing was not a major program measure at that time.

Data Collection

The Energy Trust provided tracking system data and monthly gas and electric billing data for customers who participated in HES and received air sealing or duct sealing or duct insulation measures from 2005 through 2008. ETO also provide gas and electric billing data for two comparison groups: one composed of 2009 HES participants with actual post-treatment billing data removed, and one composed of a stratified random sample of non-participants. ETO provided daily outdoor temperature data from January 1, 2000 through March 31, 2009 for 11 local weather stations.

Program Treatments

The tracking data included 15,767 measure level records for 4,457 participants and included information about all measures from all ETO programs -- ranging from building shell measures to tankless water heater rebates to refrigerator recycling. The evaluation focused on the 2,328 participants treated from January 2007 though August 2008. To increase sample size, the analysis included participants treated from April through August 2008 even though less than a year of post-treatment data would be available. Screening criteria were used to exclude any cases without a balance of warm and cold weather.

Program treatments for the target group are summarized in Table 1 by heating fuel (which can be both) and by whether duct sealing or air sealing was performed. Building shell and duct leakage rates reported by contractors are also summarized in the table. This leakage data was first screened to eliminate likely errors and cleaned to cap very high values at high limits. Shell leakage rates were excluded if they were outside the range 800 to 10,000 CFM50 and remaining values were capped at 8,000 CFM50. Duct leakage rates were excluded if they were outside the range 20 to 8,000 CFM50 and values were capped at 4,000 CFM50.

Table 1. Program Treatments Summary

		Gas Heat			Electric Heat		
	All	All	Air Seal	Duct Seal	All	Air Seal	Duct Seal
# Participants	2,328	1,377	608	967	962	128	883
Manufactured Home	32%	6%	0%	7%	69%	0%	75%
Program Measures							
Air Sealing	32%	44%	100%	60%	14%	100%	14%
Duct Sealing	80%	71%	95%	100%	93%	95%	100%
Duct Insulation	39%	56%	50%	39%	15%	46%	7%
Attic Insulation	27%	39%	41%	30%	11%	35%	6%
Wall Insulation	7%	11%	14%	9%	2%	9%	1%
Heating Sys Repl/Upgr	16%	18%	14%	18%	13%	38%	11%
Floor Insulation	31%	45%	43%	32%	11%	38%	6%
Windows	7%	11%	11%	10%	2%	7%	1%
Hot Water Measures	26%	35%	38%	33%	14%	34%	10%
Lighting	36%	36%	39%	32%	37%	39%	36%
Projected Savings							
Projected kWh/yr	902	314	323	269	1,759	4,595	1,590
Projected therms/yr	93	156	188	147	4	4	1
Building Shell Air Leakage (CFM50)							
	n=690		n=562	n=531		n=124	n=118
Pre Treatment	3,069		2,997	2,987		3,407	3,415
Post Treatment	2,413		2,364	2,364		2,643	2,642
Leakage Reduction	655		633	623		765	773
Duct Leakage (CFM50 to outside)							
			n=551	n=842		n=120	n=293
Pre Treatment	869		907	887		974	819
Post Treatment	332		376	343		385	308
Leakage Reduction	537		531	544		590	512

Nearly all of the target homes received duct sealing -- 80% overall and 93% of the homes with electric heat. Air sealing was performed in about one third of all homes – 44% of gas heated homes and 14% of electric heated homes. Other common retrofits included duct insulation, attic insulation, floor insulation, hot water measures (mostly low flow devices but some replacements, including tankless, and clothes washers), and lighting. Less common treatments included wall insulation, window replacement, and heating system replacements, which also includes some heat pump commissioning.

Some of the patterns in program treatments pose potential problems for assessing savings by measure:

- None of the homes received air sealing as the only treatment.

- Duct sealing was performed in nearly every home that got air sealing – all but 31 of the 608 gas heated homes that received air sealing also received duct sealing
- Most HVAC contractors, and a total of 20 of the 46 contractors that did duct sealing, did not do any air sealing work.
- The largest air sealing contractor in the program performed one third of all air sealing jobs and specialized in doing just air sealing and duct sealing but did not do duct insulation or other building shell or equipment work.
- Most homes with electric heat were manufactured homes. Manufactured homes tended to receive only duct sealing with some lighting, and hot water measures. None of the manufactured homes in the electric heat target group received any air sealing or duct insulation or wall or floor insulation.

The lack of participants receiving just air sealing or receiving air sealing without duct sealing means that the estimation of savings from air sealing will depend primarily on how the savings differed between homes that got duct sealing but no air sealing to those that received both retrofits. To the extent that air sealing work is related to other factors, such as housing characteristics or specific contractors, air sealing savings estimates may be biased. For example, if the contractors that do air sealing tend to achieve lower savings from duct sealing than other contractors, then the air sealing savings will be underestimated while duct sealing savings will be over-estimated.

Building Shell and Duct Leakage Rates and Reductions

Reported air leakage reductions averaged 655 CFM50, a little more than 20% of the pre-treatment leakage rate of 3,069. Electrically heated homes that received air sealing tended to be a little leakier and achieve greater leakage reductions than the gas heated homes. Reported duct leakage reductions averaged 537 CFM50, equal to 62% of the average initial leakage rate of 869 CFM50. The tracking system did not have pre and post retrofit duct leakage information for most electrically heated manufactured homes leading to smaller samples.

Program testing standards do not require that ducts be masked off or the duct testing fan be sealed when performing the building shell leakage test. If one assumes that at least the testing fan is open, the reported shell leakage rates include a significant fraction of the duct leakage to outside. The reported initial duct leakage is equal to 30% of the initial shell leakage. However, during a shell leakage test the duct leaks would usually experience pressures of less than 50 pa, especially in leaky systems. If one assumes a 25 pa pressure during the initial shell leakage test, then duct leakage would have contributed about 20% of the pre-treatment whole house leakage on average. If one assumes a 40 pa pressure after duct sealing, then the duct leakage reduction should have reduced measured shell leakage by about 250 – 300 CFM50. Reductions of this size imply that about 40% of the reported building shell leakage reductions are actually duct leakage reductions counted twice. Infiltration modeling suggests that the annual gas heating savings expected from the reported shell leakage reductions might be about 40 therms per year. But if duct leakage reductions are excluded from this (and accounted for as part of duct sealing impacts), then the projected savings from the shell leakage reductions would drop to about 25 therms per year. The deemed savings value for air sealing in the tracking system was 25.5 therms, so perhaps no adjustment of expectations is needed.

Analysis Approach

The billing data were separated into pre and post retrofit periods based on the starting and ending measure installation dates for each participant. For the comparison groups, two pseudo treatment dates were randomly assigned to each customer – one from the 2007 participants and one from the 2008 participants – allowing comparison cases to be used for each year of the program. Pre and post treatment meter readings were eliminated if they occurred more than 14 meter readings and 450 days before or after the actual or pseudo treatment date.

The pre and post treatment gas billing data for each participant and comparison group customer was weather-normalized using a variable-base degree day regression model similar to PRISM. This model differs from PRISM in that it employs a Bayesian approach to estimating the balance point temperature which helps to avoid extreme balance point temperature estimates. Electric usage data were analyzed using a heating and cooling degree day adjustment method based on aggregating usage and degree day data into three seasons (winter, summer, and neither) and then solving for baseload, heating, and cooling slopes. Heating degree days were calculated at base 60°F and cooling degree days at base 70°F.

Weather normalization results were screened for reliability by removing cases where:

- the gas regression model fit was not very good -- R-squared <0.70 or CV(total)>20% or CV(heat)>100%
- there was insufficient data -- for gas: <180 days or <40% of a normal year's HDD or (max HDD/day- min HDD/day) < average HDD/day; for electric: <=270 days, <40% of normal year's HDD or CDD, no true baseload months.
- the usage was inconsistent with an occupied single family home heated by the specified fuel – for electric total >70,000 kWh/yr or heating <2,000 kWh/yr; for gas total <300 therms/yr or negative baseload or heating;
- the change in total usage was greater than 65%
- the total usage was outside the range of usage found among participants (only applied to comparison groups).

The data screening resulted in usable gas weather normalization results for 605 participants, 1,974 comparison group cases from future participants and 7,444 comparison group cases from randomly selected (stratified) non-participants. More than a third of the target participant group had insufficient data for the usage analysis – primarily due to the attempt to include homes treated through August 2008, most of which did not have sufficient usage data. About 10% of each group was lost due to usage outside the acceptable range. Poor usage data fits were responsible for just 7% of participant attrition and less than 0.5% of cases were excluded as savings outliers. Overall, 48% of target participants and more than 60% of each comparison group passed the screening criteria.

For the electric analysis, there were usable results for 334 participants, 594 comparison group future participants, and 5,270 random comparison group cases. There was insufficient usage data for the analysis for 38% of the target and future participant groups and 48% of the random comparison cases. Usage out of range was found for 8% of participants, 10% of later participants, and 30% of random comparison cases. Most of this attrition was apparent electric heating loads of less than 2,000 kWh, which screened out many random comparison cases that don't have electric heat and also likely screened out many participant cases that use supplemental fuels. About 2% of participants were savings outliers while just 0.1% of later participants experienced such large usage changes.

The basic analysis involved calculating the mean savings for the participants and then subtracting the mean savings of a weighted comparison group to estimate net savings. Comparison group cases were weighted to match the participant group using post-stratification on weather station (2 stations for gas and 3 for electric), pre-treatment annualized total gas usage (6 bins), electric usage components (6 bins for heating load and 6 bins for total load), and program participation year (2 years, to match comparison group cases from the same treatment date range). This weighted matching method provides a flexible way to improve the comparability of the comparison group without requiring many of the assumptions inherent in a regression-based adjustment approach. This stratification was performed separately in all savings break-outs for each cohort group analyzed, e.g., homes that received duct sealing have the comparison group weighted based on the distribution of strata for just the participants that received duct sealing.

Gas Savings

The most obvious and straightforward approach to assessing savings from duct sealing and air sealing is to directly analyze net savings for participants who only received those treatments -- preferably each treatment by itself. Of the 605 gas heated homes in the analysis, none received just air sealing, 65 received just duct sealing, and 93 received air sealing and duct sealing. These sample sizes are fairly small, especially for air sealing which only occurred with duct sealing. In addition to sample size concerns, the fact that most homes received more than just these treatments raises concerns about why these homes did not and how they may differ from the majority of homes. Table 2 summarizes the net gas savings for all participants that received air sealing and/or duct sealing as their only treatments.

Table 2. Net Gas Savings: Duct Sealing and Air Sealing (therms/year)

	# Homes	Pre	Post	Save	Net Savings	
Air Sealing Only	0					
Duct Sealing Only	65	634	569	65	**55 ±17**	8.7% ±2.7%
Air Sealing & Duct Sealing	93	772	733	39	**16 ±16**	2.1% ±2.1%
Comparison Groups						
- Duct Sealing Only	8,278	629	619	10		
- Air Sealing & Duct Sealing	6,954	767	745	23		

Notes: The later-treated and random comparison groups had nearly identical usage trends and so were combined into a single comparison group. All ± values are 90% confidence intervals on the mean.

The net annual gas savings are estimated at 55 ±17 therms from duct sealing but just 16 ±16 therms from the combination of duct sealing and air sealing. These results imply that air sealing actually reduces savings. We explored the data further to try to explain this unexpected result.

The homes that received just duct sealing had nearly 20% lower pre-treatment usage than the homes that received both treatments. This difference can be traced to the fact that the duct sealing only group includes 27 manufactured homes, which have lower usage on average, while the air sealing plus duct sealing group has no manufactured homes. Excluding manufactured homes from the analysis boosts the net savings even higher in the remaining 38 duct sealing only homes to 84 ±23 therms (12.3% ±3.4%).

A closer examination of the data revealed that one contractor (referred to as contractor Z) performed nearly all of the air sealing work in this analysis. Contractor Z specialized in performing only air & duct sealing work and not other treatments such as duct or building shell insulation. This treatment approach made them different from most other contractors and led to their jobs dominating the group of homes that received just these two measures. Table 3 shows the savings by treatment group, excluding manufactured homes, broken out by whether contractor Z performed the work.

Table 3. Net Gas Savings: Duct & Air Sealing Only, by Contractor Z

	N	Pre	Post	Save	Net Savings	
Duct Sealing Only – Contractor Z	9	614	544	71	**56 ±44**	9.1% ±7.1%
Duct Sealing Only – Not Z	29	713	604	109	**93 ±28**	13.1% ±3.9%
Air & Duct Sealing – Contractor Z	85	760	723	37	**14 ±17**	1.8% ±2.3%
Air & Duct Sealing – Not Z	8	897	839	58	**42 ±60**	4.6% ±6.7%

In both groups, the contractor Z homes had lower average savings than the other homes. However, there are just nine Z-treated homes in the duct sealing only group and eight non-Z homes in the air & duct sealing group. The small samples make the findings indicative, not statistically significant. Still, the results in the table show that the savings among homes that received air & duct sealing is largely driven by the low savings of contractor Z.

To the extent that contractor Z's work differs from other contractors or from the program design, the low savings found in homes treated by them may not help in making decisions about the current or potential value of these treatments. It turns out that contractor Z was actually suspended from the program in January 2009 due to poor work quality found in QC visits. Contractor Z also reported smaller leakage reductions than the other contractors:

- contractor Z reported less than half the average air leakage reduction of other contractors -- 381 CFM50 vs. 765 CFM50;
- contractor Z reported a 421 CFM50 average reduction in duct leakage, considerably less than the 583 CFM50 average reported by the other contractors.

If contractor Z homes are excluded from the analysis, there are just 29 homes that received duct sealing only and 8 homes that received air & duct sealing. The duct sealing only homes had surprisingly large savings of 93 ±28 therms equal to 13.1% of total gas usage and 17.5% of the 531 therm average heating usage. The 8 homes that received both treatments saved less than this, but the sample size is so small that the differences are not statistically significant.

The overall conclusions from this analysis of homes receiving just air and/or duct sealing are:

- poor quality air and duct sealing does not produce much energy savings;

- the program QC systems functioned properly in identifying a problem; and,
- program management apparently made a sound decision in suspending contractor Z.

The simple net savings analysis for homes that received only air sealing and duct sealing treatments provided some useful insights into program performance, but did not provide a very reliable assessment of the energy savings from air sealing or duct sealing retrofits done by contractors other than contractor Z. Rather than simply examine savings for homes that received only the two measures of interest, the savings from air and duct sealing can also be assessed for the larger group of homes that received additional program measures. For these homes, the savings from other measures needs to be accounted for in the analysis so that the incremental savings of air sealing and duct sealing can be estimated. We developed regression models of gas savings as a function of program treatments in an attempt to assess the impacts of treatments individually. We explored several specifications and fitting methods. One issue in this analysis is whether to include homes by contractor Z to assess savings retrospectively, or to exclude these homes and make the assessment more prospective. We explored both approaches

Table 4 shows the results from a series of regression models of gas savings.

Table 4. Gas Savings Regression Analysis

	Regression Model (see notes)					Models: no Contractor Z			
	OLS	R-1	R-2	R-3	R-4	R-1NZ	R-2NZ	R-3NZ	R-4NZ
Air Sealing	*-24*	*-12*	*-10*	*-13*	-26	*-7*	*-6*	*-13*	*-24*
Duct Sealing	48	41	40	49	56	38	38	48	55
Other Measures:									
Duct Insulation	40	36	43	38	31	*32*	40	37	*25*
Attic Insulation	69	81	79	84	85	78	76	83	82
Wall Insulation	78	67	58	77	78	67	58	78	79
Floor Insulation	*27*	39	38	43	41	36	37	42	39
Heating System Replace	118	85	90			90	93		
Window Replacement	*24*	*20*				*19*			
Hot Water Measures (all)	*-9*	*10*				*7*			
Other / Constant	*25*	*8*	*6*	*-14*	*5*	*16*	*11*	*0*	*17*
# Observations	605	605	537	470	438	502	434	368	336

Table Notes
Values in italics are not statistically different from zero at the 95% confidence level.
Dependent variable in all models is the measured gas savings from the pre/post billing analysis
Model definitions:
OLS= ordinary least squares full model on full analysis sample
R-1 = robust regression using Stata rreg command on same model as OLS
R-2 = R-1 but excludes homes with window replacement or major projected hot water savings (>50 th)
R-3 = R-2 but excludes homes that received heating system replacements
R-4 = R-3 but excludes all manufactured homes
NZ version of models are identical except all homes treated by contractor Z are excluded

The table shows savings ranging from 38 to 56 therms from duct sealing and negative savings for air sealing. The air sealing savings are not statistically different from zero for all models except R-4, which excludes manufactured homes. The exclusion of contractor Z from the modeling does not have a large effect on the estimates – air sealing savings estimates get slightly less negative and duct sealing and insulation savings decline slightly.

The shift in some model coefficients from using robust regression suggest that outliers have affected the OLS model. In model R-1, window replacements and hot water measures did not produce statistically significant savings. Model R-2 excluded the 68 homes that received these two retrofits. Model R-3 further excluded 67 homes that had heating system replacements. This model was specified because, although heating system replacements provided large and significant savings, the impacts may vary significantly from home to home and the retrofit may interact with the duct sealing and insulation measures in a variety of ways. In addition, none of the manufactured homes in the analysis received a heating system replacement. Model R-4 was the same as R-3 but also excluded the 32 manufactured homes remaining. The increase in estimated duct sealing savings, decrease in air sealing savings, and decrease in duct insulation savings may be related to the fact that manufactured homes did not receive duct insulation or air sealing and also tended to save less gas than site built homes.

Regression models that attempted to estimate duct sealing or air sealing impacts based directly on reported leakage reductions were not successful in capturing any reliable or statistically significant relationship. However, a model (not shown in the table) that separated duct leakage reduction impacts between homes reporting high leakage reductions (800 CFM50) and those reporting lower leakage reductions yielded the same over impact estimate, but suggested that savings were nearly twice as large in homes that achieved large reductions than homes that achieved smaller reductions.

Model R-3 produced almost identical coefficient estimates for every retrofit whether or not contractor Z was included. Overall, model R-3 appears to provide the most reliable impact estimates and may be considered the best estimates of average gas savings from the retrofits. However, arguments could be made in favor of R-1 or R-2 depending on the importance one gives to a more representative sample compared to potential bias from collinearity between retrofits and housing characteristics.

The estimated savings by measure are similar to a prior billing analysis of 2006 participants that focused on duct sealing and duct insulation. That analysis found duct sealing savings of about 42 therms and duct insulation savings of about 28 therms.

The lack of savings from air sealing is a cause for concern and the exclusion of contractor Z homes did little to change the conclusion that the air sealing work was apparently ineffective or had negligible impact. The poor savings may be a result of biases related to the decision process to perform air sealing. If air sealing work was performed in homes that tended achieved smaller savings from the other retrofits, then the estimated savings may reflect the impacts of these other differences. This type of bias could be related to differences in contractors or housing characteristics. A lack of detailed housing information and the relatively modest sample size in this analysis limited our ability to pursue some of these potential issues. The analysis of reported leakage reductions indicated that a significant fraction of reported shell leakage reductions may have actually been double counting of duct leakage reductions. This finding may also explain some of the apparent lack of savings.

Electric Savings

The electric usage analysis produced savings results for 334 participants – 254 manufactured homes and 80 site-built homes. Given this skew the large fraction of manufactured homes and the need to identify electrically heated homes for the air sealing and duct sealing analysis, the later-treated participants should provide a much better comparison group than the random stratified sample where building type and heating fuel are unknown. An initial analysis found that the random comparison group experienced large changes in usage, especially in the estimated heating portion of the usage, and so the later-treated comparison group was used instead.

Of the 334 participants in the analysis group, 175 received duct sealing and/or air sealing as the only program treatments. That group is comprised of 165 manufactured homes that received just duct sealing, 7 site built homes that received just duct sealing, and 3 site built homes that received duct sealing and air sealing. Given this breakout of treatments, only duct sealing in manufactured homes may be evaluated as a single measure. Air sealing in general and duct sealing in site-built homes can't be reasonably assessed. The net electric heating savings for manufactured homes receiving just duct sealing are summarized in Table 5.

Table 5. Net Electric Heating Savings: Duct Sealing in Manufactured Homes
(kWh/yr for heating component)

	# Homes	Pre	Post	Save	Net Savings	
Participants						
MH Duct Sealing Only	165	6,687	6,088	599	**600 ±303**	9.0% ±4.5%
Comparison Group						
- Later participant MH	295	6,359	6,361	-2		

Notes: All values are kWh/year per home. All ± values are 90% confidence intervals on the mean.

Net heating savings averaged 600 kWh/yr for the 165 manufactured homes that received duct sealing as their only program treatment. This estimate has a fairly wide uncertainty with a 90% confidence ranging from 297 to 903 kWh/yr. In addition to this wide confidence interval, the analysis found net savings of 1,220 kWh/yr when assessing total electric usage rather than just the heating component. The large savings are due to an apparent savings in baseload usage. Although it is certainly possible for some heating savings to appear within the estimated baseload, this net savings appears larger than expected and remains unexplained.

We attempted to fit a variety of measure savings regression models to better estimate duct sealing savings and produce estimates of air sealing savings in homes that also received other program measures. This modeling was unsuccessful in finding any consistent relationships between the various program treatments and observed savings. Many of the treatments were performed in few homes and the inherent variability in electric usage and small samples made the effort fruitless.

Overall, the only conclusion that can be drawn from the electric usage analysis is that savings of about 600 kWh/yr were apparently achieved in manufactured homes but even this estimate has some potential reliability concerns.

Appendix C: Energy Trust 2006-2007 Existing Homes Impact Analysis

Energy Trust Home Energy Solutions Existing Single Family 2006 and 2007 Gas Impact Analysis

Prepared by Brien Sipe
January 20, 2010

Introduction

In order to estimate gross savings for the 2006 and 2007 Home Energy Solutions (HES) gas weatherization program, the following study utilizes a measure level billing analysis. The motivation for this study stems from some uncertainty in the modeling approaches used in impact analyses conducted on the 2005-06 and 2007 program years, leading to unstable or unintuitive results.

To date, the 2003-2004 impact findings have been driving the program's estimated savings. This report builds on a body of studies prepared by Michael Blasnik & Associates (2005-06 duct sealing and insulation, 2007-08 air sealing duct studies) and Stellar Processes (2005-06 duct insulation and sealing study) which targeted specific aspects of the 2005-07 program years. The intent of this and previous studies are to derive savings estimates for use in the annual true-up process, as well as to inform savings predictions for future program planning.

This report discusses the general data cleaning and modeling procedures followed by a discussion of savings estimates by measure type in existing single family homes. Savings estimates are robust, and indicate some measures within the program mix save significantly more than current estimates, while a number of others, notably shell insulation measures, save considerably less.

To provide flexibility in the data analysis, this study uses a normalized annual consumption approach, similar to the PRInceton Scorekeeping Method (PRISM). By combining both program years, many modeling issues were circumvented, namely the frequent combination of certain measures (floor insulation, duct insulation and duct sealing) which allowed more robust samples for estimating average measure savings.

Key Findings

The following details highlights from the analysis, as well as a comparison of model estimated savings to those estimates currently used by the program.

Single family gas findings:

- Average attributable program savings for the 2006-2007 years were 9% of total household gas usage.
- Estimates of savings for gas duct sealing appear to be substantially higher than what is currently booked by the program (59 compared to 25 therms).
- The data suggest duct insulation savings could increase slightly from current estimates (16 from 12).

    - For planning purposes, a higher level of duct insulation savings, at 34, could be used as marked differences in estimated savings exist between 2006 and 2007, possibly linked to changes in how this measure was being installed.
- Evidence from this study suggests gas savings for air sealing in 2006-07 are 0.
    - This finding coincides with studies conducted by Michael Blasnik & Associates, and Heschong Mahone Group's 2007 impact analysis.
    - Test requirements at the time may have allowed for duct leakage reductions to count toward whole house leakage reductions.
- Ceiling, floor and wall insulation estimates of gas savings per square foot range from 44%-64% of what is currently predicted.
- Estimates of window 'replacement' savings in gas heated homes are significantly less than current estimates of 'incremental' savings. This drop in savings will place an even higher importance on the quantifying of non-energy benefits for maintaining measure cost effectiveness.

Table 10 below lists the recommended estimates of therm savings for true-up use as well as place holder values for future program planning. Current thinking is that Ordinary Least Squares (OLS) estimates provide the best representation of what actually occurred in the field in these program years, which include large outliers that effect point estimates. Future predicted savings are based on 'robust' regression estimates, which reduce the influence of outliers on the estimated savings and provide a more moderated portfolio of savings estimates. Future impact work will result in measure level savings estimates for each of the years using these predicted savings values, in other words, predicted savings will all be vetted as data becomes available.

While relatively consistent, these two techniques did lead to disparate estimates of savings for two measures: duct sealing and insulation. Duct insulation's predicted value is based on a 2007 only estimate of savings. Evidence points toward a large change in savings between the 2006-2007 program years, possibly due to different characteristics of treated households or increasing effectiveness of measure installation. The variation in the duct sealing savings results from outlying cases which achieved substantial savings in treated homes. When using a robust approach, these outliers receive less weight in the model resulting in a lower estimate of savings.

In the case of predicted air sealing savings, changes in the implementation of the measure in 2008 and 2009 have led to an expectation of viable savings for the post 2007 program years.

To arrive at the estimate of predicted savings, a weighted average realization rate for weatherization was applied to the original value (26 * 65% = 17 therms).

Table 10 Single family estimated therm savings by measure

Measure	Current FastTrack value	2006-2007 impact estimates	2008-2010 predicted and 2011 suggested working estimate
Air sealing	26	0	17
Duct sealing	21	59	34
Gas furnace	71	82	TBD
Windows	44	28	TBD
Ceiling insulation*	95 (0.08)	61 (0.051)	61 (0.052)
Duct insulation*	12	16 (0.073)	34** (0.148)
Floor insulation*	89 (0.08)	40 (0.036)	40 (0.041)
Wall insulation*	105 (0.10)	54 (0.052)	54 (0.056)

*Insulation measure estimates are presented for the average sized insulation job in 2006-07. Therm savings per square (linear for duct insulation) foot of insulation installed are in parentheses.
** Future suggested value is based on 2007 estimate alone, as there is evidence of a significant change in the savings between the two years.

Methodology

Each sites pre and post treatment period consists of the full year prior to, and following, the year of treatment (a 2007 participant's pre and post years are 2006 and 2007, respectively). Participants with treatments in the pre or post years were removed from the analysis. In addition, observations with treatment dates within a billing period which straddled the beginning or end of a year were dropped. This approach simplified the matching of treatment to comparison group and minimized any weather related bias due to skewed treatment dates in the years of interest.

Billing data cleaning

Energy Trust has developed a standardized procedure to 'clean' billing data prior to its use in billing analysis in-house or by third party contractors. The major steps performed by the routine are:

- Duplicates removed.
- Due to issues with older utility data, sites are examined to ensure a one-to-one relationship between a United States Postal barcode and utility identified 'site'.
- Estimated meter readings added to next actual reading, to ensure meter readings accurately align with weather data.
    - Sites with several consecutive estimates were removed in a later step if their remaining observations fall below a minimum threshold.
- Excessively short or long readings are removed prior to normalization (less than 10 days, greater than 60).
- Sites with occupancy changes during the study period were flagged to assess influence on savings estimates (no substantive changes to estimates were observed).

Comparison group

HES participants with gas or electric savings recorded during 2005 or after July 2009, but in no other year, were used as a comparison group in an effort to control for secular changes in energy consumption. Participants in 2005 could be compared to 2007 participants, while 2009 participants could act as a comparison group for both 2006 and 2007 participants. While the 2005 'past' participant group was not used formally, it provided additional evidence that a surprisingly large non-programmatic decline in gas usage occurred from 2006 to 2008 among the 2007 treatment/comparison cohort.

To ascertain overall net savings attributable to the program, the comparison groups were stratified based on participation year, weather station and consumption quartiles to bring the pre-period usage between the two groups into closer alignment and allow for a more comparable estimate of 'net' attributable program savings.

Modeling approach

Analysis was conducted using a method similar to the PRInceton Score-keeping Method (PRISM). The algorithm decomposes energy use into estimated heating, cooling and base load components. To do this, an optimum 'set-point' or reference temperature is found below (above) which energy use for heating (cooling) is detected. The reference temperature is a combination of consumer preference for thermostat settings, and the thermal integrity of the structure. Long run average weather data[5] is then used to determine energy use in an 'average'

[5] Energy Trust uses TMY3 weather data to align with the Northwest Power and Conservation Council's Regional Technical Forum.

or normal year. An example of long run average energy use is provided in Table 11 below, using estimated coefficients from a normalized annual consumption, or NAC, analysis.

Normalized annual consumption (NAC) and measure level savings model specifications:

(1) Pre/Post heating and cooling model: $NAC_i = \alpha_{i1} + \beta_1 HDD_i(\tau_h) + \beta_2 CDD_i(\tau_c) + \varepsilon_i$
(2) Pre/Post heating model: $NAC_i = \alpha_{i1} + \beta_1 HDD_i(\tau_h) + \varepsilon_i$
(3) Measure level savings model: $DeltaNAC_i = \alpha_{i2} + \beta_m ECM_i + \varepsilon_i$

Where:
α_{i1} = Estimated average daily use, the 'base load' in models (1) and (2)
α_{i2} = Savings not attributable to measures installed at participant sites (3)
$HDD_i(\tau_h)$ = Model predicted heating slope at reference temperature τ_h
$CDD_i(\tau_c)$ = Model predicted cooling slope at reference temperature τ_c
ECM_{mi} = vector of ECMs installed at site i
ε_i = Unexplained error term

Calculation of the pre-period NAC for the example below would be:
NAC = Baseload: [365.25(1.15)] + Heating load: [3466(.308)] = Normalized annual consumption: [1487]

Table 11 Example of output from NAC model for a study site with gas heat

Period	Average daily use (α_{i1})	Estimated Ref. temp (τ_h)	heating slope (β_1)	Model R2	Long run HDD (TMY3)	Normalized annual consumption
Pre	1.15	62	0.308	0.992	3466	1487
Post	0.34	64	0.314	0.996	4011	1383

Following the model estimation, a number of screening steps are used to remove outliers resulting from poor data quality, changes in consumption far beyond what could be expected by program treatments, lack of data, and to flag sites which do not have usage related to weather. Attrition tables for each housing type can be found in their respective sections of this report.

Post normalization data screening:

- Sites were flagged if pre to post change exceeded 65%, changes that could signify other major alterations to the household unrelated to ECM installation.
- Gas sites were flagged if their Pre/post R2 < 0.7
- Michael Blasnik provided guidance on additional screens to verify adequate variation in the model to estimate heating/baseloads. Site's are flagged when the sum of HDD's for observed billing periods were less than 40% of the long run average, or Max-Min HDD/Day were less than Average HDD/day. Prior screens, assessing number of observations and R2 tend to capture most of these sites.
- Sites with pre period consumption above the 99^{th} or below the 1^{st} percentile were removed.
    - Non participant consumption was bounded based on the min and max of participant consumption.
- Sites with less than 6 pre or post observations were flagged.
    - This criteria resulted in a large amount of attrition due to the lack of readings with '0' read values in Energy Trust's utility database. Removal of these observations is due to an older data handling routine used prior to 2007. This could result in

the heating related consumption being biased upward, but this bias, if it exists, is present for both participants and non-participants.

To estimate measure level savings, the pre-post deltas calculated in the first stage of the NAC analysis become the dependent variable, with the ECMs installed at the participating sites being used to explain this calculated delta. Future program participants are used to attempt to control for non-programmatic changes in consumption, which may be related to changing consumer preferences, price effects, and macroeconomic changes in the economy.

Single family homes with gas heat analysis

Single gamily gas heated homes are the largest segment of the residential retrofit program. This section details the attrition of the sample due to data screens, summary statistics for the participating homes in the two program years and measure level estimates of impacts on energy usage.

Large attrition from a lack of adequate utility bills was due to a number of issues, which are described in **Table 12**

Table 10. Due to issues with address entry and lack of a unique postal barcode, many utility accounts could not be identified. Another source of this attrition is sites where the number of observations in the pre and post period was less than 6, leading to the site being dropped from the analysis. As mentioned in the data screen section above, this attrition was due to the current billing database lacking gas readings where the usage level was '0' in a month.

Other sources of attrition come the lack of 'gas' being identified as the homes heating fuel, sites with consumption changes beyond what could be expected by program participation, and extreme outliers. Finally, sites were flagged if model estimation indicated a site's gas consumption wasn't weather sensitive. These sites were retained in the sample to allow for sensitivity of savings estimates in the presence of data points which are not 'well behaved'.

Table 12 Single family gas attrition for 2006-2007

Attrition source	2006 Count	2006 Percent	2007 Count	2007 Percent
Unique sites with gas savings	8173	100%	9611	100%
Sites where bills were found intact	5881	72%	6458	67%
Sites with at least 6 observations pre and post	4806	59%	5435	57%
Sites with therm consumption between the 1st and 99th percentile in pre-period	4754	58%	5364	56%
Sites without dramatic changes in consumption pre to post (< 65% change)	4579	56%	5165	54%

Sites with R2 > 0.7[6]	4205	51%	4718	49%
Site has at least 180 days in pre-post periods & contains adequate variation in weather	4204	51%	4714	49%
Heating system was identified as 'gas'	3998	49%	4519	47%
Sample for analysis	3998	49%	4519	47%
Final gas non-participant sample*	5082	-	5299	-

* Non-participants were screened using the same criteria.

Summaries of pre-period energy usage and net savings for participants are presented in

Table 13 below. Average therm savings for sites participating in the program were 73 and 66 therms for the 2006 and 2007 program years, respectively. In total, program participants reduced their consumption by about 9% of their total gas load.

Participants from 2009 were used as a comparison group for both 2006 and 2007 participant cohorts to identify secular trends in energy consumption that were not directly attributable to the program. A substantial non-programmatic downturn in consumption occurred in the 2007 comparison group consumption, due to the size of this drop, those who participated in 2005, were also used as a comparison group. From 2006-2008, consumption among this group saw a 25 therm drop in usage (those who participated in any program year between 2006-2008 were removed from the analysis).

Table 13 Average annualized therm savings for program participants and comparison groups

Cohort	N	Average pre-period therm usage	Average therm savings	Net of comparison group	95% confidence interval
2006 participant	3998	822	87	77	±4
2007 participant	4519	815	96	69	±4
All participants	8517	818	92	73	±3
2006 comparison	4373	816	10		
2007 comparison	4630	815	27		
All comparison	9003*	816	19		

*Comparison N is smaller than available N listed in **Table 12** due to stratification approach employed.

In addition to similar pre-period usage between the program years, age and size of home, summarized in Table 14, were nearly identical between the two years, leading to the conclusion that a combined sample would be an appropriate. Despite this, sensitivity analysis was

[6] There is some concern on the removal of sites that do not have 'well-behaved' usage data. Appendix A explores the model specifications used to estimate measure level savings with and without goodness of fit screens. The resulting differences (shown in **Table** 23) in estimates are slight if not negligible.

conducted to estimate if large discrepancies existed between years for measure level savings, with discussions of annual impacts discussed in the measure level savings section below.

Table 14 Average age and size of homes participating in single family gas program by year

Housing characteristics	2006 participant	2007 participant
Mean home age	47	47
Mean size in square feet	1948	1974

Total counts of single family gas measures installed by year are presented in Table 15 for the program and study sample. Nearly identical proportions of measures installed in the annual datasets led to the decision to combine the datasets and estimate average savings across 2006 and 2007.

Table 15 Gas measure counts by year, program and study totals*

Measure type	2006 measure count	2006 measures in dataset	2007 measure count	2007 measures in dataset
Air sealing	208	120	270	150
Ceiling insulation	1238	784	1340	791
Hot water measures	2851	1317	3796	1607
Duct insulation	531	319	449	256
Duct sealing	334	206	377	224
Floor insulation	697	404	818	461
Gas furnaces	4811	3005	5071	2945
Wall insulation	533	316	545	290
Windows	325	185	339	168
Total	11528	6656	13005	6892

*Clothes washers, a non HES measure, are excluded from this table, although they appear in the model estimates of savings.

Measure level savings model descriptions

1. OLS estimate
2. Robust regression – model down-weights cases with large residuals to reduce the influence of outliers on the estimates
3. OLS estimate with per installed sqft estimates of insulation savings, N drops due to the removal of outliers (sites with reported installed sqft under the 1st or over the 99th percentile) as well as cases where data was missing.
4. Robust regression with per installed sqft estimates of insulation savings, N drops due to the removal of outliers (sites with reported installed sqft under the 1st or over the 99th percentile) as well as cases where data was missing.

Models 1 and 2 use simple dummy variables to represent each measure installed at a participant site. Models 3 and 4 utilize the square foot attribute captured in FastTrack to estimate the incremental impact of each additional square foot (linear foot in the case of duct insulation) of insulation. Given that insulation jobs can vary substantially in the square footage installed, and that a per square foot estimate of savings are used to book savings, models 3 and

4 contain are a more useful overall model. Because of this, these savings estimates were chosen to be incorporated into the true-up and planning process.

Both specifications incorporate an ordinary least squares (OLS) and a robust estimation. Robust regression uses an iterative function to down-weight cases that are determined to be outliers, using criteria suggested by the literature[7]. This process results in clearly observed changes in several savings estimates as can be seen in Table 16 below. Other measures of robustness were employed (DFBETAs) to evaluate if individual outliers substantially affected coefficient estimates. Given that model estimates did not differ substantially from the OLS models in this sensitivity analysis, it was decided to only report OLS and robust findings.

Measure level savings estimates

Each measure and its estimated annual impact on therm consumption for each model specification are presented in Table 16 below. A positive number indicates the average reduction in annual therm use accompanying installation of a particular measure. Proposed estimates for incorporation into Energy Trust's annual true-up process are in bold (Model 3). Discussions involving program staff and oversight have settled upon the use of OLS estimates as a means to capture the average of what occurred in the field in a particular program year. These estimates are influenced by large outliers, which is quite dramatic in the case of duct sealing work as shown below.

For future predicted savings, the robust numbers in model 4 are being considered as place holders. Given that the robust estimates can mitigate the effects of outlying savings estimates (such as massive savings resulting from a complete overhaul of a duct system) they provide a more moderate estimate of measure level savings.

High levels of co-linearity between measures can be an issue in an analysis at the measure level. Examining the variance inflation factor yields a high of 2.9 (for gas furnaces) indicate that co-linearity is not a significant problem (the literature suggests a level of 6 and above are cause for concern).

Both clothes washers and HER hot water measures have such small estimated savings (3% and 1% of average load, respectively) that their impact is likely within the noise (constant) and is not of specific interest in this analysis. Dropping them from the study, however, would have resulted in a substantially reduced sample.

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[7] Down-weighting occurs when a case's absolute residual value exceeds a distance from the median absolute deviation from the median residual described by the literature. Extremely large outliers are given weights of 0.

Table 16 2006 and 2007 combined estimates of gas measure level savings

Variables	1 - OLS	2 - Robust	**3 – OLS/SQFT**	4 - Robust/SQFT
Air sealing	-8.378	8.849	**-13.88**	0.0879
Ceiling insulation	63.65***	62.06***		
Clothes washer	-0.661	-0.7	**0.765**	1.043
HER hot water measures	-1.553	-4.458	**0.281**	-2.742
Duct insulation	17.94	18.39*		
Duct sealing	59.65***	36.39***	**59.26*** **	34.33***
Floor insulation	41.41***	43.72***		
Gas furnace	80.19***	73.27***	**82.08*** **	75.27***
Wall insulation	44.29***	50.17***		
Windows	22.93**	14.61	**27.88** **	16.42*
Ceiling insulation/sqft			**0.0510*** **	0.0519***
Floor insulation/sqft			**0.0357*** **	0.0406***
Wall insulation/sqft			**0.0515*** **	0.0564***
Duct insulation/lft.			**0.0725** **	0.0729***
Constant	35.67***	32.81***	**33.81*** **	30.70***
Observations†	8179	8179	**8131**	8131
R-squared	0.082	0.099	**0.086**	0.105

*** p<0.01, ** p<0.05, * p<0.1
†Additional data screens reduce N below that listed in **Table 12** above, which shows sample attrition. These screens included: removal of sites with infrequently installed or previously evaluated measures (e.g., backup gas furnaces, boilers and tankless gas water heaters).

Measure level savings discussion

Air sealing

The most surprising finding from modeling is the lack of savings associated with the air sealing measure. High co-linearity between duct and air sealing was one suspect (195 of 275 air sealing measures in the final model were installed alongside duct sealing). Forming a composite measure of duct sealing plus air sealing and re-running all models (**Table 17**), we obtain comparable savings between the combined measure and duct sealing alone. While model 2 does shows savings for the composite beyond that of duct sealing alone but the estimates do not differ statistically. Models 3 and 4, yield nearly identical savings between duct sealing alone and the composite measure. In no model are the estimates statistically different from each another. In sum, the data point toward negligible savings for the air sealing measure in these two program years.

Michael Blasnik's (2009) examination of the 2007 and early 2008, and HMG's work on the 2007 program year both found a no incremental savings associated with air sealing. Blasnik's research suggests that reductions in duct leakage could have been counted toward shell leakage reductions during this period of the program. Taping off duct registers while testing shell leakage rates was not required until 2009, leaving an opportunity for double counting of duck leakage reductions.

Table 17 Incremental gas savings associated with air sealing from regression models

Variable	1 - OLS	2 - Robust	3 – OLS/SQFT	4 Robust/SQFT
Duct sealing	55.52***	34.02***	54.40***	31.74***
Duct sealing + Air sealing	55.81***	47.75***	50.86***	37.29***

*** p<0.01, ** p<0.05, * p<0.1

Duct sealing

Attention should also be drawn to the change in the duct sealing parameter estimate between OLS and robust regression. The robust approach indicates that there are outliers which are skewing the mean estimate up, possibly indicating the occasional duct sealing job which yields extremely high savings. This phenomenon is observed both in the 06 and 07 years when estimated separately. Similar findings were reported by Michael Blasnik & Associates when conducting duct and air sealing specific analyses on the 06 and 07 program years. For the purposes of program savings and planning, the OLS estimate provides an average that is influenced by everything that occurred in the field, including all exceptional, as well as poor, work conducted, and form the recommended estimates for the true-up process, while the robust estimates could better serve as a forward looking predictor of savings.

Duct insulation

Sensitivity analysis on duct insulation showed the opposite effect on savings as were observed with duct sealing. When yearly models were estimated, duct insulation provided no statistically significant savings in 2006, while savings for 2007 were substantially higher, and significant. When combined, 2006 serves to pull down the overall impact for the measure. Studies conducted by Michael Blasnik found a similar upward trend in impacts across 2006 and 2007 for duct insulation. Evaluating average linear feet of duct insulation installed at the OLS impact from model 3 yields an average of 16 therms, slightly higher than the current expected value.

Table 18 Duct insulation estimate savings

Insulation type	Mean linear feet of installed insulation	Average SQFT impact estimate from (model 3)	Mean estimated therm savings (model 3)
Duct insulation	227	0.0725	16

As with duct and air sealing, a composite measure was created to access savings estimates among duct insulation and sealing installations alone, and when performed together. These findings, by year, can be found below in **Table 19**. A pronounced difference in estimated savings occur when moving from 2006 to 2007, with the combined measure saving considerably more than duct sealing alone in 2007, but far less in 2006. In both 2006 and 2007, three contractors dominated the installation of duct sealing and insulation together, although no one contractor's removal from the sample can be tied to significant changes in the estimate of savings.

Table 19 Incremental gas savings associated with duct sealing and duct insulation measures

Measure	Model	2006	2007	Both years
Duct insulation	Model 1	24.33	24.25	25.06**

	Model 2	26.60*	24.21	24.56**
Duct sealing	Model 1	97.83***	62.39***	73.08***
	Model 2	66.47***	44.41***	49.79***
Duct sealing/insulation	Model 1	48.62**	103.1***	68.92***
	Model 2	37.59**	72.38***	47.66***

*** p<0.01, ** p<0.05, * p<0.1

Examining the usage information (**Table 20**) for those sites receiving one or both of these duct measures revealed a pronounced change in the pre-period usage between the two program years. Average pre-treatment usage among duct sealing only sites dropped by over 60 therms between the two program years, while those sites receiving both duct measures increased between the two years. These changes coincide with the fluctuations in the savings estimates presented above in **Table 19**.

Table 20 Average pre-period therm use by sites receiving duct sealing and insulation by year

Measure	2006 participant average pre-period therm usage	2007 participant average pre-period therm usage
Duct sealing only	864	796
Duct sealing and insulation	800	859

Windows and gas furnace incremental savings

Both windows and gas furnace estimates represent ‘replacement’ savings or old and potentially obsolete equipment. For program purposes ‘incremental’ savings are captured as the delta between the current baseline and the energy efficient upgrade. Given that gas furnaces will soon be phased out no change in the savings estimate are recommended.

Notably, the predicted replacement savings for the average window installation averages 14-28 therms depending on model, significantly lower than the current expected incremental savings of 44 therms for program years 2006-07. Base line calculations are likely to be a part of an upcoming market transformation study focusing on windows. At that time, incremental savings can be derived from replacement savings estimates from these study findings.

Shell insulation measures

Models 3-4 provide estimates of per square of all insulation types. As mentioned previously, the robust regression estimate of duct insulation improves markedly, and is likely a result of the 2006 program year’s downward influence on the impact estimate.

Table 21 below provides the total average savings by insulation measure for model 3 based on the average sized installation in the sample. These estimates are significantly lower than current estimates (0.10 therms/sqft for wall insulation, 0.08 therms/sqft for ceiling and floor insulation).

Table 21 Mean square feet of insulation installed by insulation type

Insulation type	Mean SQFT installation*	Average SQFT impact estimate from (model 3)	Mean estimated therm savings

			(model 3)
Ceiling insulation	1193	0.051	61
Floor insulation	1113	0.0357	40
Wall insulation	1045	0.0515	54

*Average SQFT of insulation work from 2006-2007 program tracking data.

Annual estimates of savings

Measure level savings are presented below in

Table **22**, controlling for the effect of each program year. Variable names with the '2006' suffix indicate the effect of installation in 2006, with 2007 being the base year. Thus, a 2006 coefficient significantly different from zero would indicate a statistical difference in the impact of measure savings between the two program years.

The majority of weatherization measures installed do not differ statistically between the two program years, with a few notable exceptions. Estimates of savings for duct insulation vary by a magnitude of 2-4 between the two years. Based on these findings, it's recommended that future predicted savings be based on the 2007 only savings, whereas the 2006-2007 true-up process should incorporate the average estimated OLS figure. Evaluating the Robust 2007 duct insulation savings estimate *only* yields an estimate of 34 therms, forming the basis of future predicted savings.

Table 22 Gas impact estimates associated with individual years

Variables	1 - OLS	2 - Robust	3 – OLS/SQFT	4 Robust/SQFT
Air sealing	-30.77	-1.465	-44.22**	-17.18
Air sealing 2006	42.17	15.18	57.63**	29.19
Ceiling insulation	64.56***	63.93***		
Ceiling insulation 2006	0.723	-0.529		
Clothes washer	6.804	6.246	7.777	7.361
Clothes washer 2006	-12.26	-11.63	-12.11	-11.34
HER hot water measures	7.254	3.345	8.636	4.569
HER hot water measures 2006	-17.39***	-15.84***	-17.22***	-15.65***
Duct insulation	28.13*	25.37*		
Duct insulation 2006	-19.04	-9.415		
Duct sealing	68.96***	45.03***	64.52***	40.38***
Duct sealing 2006	-15.59	-15.17	-10.34	-10.64
Floor insulation	33.90***	44.84***		
Floor insulation 2006	16.37	-7.081		
Gas furnace	88.38***	80.45***	89.98***	82.13***
Gas furnace 2006	-14.49***	-13.04***	-14.72***	-13.20***
Wall insulation	59.97***	64.52***		
Wall insulation 2006	-30.59*	-30.07**		
Windows	22.28	3.311	27.80*	6.212
Windows 2006	2.447	24.09	0.87	22.28
Ceiling insulation/sqft			0.0489***	0.0511***
Ceiling insulation/sqft 2006			0.00457	0.00269
Floor insulation/sqft			0.0301***	0.0400***
Floor insulation/sqft 2006			0.0114	-0.00359
Wall insulation/sqft			0.0592***	0.0634***
Wall insulation/sqft 2006			-0.0158	-0.0151
Duct insulation/linear foot			0.163***	0.148***
Duct insulation/linear foot 2006			-0.128*	-0.102*
Constant	34.57***	31.92***	33.14***	30.21***
Observations	8179	8179	8131	8131
R-squared	0.085	0.102	0.089	0.109

*** p<0.01, ** p<0.05, * p<0.1

Trends in impact changes across 2006-2007 resemble trends observed in Michael Blasnik's reports on the 2005-06 and 2007-08 duct and air sealing analyses (although the actual point estimates differ substantially in the case of some measures).

Worth noting is the substantial difference in estimated savings for duct insulation per linear foot across 2006 and 2007 (models 3 and 4). Similar levels of co-linearity (correlation R .48-.55) exist between duct insulation and duct sealing/floor insulation in both program years. The use of 'composite' measures mentioned in the measure level discussion significantly reduced the co-linearity of these measures although leading to smaller N's for each independent variable.

Exploring model estimates with and without R2 screens

Given that normalized annual consumption analysis places data quality screens that filter out 'poorly behaved' utility data, it is worth examining the effect that data screens have on measure level savings estimates. **Table 23** explores model specifications one and two with and without the 'goodness of fit' model screen (R2). Point estimates are relatively stable with the exception of floor insulation in the OLS models. Robust estimates yield stable coefficients with and without the data screen, indicating that cases being screened out using R2 are likely outliers anyway.

Table 23 Original gas specifications without goodness of fit model screens

Variables	OLS	OLS with no R2 screen	Robust	Robust with no R2 screen
Air sealing	-8.378	-0.6	8.849	14.04
Ceiling insulation	63.65***	59.82***	62.06***	60.96***
Clothes washer	-0.661	-1.464	-0.7	0.749
HER hot water measures	-1.553	0.0728	-4.458	-1.854
Duct insulation	17.94	26.94**	18.39*	18.54**
Duct sealing	59.65***	56.67***	36.39***	33.88***
Floor insulation	41.41***	30.24***	43.72***	39.16***
Gas furnace	80.19***	74.15***	73.27***	69.63***
Wall insulation	44.29***	41.30***	50.17***	45.80***
Windows	22.93**	25.85**	14.61	17.09*
Constant	35.67***	36.65***	32.81***	31.76***
Observations	8179	8907	8179	8907
R-squared	0.082	0.066	0.099	0.081