ORNL/CON-500

EVALUATION OF THE DISTRICT OF COLUMBIA ENERGY OFFICE RESIDENTIAL CONSERVATION ASSISTANCE PROGRAM FOR NATURAL GAS-HEATED SINGLE-FAMILY HOMES

March 2007

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ABBREVIATIONS, ACRONYMS, AND INITIALISMS

Btu	British thermal unit (1,055 joules)
CV	coefficient of variation
DCEO	District of Columbia Energy Office
DOE	U.S. Department of Energy
FI	flatness index (see Fels, et al. 1995)
FY	fiscal year
HDD	Heating degree day
LIHEAP	Low-Income Home Energy Assistance Program
MBtu	million Btu
NEAT	National Energy Audit
ORNL	Oak Ridge National Laboratory
PRISM	Princeton Scorekeeping Method
R^2	fraction of the variance in the data that is explained by a regression
RCAP	Residential Conservation Assistance Program
RETF	Reliable Energy Trust Fund
se	standard error
therm	100,000 Btu
WAP	Weatherization Assistance Program

EXECUTIVE SUMMARY

At the request of the U.S. Department of Energy (DOE), Oak Ridge National Laboratory (ORNL), with assistance from the District of Columbia Energy Office (DCEO) performed an evaluation of part of the DCEO Residential Conservation Assistance Program (RCAP). The primary objective of the evaluation was to evaluate the effectiveness of the DCEO weatherization program.

Because Weatherization Assistance Program (WAP) funds are used primarily for weatherization of single-family homes and because evaluating the performance of multi-family residences would be more complex than the project budget would support, ORNL and DCEO focused the study on gas-heated single-family homes. DCEO provided treatment information and arranged for the gas utility to provide billing data for 100 treatment houses and 434 control houses. The Princeton Scorkeeping Method (PRISM) software package was used to normalize energy use for standard weather conditions.

The houses of the initial treatment group of 100 houses received over 450 measures costing a little over $180,000, including labor and materials. The average cost per house was $1,811 and the median cost per house was $1,674. Window replacement was the most common measure and accounted for about 35% of total expenditures. Ceiling and floor insulation was installed in 61 houses and accounts for almost 22% of the expenditures. Twenty-seven houses received replacement doors at an average cost of $620 per house. Eight houses received furnace or boiler replacements at an average cost of about $3,000 per house.

The control-adjusted average measured savings are about 20 therms/year. The 95% confidence interval is approximately −20 to +60 therms/year. The average pre-weatherization energy consumption of the houses was about 1,100 therm/year. Consequently, the adjusted average savings is approximately 2% (±4%)—not significantly different than zero.

Most RCAP expenditures appear to go to repairs. While some repairs may have energy benefits, measures selected to meet repair needs generally have smaller energy benefits per unit cost than measures selected for energy conservation purposes. To the extent that extensive repairs are necessary or desirable, expectations of energy savings need to be adjusted.

Since 2002, the DCEO has implemented a number of program improvements it believes enhance program performance. In 2003, DCEO published formal guidance for weatherization in RCAP (DCEO 2003). Consequently, the results of this study may not adequately represent the current performance of the program. DCEO should re-examine current RCAP weatherization patterns and energy savings to assess the effects of program changes.

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1. INTRODUCTION

The District of Columbia Energy Office Residential Conservation Assistance Program (RCAP) acts as the grantee for the U.S. Department of Energy's (DOE) Weatherization Assistance Program (WAP). In this capacity, it provides weatherization services to eligible District residents by installing energy efficiency measures (e.g., insulation) in their homes. The grant funds to support this program come from various sources: DOE, the U.S. Department of Health and Human Services' Low-Income Home Energy Assistance Program (LIHEAP), and the rate-payer-financed Reliable Energy Trust Fund (RETF). In addition, contributions from multi-family landlords toward the purchase and installation of additional conservation measures provide leveraged funds, thus expanding services for clients living in those buildings. Using funds from WAP, LIHEAP, and RETF, the District of Columbia Energy Office (DCEO) operates the RCAP through various community-based organizations. In recent years, the RCAP has served about 700 housing units each year, about 75% of which are multi-family housing units.

At the request of the DCEO and the U.S. Department of Energy (DOE), Oak Ridge National Laboratory (ORNL) and the DCEO performed an evaluation of the RCAP. The primary objective of the evaluation was to assess the effectiveness of the DCEO weatherization program. Two measures of effectiveness were examined: (1) estimates of the annual net energy savings (MBtu/year) per household served; and (2) simple payback period. As calculated for this report, simple pay back period is the total cost of labor and materials of installed weatherization measures divided by the estimated dollar value of annual energy savings from those measures.[1] A secondary objective of this study was to provide information about individual weatherization measure effectiveness that would help the DCEO improve its weatherization program.

The evaluation focused on the parts of the RCAP that are the target of most DOE funding. The study was intended to provide the most benefit to the DCEO within the constraints of the project resources. Because WAP funds are used primarily for weatherization of single-family homes and because evaluating the performance of multi-family residences would be more complex than the project budget would support, the DCEO and ORNL decided to focus the study on single-family homes. In the District of Columbia, single-family homes are most often heated with natural gas. Because evaluating both gas and electrically heated homes would require more than the available resources, ORNL and DCEO chose to focus the effort on gas-heated homes.

In total, RCAP weatherized approximately 1,400 housing units in fiscal years 2001 and 2002. Single family homes accounted for about 10% of the units weatherized. The remainder housing units were units in multi-family buildings. No mobile homes were weatherized by RCAP with DOE funds.

[1] Discounted benefit-to-cost ratio, a more sophisticated measure, had originally been contemplated as the measure of cost effectiveness. Simple payback period was selected because it required no assumptions about measure lifetimes, discount rates, or fuel price escalation.

2. APPROACH

2.1 ANALYTICAL METHODS

The Princeton Scorekeeping Method (PRISM, Fels et al. 1995) was selected as the principal analytical method to be used for estimation of program energy savings because it works well with utility billing data. PRISM uses a regression technique to adjust for year-to-year weather variations. PRISM also allows for use of a control group to adjust for other factors that may affect household energy use such as the price of fuel or the state of the economy. Because natural gas prices had been volatile and the state of the economy had been changing rapidly during the study period, ORNL and DCEO decided to employ a control group to correct for factors other than weather that might affect energy savings estimates.

ORNL has recently developed an alternative method, the ORNL Aggregate Method, for analyzing energy billing data (Schmoyer and Berry 2003), which was also used for this DCEO study as an independent check on the results of the PRISM analysis.[2] The method is called "aggregate" because energy consumption, billing days, and degree days are input only as pre- and post-treatment totals. That is, for each house, three pre-weatherization and three post-weatherization parameters are used: total energy used, total billing days and total degree days. The heating degree day reference temperature is not estimated for each house, as in PRISM, but is fixed for all houses.[3] Because the Aggregate Method does not require house-specific reference temperatures, it is more tolerant of households with only a few months of data, and it can use data for houses with anomalous energy consumption patterns. Previous use of the model was for a large set of gas and electric billing data for homes weatherized in Texas (Schmoyer and Berry 2003).

2.2 CONTROL GROUP

A pseudo-weatherization date had to be assigned to each control house. This could have been done simply by selecting a weatherization date at random from the distribution of weatherization dates for the treatment houses. However, because periods of billing data for the houses vary, this approach leads to numerous control houses with pseudo-weatherization dates either near the beginning of their overall observation period, with few "pre-weatherization" days, or near the end of their observation period, with few "post-weatherization" days. To minimize this effect, pseudo-weatherization dates were assigned as follows. The midpoint of the overall observation period (the period for which utility billing data were available) was calculated for each house, both treatment and controls. For each control house, the pseudo-weatherization date was taken to be the actual weatherization date for the treatment house nearest in

[2] The Aggregate Method uses a least squares regression analysis to explain energy consumption as a function of the number of billing days and degree days. Using the regression parameter estimates, normalized annual savings are estimated as the pre-minus-post difference in consumption normalized to 365 days and the annual degree day average. Control-adjusted normalized annual savings are estimated as the difference between the treatment and control normalized annual savings estimates. For details of the method, see Schmoyer and Berry (2003).

[3] For this study, we used 65°F. To confirm that the assumed reference temperature did not affect Aggregate Method results, we ran sensitivity tests with reference temperatures of 55°F and 75°F with the DCEO data. Changing the reference temperature did not appreciably affect the estimates.

observation period midpoint to that control house. By using this method, the number of pre and post days for the weatherized and control groups were made to be comparable.

2.3 DATA

The DCEO estimated that about 100 gas-heated, single-family houses were weatherized each year. For a variety of reasons, sample attrition is large among low-income homes analyzed in studies such as this one. In addition, the results show high variability from house to house. To account for the high house-to-house variability, we set a goal of having 100 treatment houses for analysis. Recognition that attrition would likely be substantial, led to a decision to analyze homes that had been weatherized during two fiscal years (FY), FY 2001 and 2002 (October 1, 2000 through September 30, 2002).

DCEO performed a hand-count of FY-2001 and computer count of FY-2002 weatherization records which gave an initial treatment (weatherized) group of 174 houses. Careful review of the 174 records reduced the treatment group to 100 houses. The eliminations were made for a variety of reasons: errors made during the hand count, inclusion of houses that had received emergency services but no regular weatherization during the study period, duplicate records, and one had weatherization services provided in two consecutive years.

The initial control group was formed from 776 houses on the DCEO FY 2002 *Priority List*; households that were LIHEAP eligible at the beginning of FY 2002 but that had not received weatherization services by the end of that FY. Review of these records reduced the control group to 434 houses. Forty-nine houses were eliminated because the records showed invalid gas account numbers or because the heating fuel was not gas or could not be determined. Sixty-two were eliminated because they had received weatherization or emergency treatments during the study period. The absence of electric account numbers in the records led to the elimination of 156 houses.[4] Others were eliminated because they were found to be multi-family units, had electric account abnormalities, invalid or duplicate Social Security numbers, invalid addresses, invalid LIHEAP approval dates, or were found to be duplicate records.

For each house (treatment and control) that survived the initial screening, DCEO assembled weatherization records, including the LIHEAP application date, a list of weatherization measure types and associated costs,[5] total weatherization cost, weatherization completion date,[6] funding source, and if applicable, emergency measure(s) and cost, and emergency service completion date. DCEO requested billing data from the gas and electric utilities that serve the District of Columbia (Washington Gas and Pepco, respectively) for the calendar years 2000 through 2003. When the utilities provided the data, DCEO removed personal information from the data and forwarded it to ORNL for analysis. ORNL downloaded

[4] Initially, we planned to analyze electric billing data as well as gas billing data. Resource limitations led us to abandon analysis of electric billing data.

[5] Weatherization costs include labor and materials, but do not include audit or other administrative costs.

[6] Only weatherization completion dates were available. We took the end of the pre weatherization period to be the end of the last billing period before the weatherization completion date.

corresponding weather data for the District of Columbia from the Average Daily Temperature Archive web site (University of Dayton 2007).

ORNL closely examined the billing and weatherization data for the two groups. The gas billing data had codes for missed and estimated meter readings that led to the elimination of a substantial number of observations for some houses. Review of the billing data led to elimination of additional houses from the energy savings analysis. Fourteen control group houses had no gas billing data. These deletions reduced the control group to 418 houses. Because PRISM will not run with fewer than 4 observations, other houses did not run successfully. After all these corrections, 367 control houses had successful pre- and post-weatherization PRISM models.

The treatment group was also subject to deletions due to insufficient gas billing data. Sixteen treatment-group houses had emergency treatments; billing data that would have been contaminated by the potential effects of the emergency treatment were removed.[7] After all these corrections, 82 treatment houses had successful pre- and post-weatherization PRISM models.[8]

The ORNL Aggregate Method is more tolerant of cases with few observations so it was able to use data from some houses the PRISM method could not use.

Because of anomalously high apparent savings for the control group for ORNL's initial analysis, DOE asked ORNL to examine factors that might cause the control group to be an improper control for the treatment group. The reexamination found no problems with the control group. However, it did reveal a systematic problem with the gas billing data provided by Washington Gas. The reexamination and the resolution of the problem with the billing data are explained in the addendum. The savings results (Section 4) below reflect the correction of the problems identified during the reexamination.

[7] Generally, emergency treatments are replacement or repair of furnaces or boilers. Some houses had water heaters replaced and one house had a window repaired. Sixteen treatment houses received emergency treatments.

[8] One house had emergency furnace cleaning five days before weatherization. Because furnace cleaning is a common weatherization measure and to avoid loss of an otherwise usable house, it was treated as a normally weatherized house.

3. WEATHERIZATION MEASURES INSTALLED IN TREATMENT-GROUP HOUSES

The houses of the treatment group received over 450 measures costing a little over $180,000. These costs include labor and materials, but do not include other Program costs, such as auditing or record keeping. The average cost per house was $1,811 and the median cost per house was $1,674. The least spent on weatherization in a single house was $90 and the maximum was $4,929. A detailed summary of the measures and their costs are presented in Table 1. Window replacement was the most common measure and accounted for about 35% of total expenditures. Ceiling and floor insulation was installed in 61 houses and accounts for almost 22% of the expenditures. Twenty-seven houses received replacement doors at an average cost of $620 per house. Five houses received replacement storm doors at an average cost of $600 per house. Four houses received replacement furnaces and four received replacement boilers at an average cost of about $3,000 per house.

Houses eligible for RCAP weatherization are also qualified to receive emergency energy-related services for health and safety reasons. Sixteen of the 100 houses also received emergency services for a total cost of $31,000. The average cost was $1,960 and the median was $1,650. Emergency expenditures per house ranged from $75 to $3,800. The least costly service was repair of a window. The most costly treatments were replacement of a furnace or boiler for costs that ranged from $2,200 to $3,800 (9 houses). Two houses received new domestic water heaters. Three had furnace repairs, and one received a new clock thermostat. Because these emergency services are not part of the WAP, they were not included in those studied in this evaluation.

Table 1. Summary of treatment-group weatherization measures [a]

Measure	Houses receiving measure		Total cost		Average cost per house
Attic insulation	33		$23,333		$710
Floor insulation	28		$16,296		$580
Pipe Insulation	1		$65		$65
Duct insulation	4		$448		$112
Insulation subtotal		*66*		*$40,141*	
Door replacement	27		$16,611		$620
Other door measures [b]	170		$7,274		$43
Storm door replace	5		$2,996		$599
Door subtotal		*202*		*$26,881*	
Window replacement	51		$63,480		$1,245
Outside storm window	7		$7,565		$1,081
Other widow measures [c]	27		$4,593		$170
Window subtotal		*85*		*$75,638*	
Furnace replacement	4		$12,100		$3,025
Furnace clean/repair	20		$4,788		$239
Boiler replacement	4		$12,255		$3,064
Boiler repair	2		$222		$111
Thermostat replacement	14		$2,038		$146
Heating system subtotal		*44*		*$31,404*	
Gas water heater repair	1		$45		$45
Air conditioner service	4		$175		$44
Install air conditioner	1		$175		$175
Roof vents	1		$169		$169
Miscellaneous	50		$5,628		$110
Other subtotal		*57*		*$6,210*	
Total	*454*		*$180,273*		

[a] This includes all one hundred treatment houses for which DCEO collected data. Some houses were not analyzed with PRISM because of data problems explained elsewhere.

[b] Many houses received multiple door measures. Other door measures include caulking and weatherstripping; and sweep, threshold, jamb and lock repair or replacement.

[c] Some houses received multiple window measures. Other window measures include: caulking, resetting glazing and replacing glass.

4. RESULTS

4.1 AVERAGE ENERGY SAVINGS

The control-adjusted average energy savings were not significantly different than zero. As shown by Table 2, the control-adjusted average savings was 21 therms/year. However, a 95% confidence interval would include values between about −20 and +60 therms/year per house.[9] The average pre-weatherization energy consumption of the houses was about 1,100 therms/year, so adjusted average savings is approximately 2% (±4%). Thus, the savings are not significantly different than zero.

Table 2. Average energy savings of gas-heated, single-family houses weatherized in 2001 and 2002 by RCAP

Number of houses used to estimate savings	Average energy savings, therms (standard error)	Pre-weatherization energy consumption, therms (standard error)
	PRISM-recommended criteria [a]	
Treatment: 68	Treatment: 34 (16)	Treatment: 1,092 (49)
Control: 265	Control: 13 (10)	Control: 1,160 (27)
	Adjusted: 21 (19)	Difference: −68 (56)
	All houses with both pre- and post-weatherization PRISM models	
Treatment: 82	Treatment: 42 (20)	Treatment: 1,090 (45)
Control: 367	Control: 46 (13)	Control: 1,121 (26)
	Adjusted: −4 (24)	Difference: −31 (52)
	Aggregate Method	
Treatment:	Treatment: 21 (51)	Treatment: 1,107 (71)
Control:	Control: 63 (22)	Control: 1,104 (30)
	Adjusted: −42 (56)	Difference: 3 (77)

[a] Interested readers are referred to the *PRISM User's Guide* (Fels et al. 1995).

As a check on the above result, ORNL analyzed the data with the Aggregate Method. Because the Aggregate Method is more tolerant of missing data than PRISM, more observations could be used for it. A few observations were deleted because of missing dates or consumption values of zero, but in all data from 93 treatment houses and 418 control houses were used. The R-square was 0.73. The conclusions of the Aggregate Method analysis were essentially the same as the conclusions of the PRISM analysis; the control-adjusted normalized annual savings estimate is −42 (±112) therms/year. The 95% confidence interval includes values between about −154 and 70 therms/year. Thus, the Aggregate Method also concludes that the control adjusted normalized annual savings are not significantly different than zero.

[9] Because the numbers are not exact, we have rounded the estimate to two significant digits. The number in parentheses represents approximately the 95% confidence interval, calculated as twice the standard error and rounded to one significant figure.

4.2 ANALYTICAL ISSUES

Typically, billing data for low-income homes are quite noisy. There is substantial discussion in the weatherization evaluation community about how selective to be when accepting PRISM models for individual houses.[10] PRISM recommends accepting only models that have an R^2 that is 0.7 or better and a coefficient of variation (CV) that is 0.07 or less; and models (regardless of R^2) with a CV of 0.04 or less, a flatness index (FI) less than 0.12 and a standard error of reference temperature, "τ," that is determined. (See Fels et al. 1995; pages II-77 & 78, II-37, and II-36.) Blasnik (1989) argues that attrition due to the regression "reliability criteria" introduces a bias into the savings estimates.

The gas billing data for the houses in this study were also noisy. As explained above, we reviewed the raw data for inconsistencies and made all corrections that appeared to be justified. The result was a control group of 418 houses and treatment group of 100 houses. PRISM has a feature to allow examination of the effects of reliability criteria. In light of the concern about bias introduced by sample attrition, we examined several sets of reliability criteria. Two sets of criteria are displayed on Table 2. Applying no reliability criteria yielded the numbers of houses noted above, 367 control and 82 treatment houses. The attrition was mainly due to pre- or post-weatherization periods with fewer than 4 observations. Using the PRISM-recommended reliability criteria for both pre- and post-weatherization periods reduced the samples to 265 control and 68 treatment houses. As shown by Table 2, the results of using PRISM-recommended criteria or no criteria are essentially the same, estimated adjusted savings that are not significantly different than zero.

Another issue has to do with the reasonableness of PRISM regression models. PRISM is a method for finding the best least-squares fit to a set of data that is assumed to represent a combination of heating and baseload gas usage. Sometimes the best fit to a set of billing records does not make much sense. For instance, for heating-only models appropriate to gas billing data we saw unrealistic reference temperatures (the outdoor temperature below which the house is heated), such as reference temperatures below 40°F or above 75°F. Another indication that PRISM had developed an unrealistic model was negative heating slopes, that is, the warmer the outside temperature the more space heating used. While such models may best fit the available billing data, these patterns do not match the way occupied houses behave, unless other factors (e.g., changing occupants or extreme behaviors) dominate household energy use. PRISM provides a number of customization options. We exercised the option of constraining the heating reference temperature to the range, 45°F to 70°F. (No option for dealing with negative heating slopes is available.) Addition of the constraint increased the number of houses that ran. Because the average savings were similar whether or not the reference temperature was constrained, we used the results of the models with constrained reference temperatures. The results listed in Table 2 reflect the effects of constraining heating reference temperatures.

[10] For instance, see Blasnik 1989.

4.3 MEASURE EFFECTIVENESS

In an effort to determine which measures contributed the most to energy savings, ORNL performed multiple linear regression analyses of savings vs. the types of measures installed. The largest weatherization expenses were for floor insulation, attic insulation, door replacement, window replacement, and furnace or boiler replacement. For the 68 houses that met the PRISM-recommended reliability criteria, ORNL performed multiple linear regression analyses using the five measure types as independent variables; once using measure cost, and again using a binary (0 or 1) indicator as to whether the measure type was installed. The dependent variable was the PRISM-estimated normalized annual savings.

Only boiler or furnace replacement has significant predictive power in all regression analyses. For the regression using the presence indicator, the boiler-furnace replacement had an estimated savings of 208 therms/year, with a 95% confidence interval of 101 to 316 therms/year. For the regression using the cost of the measure versus NAS, the boiler-furnace measure was again significant with an estimate of 0.065 therm/year per dollar of measure cost, with a 95% confidence interval of 0.031 to 0.099 therm/year per dollar of measure cost. Regression of NAS versus boiler-furnace replacement alone also yielded significant savings; 178 therms/year (confidence interval 81 to 275).

Because boiler and furnace replacements cost between $2,500 and $3,500, there is a strong correlation between total weatherization cost and furnace or boiler replacement. The average weatherization cost per house is about $1,800, so any house that has a furnace or boiler replacement has benefited from above-average expenditures. Not surprisingly, total weatherization cost is significantly correlated with savings, but much of that correlation may be attributable to the effects of boiler-furnace replacement. In fact, total weatherization cost accounts for less variation than does presence or absence of boiler-furnace replacement; $R^2 = 0.09$ for weatherization cost vs. $R^2 = 0.17$ for presence of boiler-furnace replacement.

Attic insulation also had a significant predictive power for the regression of NAS vs. installation of measures model with all five measures. For a single measure (attic insulation only) regression model, installation of attic insulation no longer had significant predictive power. For the regression against cost of weatherization measure, the effect of attic insulation was no longer significant at the 95% level.

The only other factor that offered significant predictive power was pre-weatherization normalized annual consumption (NAC). A correlation between NAS and pre-weatherization NAC is often observed in studies like this, but it is not clear that it is meaningful. Effects of scale, and the regression-toward-the-mean[11] effect may well be responsible for its statistical significance.

It would be a mistake to interpret the above results to mean that only replacement boiler or furnace installations are effective weatherization measures. Because the sample on which the regressions were run is small, only 68 houses, and because NAS, the dependent variable, is only a statistical estimate rather than a directly measured value, smaller savings effects may not be detectable from this analysis. Because furnace or boiler replacement is so expensive, none of the seven houses that received that measure

[11] References on the subject are too numerous to list. Interested readers are encouraged to do an Internet search.

received any other measures. Consequently, boiler-furnace replacement effects are more readily detected by statistical means than are measures that are installed in conjunction with other measures. Finally, while furnace or boiler replacement savings should be relatively large to justify the very high measure cost (between $2,500 and $3,500), other measures come in smaller and more variable sizes. For instance, expenditures per house on attic insulation ranged from $15 to $2,400, with an average expenditure of $700. Thus, while these results suggest that furnace or boiler replacements are effective energy saving measures, they do not support a conclusion that the other measures are not effective energy saving measures.

5. DISCUSSION

Based on the sample of 100 gas-heated, single-family houses, the RCAP spends between $90 and almost $5,000 per house, with an average of $1,800 per house. The average weather-adjusted gas savings of weatherized houses was found to be between 0 and 70 therm/year. Adjusting savings for the savings of the control group, the savings was between −20 therms and 60 therms per year. The most likely average adjusted savings was about 20 therms; but it is not statistically different than zero. Using $1.30 per therm and the *most optimistic estimate* of average gas savings, 60 therms per year, gives a simple payback period of about 23 years.

Hendron (1997) performed a previous analysis of energy savings in single family homes weatherized by the DCEO program. That study yielded estimated average first-year gas savings of 110 therms (8.5%) for 159 gas heated houses. Hedron reported neither confidence intervals nor use of a control group, so no control group-adjusted savings are available for comparison. The reported savings are more than twice those found in this study *before adjusting for control group savings*. The control-adjusted savings found by the current study are low compared to typical state-average results (Berry and Schweitzer 2003) who report average household natural gas savings of about 22%, based on 1998–2002 data.

The apparent lack of statistically-significant program energy savings strongly suggests the need for more in-depth evaluation of the program. Analysis of electric utility billing data might reveal some effects not found in the gas data. However, because few cooling measures were installed, there is little reason to expect substantial electricity savings.

A careful look at the measures that were installed may be fruitful. For the 100 houses for which data were available, Table 1 shows the installed measures organized by the component of the house the measure treated. Another way to tabulate the data is to distinguish between repairs and weatherization measures. Table 3 lists the same measures organized to distinguish measures that are clearly weatherization measures (insulation and infiltration) from repairs. Less than 30% of the expenditures are for insulation and infiltration measures. Over half the expenditures are spent on repairs. Additionally, about 17% of the expenditures go to items for which it is not clear whether they are repair or weatherization measures.

The distinction between repairs and weatherization may not be clear as may be suggested by categorization we have used for Table 3. For instance, boiler replacement may have been selected because the old boiler was barely functioning (repair) or because there was a much more efficient boiler available (weatherization). Similarly, window replacement could be selected because the existing window is leaky or because the existing window is decayed to the point that it n longer functions to keep out outside air. Nevertheless, Table 3 indicates that most weatherization funds are going to repairs rather than measures intended primarily for energy savings. Perhaps there should be little surprise that energy savings found in this study are low. On the other hand, given the poor quality of the low-income housing stock, the high proportion of expenditures for repairs may be desirable, or at least unavoidable. If so, energy savings expectations may need to be adjusted.

Table 3. Measures installed on 100 gas-heated, single-family RCAP weatherized homes

Measure	Houses receiving the measure	Total cost [a]
Insulation & infiltration measures		
Attic insulation	33	$23,333
Floor/crawl space insulation	28	$16,296
Door sweep, caulk or weather strip	134	$3,902
Outside storm window	7	$7,565
Window caulked	19	$1,432
Duct insulation	4	$448
Hot water pipe insulation	1	$65
Insulation & infiltration subtotal	*226*	*$53,040*
Repair measures		
Door replacement	27	$16,611
Door jamb, lock or threshold replacement	36	$3,372
Storm door replacement	5	$2,996
Window replacement	50	$63,480
Window lock replacement	1	$1,625
Widow glass replacement	8	$2,113
Air conditioner service	4	$175
Furnace clean or repair	20	$4,788
Boiler repair	2	$222
Gas water heater repair	1	$45
Thermostat replacement	14	$2,038
Repair subtotal	*168*	*$96,888*
Measures with uncertain purpose		
Furnace replacement	4	$12,100
Boiler replacement	4	$12,255
Install air conditioner	1	$175
Roof vents	1	$169
Miscellaneous	50	$5,628
Uncertain purpose subtotal	*60*	*$30,345*
Total, all measures	*454*	*$180,273*

[a] Sums may not add due to rounding.

6. CONCLUSIONS AND RECOMMENDATIONS

The District of Columbia Energy Office (DCEO) operates the Residential Conservation Assistance Program (RCAP) to weatherize low-income homes as part of the U.S. DOE Weatherization Assistance Program. The program provides weatherization and emergency services to eligible homes.

This study of single-family, gas-heated houses weatherized during FY 2001 and 2002 found no significant savings of energy. As a courtesy, ORNL provided the preliminary results of this study to DCEO staff. The following statement reflects the DCEO comments on improvements to the RCAP program since the 2001-2002 period to which the results reported above apply.

> *Because a number of program improvements have been and are being implemented, the DCEO Staff believe current program performance is likely better than found for the years examined in this study. The Weatherization Standards Technical Manual was published in October 2003 and is being used. The DCEO Conservation Division attempts to inspect every weatherized home and typically inspects about 85% of weatherized houses. DCEO has developed a new version of its cost-control list. Using this schedule, DCEO has been able to identify and eliminate excessive weatherization charges. Contractors who do not perform well are not used further.*
>
> *All audits are performed by Conservation Division energy auditors. All Conservation Division auditors are certified home energy auditors. For single family homes, auditors use the latest version of NEAT. The Conservation Division recently added an improvement to infiltration reduction—sealing interior walls that could conduct cold air into the building from the basement or attic. To further improve weatherization program the DCEO has purchased an infrared camera for diagnostics. The camera was employed for the first time during the winter of 2005-2006.*

In late 2003, DCEO published formal guidance for weatherization in RCAP (DCEO 2003). Those standards were not in place until after the weatherization periods studied here. It is possible that implementation of the new guidance has improved program performance. In light of these results and the program improvements implemented since the winter of 2002-2003, DCEO should consider performing a follow-up evaluation to asses the performance of the current program.

RCAP expenditures averaged about $1,800 per house. Most of those expenditures appeared to go to repairs or replacements of existing equipment. While some repairs have energy benefits, measures selected to meet repair needs generally have smaller energy benefits than measures selected for energy conservation purposes. To the extent that extensive repairs are necessary or desirable, expectations of energy savings need to be adjusted. DCEO should consider the place of repairs in the RCAP. If it decides that continued high level of expenditures on repairs are necessary or desirable, it should initiate discussions with DOE on how to balance the needs for repairs against the goals for energy savings.

Energy audits such as the National Energy Audit (NEAT) are widely used to select weatherization measures. Given the large quantities of repairs, auditors are faced with decisions that energy audits do not address. Selecting the highest priority repair items within the limited budget is likely to be a challenge. Determining the proper proportion of repairs to building efficiency measures must be much more difficult. The DOE should consider developing guidance for state grantees and, perhaps, a protocol or audit-like tool to guide auditors in choosing between repairs and weatherization measures.

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DATA ANALYSIS ADDENDUM

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Initial results of this analysis were unusual in that *both* control and treatment groups had NAS values of about 10%. Ten percent is a typical program savings level, but it is unusual for the control group to show such large savings. The results led to a search for the reasons for the exceptionally large control group savings. The authors developed and tested several hypotheses for those control group savings. This addendum describes the hypotheses and the results of the tests, and discusses the implications.[12]

One hypothesis suggested by a reviewer was that an external factor had caused the control group to have exceptionally large apparent savings. To explore that hypothesis, we examined the natural gas prices in the District of Columbia during the study period. During the winter months (December through February) natural gas prices were about $9 to $10 per thousand cubic feet (approximately equal to one MBtu, or 10 therms) during the winter or 1999-2000. In the winter of 2000-2001, gas prices increased to about $13 (Figure A.1). During the subsequent two winters, natural gas prices averaged about $11/thousand cubic feet. The 40% increase in gas prices between the winter of 1999-2000 and the winter of 2000-2001 might be expected to cause people to use less gas to heat their homes. An abrupt fuel price

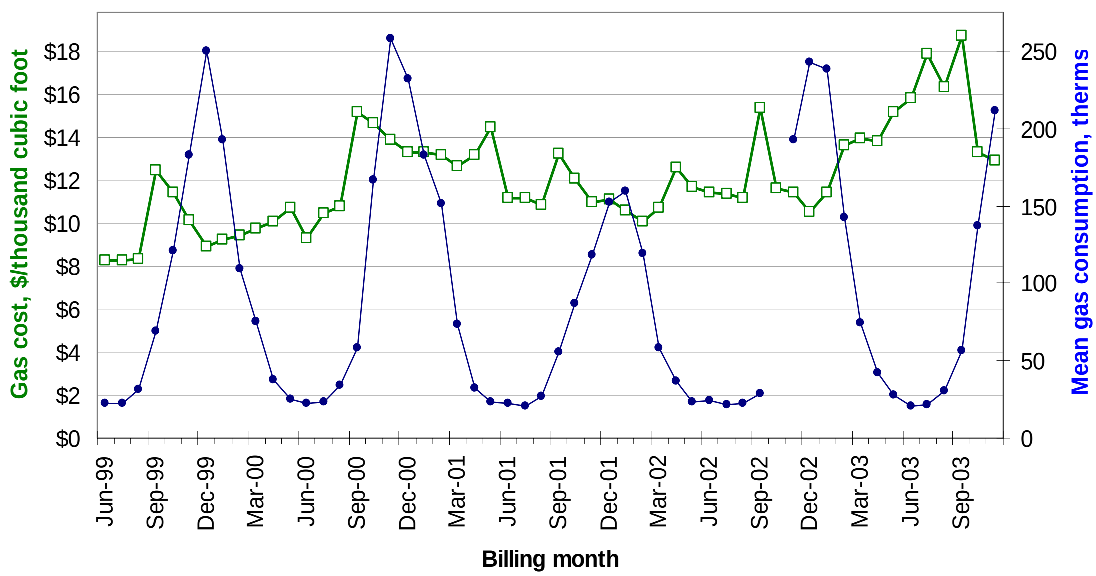

Fig. A.1. Comparison of residential gas costs to average monthly gas consumption.
Sources: Gas price data is from U.S. Energy Information Administration 2007. *EIA's Natural Gas Navigator*, at http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_SDC_m.htm, accessed January 22. Average gas consumption is from analysis of the data used by this study.

[12] In the process of pursuing these hypotheses, the authors discovered a problem with the interpretation of the data provided by the gas utility. Correcting this problem eliminated the high apparent control group NAS and led to more well behaved results for both treatment and control groups. The data problem, its symptoms and solution are described later in this addendum. While the analyses described here were performed before the data problem was identified, all the results presented here were redone after the data problem was corrected.

change like this is exactly the kind of effect control groups are intended to adjust for. Because both control and treatment groups experienced the same rise in gas prices, theory has it that control-adjusted savings should accurately describe the effect of the program. Further, Figure A.1 shows no apparent correlation between gas consumption and gas prices. Therefore, we find no reason to suspect that residential natural gas price had an effect on control-adjusted savings.

Another hypothesis was that the timing of applications for weatherization assistance. The treatment group consisted of all gas-heated, single-family houses weatherized by the program between September 30, 2000 and October 1, 2002. For most of the treatment group households, the first application for weatherization assistance was made a year or more before they received weatherization assistance. The control group was selected among houses on the DCEO RCAP waiting list at the end of at the end of 2002. Because the program weatherizes houses on a first come first served basis, most houses on the waiting list applied for assistance about two years later than the treatment group houses.

Selecting control group in this manner is the accepted practice but the conjecture was that the length of the time on the wait list was correlated with changes in homeowners' economic situation which in turn changed the amount of energy the house used. The idea was that application for weatherization assistance was usually precipitated by an economic problem caused by job loss or family composition changes. In addition to seeking assistance, it seemed plausible that occupants would change their energy use patterns to reduce their utility bills.

To test this idea, we used PRISM to analyze year to year variation in energy use of both the treatment and control group. For each group we calculated average NAC for the winters of 99-00, 00-01, 01-02, and 02-03. The largest difference between group-average treatment and control NACs for any year was 3%, but most years the difference was about 1%. From this exercise, we conclude that the conjecture is incorrect, because if there were an important time-of-application effect, it would show as a significant difference between treatment and control group NACs.

Another conjecture was that some aspect of weather that is not captured by HDD was affecting household energy use. The dominate effect of HDD on heating energy use is well established, so this was seen as a long shot. To test the idea we used the Aggregate Method to estimate average monthly energy use and to compare it to monthly HDD. The results, plotted in Figure A.2, show that mean gas use tracks HDD very well so it seems unlikely that there are other important weather-related effects that HDD does not capture.

Interpreting Washington Gas billing data. The gas billing data was provided to ORNL in a spreadsheet format, consisting of four columns. The first column was the house identifier in the form or a letter and a number. The letter "C" was used for houses in the control group, and the letter "T" was used to indicate a house belonging to the treatment group. The second column was the "billing period end date." The third column was the gas consumption in therms. The last column was the bill amount in dollars and cents. The billing period end dates were not necessarily in chronological order.

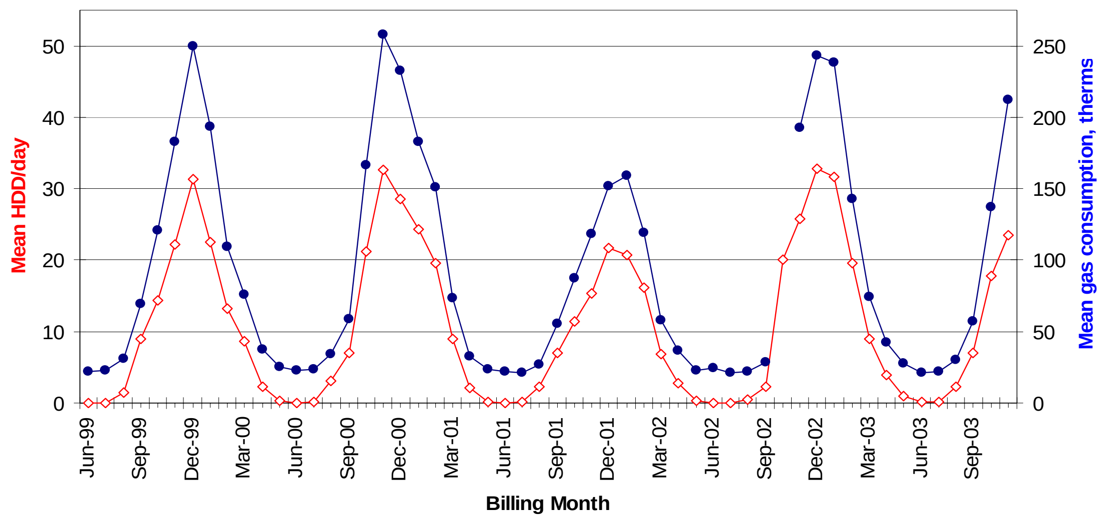

Fig. A.2. Mean HDD/day and household gas consumption by month.
Source: Average gas consumption is from analysis of the data used by this study.

The data had to be reformatted to allow inspection of the data for quality control purposes and so that it could be used by PRISM. PRISM requires billing data to be listed in chronological order as a quantity and a meter reading date. For quality control, we reordered the data chronologically and structured it in six columns: house identifier, consumption (therms), bill amount ($), end date, start date and days in period. The start date was taken to be the same as the end date of the preceding observation. Inspecting the data in this form showed that it was not unusual to have two or more entries that had the same billing period end date. We also found that there were numerous cases where the gas consumption was listed as zero and the bill amount was listed as a negative number. Utility personnel explained that the negative bill amounts were billing adjustments but were not indications that the consumption was in error.

A less common anomaly was gaps of much more that 30 days between some observations, usually about 60 or about 90 days. These gaps admit two interpretations. One interpretation is that the meter reading was missed for a month or two, so the consumption value represents the consumption for the full two- or three-month period. The alternative interpretation is that the meter was read each month, but the data for intervening months were not passed along to ORNL. Because Washington Gas personnel assured us that we had received all the billing data, we assumed that long periods between observations meant that the meter reading had been missed, and that the consumption represented the total consumption for the period.

In the process of testing the idea that there were year-to-year variations in NAC that were related to when houses applied for weatherization assistance, we examined PRISM-generated plots of energy use (therms)/days vs. HDD/day for several houses. We noticed that there was often one anomalously low consumption for the winters of 2001-2002 and the winter of 2002-2003. Closer examination showed that these observations were for periods of about 60 or 90 days ending in February or early March 2002 or

January or early February 2003. Subsequent investigation showed the presence of a similar gap in data for periods ending in September 2002.

These observations led us to reevaluate our assumption that long billing periods represented missed gas meter readings. A few tests of changing the observation period in PRISM to 30 days showed that these observations usually fell in line with the other observations when that change was made.

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