DO RESIDENTIAL ENERGY AUDITS CONTRIBUTE TO REDUCED ENERGY CONSUMPTION?

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The purpose of this paper is to analyze the effect of residential energy audits on residential energy consumption. Two fundamental questions are addressed in the analysis:

* Do residential households reduce their energy consumption as a result of the audit?

* What is the impact on energy consumption of each of the various recommendations made to the households as a result of the audit?

Two separate models are used to address the two questions listed above. They will be referred to as the "net impact model" and the "recommendations model." Both of the models use the methodology of multiple regression analysis. At the end, the paper also proposes an analytical approach that could be used in a future analysis to strengthen and extend the results presented in this paper.

THE NET IMPACT MODEL

The net impact model[2] compares the pre-audit and post-audit energy consumption of a participant in the residential energy audit program in order to measure the impact of the audit on energy consumption. This change in a participant's energy consumption is not a true measure of the effect of the audit since it is possible that non-participants had also attained possible reductions over the same period on their own. The possible reductions attained by nonparticipants are viewed as trend changes in energy consumption. Hence, the model compares a participant's pre-audit/post-audit energy consumption change to a non-participant's energy consumption change over the same time period.

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[1] The opinions expressed by the author are his alone, and do not necessarily reflect the views of the District of Columbia Public Service Commission.

[2] This is an extension of the model used by the Potomac Electric Power Company (Pepco) in its report entitled "Energy Avoidance Analysis: District of Columbia" dated December 1986.

The difference between a participant's change and a non-participant's change is defined to be the net impact of the audit program on residential energy consumption.

The general form of the multiple regression equation corresponding to this model is:

$$
\begin{aligned}
ENERGY_i = \; & a_1 + a_2(CDH_i) + a_3(CDHPART_i) + a_4(HDH_i) + a_5(HDHPART_i) \\
& + a_6(POSTAUDIT_i) + a_7(AUDITPART_i) + a_8(AUDCDH_i) + a_9(AUDHDH_i) \\
& + a_{10}(AUDCDHPART_i) + a_{11}(AUDHDHPART_i) + d_2(DUM_2) + d_3(DUM_3) \\
& + \;\ldots\; + d_n(DUM_n)
\end{aligned}
$$

where:

i	= subscript for an individual customer.
$ENERGY_i$	= monthly billing cycle energy per customer measured in millions of BTU (MBTU).
CDH_i	= Cooling Degree Hours by monthly billing cycle.
$PART_i$	= dummy variable, with value = 1 for participants, and value = 0 for non-participants.
$CDHPART_i$	= $CDH_i x PART_i$. Interaction term designed to differentiate between participants and non-participants.
HDH_i	= Heating Degree Hours by monthly billing cycle.
$HDHPART_i$	= $HDH_i x PART_i$. Interaction term designed to differentiate between participants and non-participants.
$POSTAUDIT_i$	= dummy variable, with value = 1 if month is post-audit, and value = 0 if month is pre-audit.
$AUDITPART_i$	= $POSTAUDIT_i x PART_i$. Interaction term designed to differentiate changes in pre-audit and post-audit energy use between participants and non-participants.
$AUDCDH_i$	= $POSTAUDIT_i x CDH_i$. Interaction term designed to differentiate effect of cooling degrees between pre-audit and post-audit periods.
$AUDHDH_i$	= $POSTAUDIT_i x HDH_i$. Interaction term designed to differentiate effect of heating degrees between pre-audit and post-audit periods.
$AUDCDHPART_i$	= $POSTAUDIT_i x CDH_i x PART_i$. Interaction term designed to differentiate effect of cooling degrees between pre-audit and post-audit periods and between participants and non-participants.

This equation has several notable features:

* The equation normalizes the residential energy consumption for the prevailing weather conditions.

* The equatlon tries to take account of household-specific characteristics that affect energy consumption by including a dummy variable for each household.

* The equation is designed to differentiate between participants and non-participants as well as for the pre-audit and post-audit periods for each and every variable that affects energy consumption, while combining the two groups and two periods in one equation. This makes it possible to conduct statistically valid tests across the two time periods and the two groups.

For <u>participants</u>, the equation implies:

Pre-audit $ENERGY_i = a_1\ [a_2 + a_3](CDH_i)\ [a_4\ a_4](HDH_i)$

Post-audit $ENERGY_i = [a_1 + a_6\ a_7]\ [a_2 + a_3 + a_8 + a_{10}](CDH_i)$

$+ [a_4 + a_5\ a_9 + a_{11}](HDH_i)$

Note that the household-specific dummy variable= have been ignored because they will cancel out in the calculation of the reduction.

Participant Reduction = Pre-audit - Post-audit $ENERGY_i$

$= -(\ [a_6 + a_7] + [a_8 + a_{10}](CDH_i)\ [a9 + a11](HDH_i)\ )$

For <u>non-participants</u>, the equation implies:

Pre-audit $ENERGY_i = a_1\ a_2(CDH_i)\ \ a_4(HDH_i)$

Post-audit $ENERGY_i = [a_1 + a_6]\ [a_2 + a_8](CDH_i)\ \ [a_4 + a_9](HDH_i)$

Note that the household-specific dummy variables have been ignored because they will cancel out in the calculation of the reduction.

Non-participant Reduction = Pre-audit - Post-audit $ENERGY_i$

$= -(\ a_6\ a_8(CDH_i) + a_9(HDH_i))$

Hence, the net effect of the audit, which is the difference between the participant and non-participant reductions, is:

Net audit impact = Participant Reduction - Non-participant Reduction =

$$= - (a_7\ a_{10}(CDH_i) + a_{11}(HDH_i))$$

Thus, this net impact has been calculated after taking account of weather changes, household-specific characteristics, and possible trend reductions achieved by non-participants.

THE RECOMMENDATIONS MODEL

The recommendations model focuses on only the participants in the post-audit period. The model is based on the following ideas. If a particular recommendation (such as water tank insulation) was made to a household, then this should indicate a need for the measure. In other words, with all other things equal, a household to whom a recommendation was made should have higher energy use than a household to whom the recommendation was not made. Further, the implementation of the recommendation should indicate a decline in energy consumption. In other words, with all other things equal, a household that did implement a recommendation should have lower energy consumption than a household that did not implement the recommendation.

Within the group of participants, the other factors affecting energy consumption are cooling and heating degrees, the family size, the area and type of the dwelling, and the family income.

The general form of the multip]e regression equation corresponding to this model is:

$$ENERGY_i = b_1 + b_2(CDH_i) + b_3(HDH_i) + b_4(FAMSIZE_i) + b_5(AREA_i)$$

$$+ b_6(TYPEHOME_i) + b_7(INCOME_i) + c_1(REC1_i) + e_1(IRECl_i)$$

$$+ \ldots + c_n(RECn_i) + e_n(IRECn_i)$$

where:

i = subscript for an individual customer.

ENERGYi = monthly billing cycle energy per customer measured in millions of BTU (MBTU).

CDH_i = Cooling Degree Hours by monthly billing cycle.

HDH_i = Heating Degree Hours by monthly billing cycle.

$FAMSIZE_i$ = Number of people in the household.

$AREA_i$ = Area of the dwelling in square feet.

$TYPEHOME_i$ = Type of home, i.e. single-family, apartment, etc. Represented by appropriately defined dummy variables.

$INCOME_i$ = Income of household.

$RECl_i$ = Dummy variable, with value = 1 if the first recommendation (e.g. storm windows) was made, value = 0 otherwise.

$IREC1_i$ = Dummy variable. with value = 1 if the first recommendation was made and implemented, value = 0 otherwise.

$RECn_i$ = Dummy variable, with value = 1 if the last recommendation (e.g. floor insulation) was made, value = 0 otherwise.

$IRECn_i$ = Dummy variable, with value = 1 if the last recommendation was made and implemented, value = 0 otherwise.

$b_1,\ldots, b_7, c_1,\ldots, c_n, e_1,\ldots, e_n$ = parameters to be estimated by multiple regression analysis.

In this multiple regression equation, a positive coefficient for a recommendation dummy variable indicates a need for the measure, and a negative coefficient for the implementation dummy variable indicates a reduction in energy consumption as a result of the implementation.

THE DATA

The data for the analysis relate to residential energy audits conducted by the Potomac Power Electric Company (Pepco) in Washington, D.C. The time periods involved are :

* Pre-audit period: October, 1983 - September, 1984
* Audits Conducted: October, 1984 - September, 1985
* Post-audit period: October, 1985 - September, 1986.

The energy consumption data are for both electricity and natural gas, where the latter data were obtained by Pepco from Washington Gas Light Company.

There are two types of audit that Pepco conducted: a professional audit, where a professionally trained auditor went to the customer's home, and a do-it yourself audit, where a customer mailed in a completed questionnaire to Pepco. While data are available for both types of audits, the greatest concern related to professional audits. Further, the number of do-it-yourself audits is relatively small. Hence, this analysis has focused on only the professional audits.

Pepco has also collected data on a selected group of non-participants. The number of households for which data are available is shown in Table 1. The table shows that data are available for 110 professional participants (of which 98 have gas space heating, and 12 are all-electric customers), 9 do-ityourself participants (of which 8 have gas space heating, and 1 is an all electric customer) and 103 non-participants (of which 85 have gas space heating, and 18 are all-electric customers).

THE RESULTS

The results of estimating the net impact model are shown in Table 2. The results show that the only statistically significant impact of the residential energy audit on energy consumption is on winter season electricity use by customers who have gas space heating. For all-electric customers, there is no statistically significant net impact on either winter season or summer season electricity use.

These results imply that the audits have been only marginally successful in achieving the aim of energy conservation since the winter season electriclty consumption of gas heating customers is only a small part of total household energy consumption.

The results of estimating the recommendations model are shown in Tables 3 and 4. This model has been applied only to the 98 professional participants who have gas space heating. The reported results are based on regression equations from which the INCOME and TYPEHOME variables were dropped, because preliminary estimation showed that their coefficients were statistically insignificant.

For the winter season, based on the gas use equation, there are three measures whose implementation has led to energy reductions: wall insulation, weatherstripping, and storm windows. In additlon, for pipe insulation and thermostat settings, the need appears to have been correctly identified, but their implementation does not show any statistically significant energy reductions. The implementation of the storm doors, clock thermostat, replace the heating system, automatic pilot light, and window door film recommendations does show energy reductions, but the reductions are not statistically significant.

For the summer season, based on the electricity use equation, the implementation of the storm doors. storm windows, water tank insulation and automatic pilot light recommendations leads to statistically significant declines in energy use. In addition, the need for weatherstripping, pipe insulation, and thermostat settings appears to have been correctly identified, but their implementation does not lead to any statistically significant energy reductions. Finally, the implementation of the clock thermostat and wall insulation recommendations does show energy reductions, but they are not statistically significant.

In other words, the results show that only a limited number of the recommendations made as part of the energy audits are effective in reducing gas use in winter and electricity use in summer. In particular, the storm windows recommendation is the only one that is effective in both the winter and summer seasons. These results may explain why the audits conducted by Pepco have not been very effective in reducing energy consumption.

FURTHER RESEARCH

The above results indicate that the residential energy audit program has been only marginally successful. However, the above analysis does not indicate the reasons for this phenomenon. An explanation would require two types of analyses: (1) A technical analysis that examines the nature of the audits and the recommendations made from an engineering point of view, and (2) An economic analysis that is based on a model of consumer behavior. This second type of analysis is explored in this section.

From an economist's point of view, each household is a producer of a commodity that can be labeled as COMFORT, which involves establishing a comfortable environment in the customer's residence. Each household is also a consumer of COMFORT. Thus, the economic analysis would be based on both consumer and producer theory.

The inputs for producing COMFORT are the energy used as well as the characteristics of the dwelling such as the amount of caulking, weatherstripping, insulation, etc. The relationship between these inputs (including energy used) and COMFORT would be described by a production function. Following economic theory, the household would find the cost-minimizing combination of inputs for producing different levels of COMFORT. There would be significant differences between the short-run and the long-run, since we expect some of the dwelling characteristics to be fixed in the shortrun. This cost-minimization would produce the usual cost curve, i.e. the cost of producing different levels of COMFORT.

Since the household is the producer as well as the consumer of COMFORT, the price of an additional unit of COMFORT is clearly the marginal cost of producing COMFORT. It is this price that the household uses in determining how much of COMFORT to produce and consume, based on the usual utility maximizing assumption.

This framework is likely to provide the theoretical foundations of analyzing why energy audits are not highly successful in reducing household energy use. For example, suppose that a household implements an audit recommendation that makes the home highly energy efficient. In turn, this reduces the cost of producing COMFORT, so that the price of comfort (as measured by the marginal cost) also comes down. In this situation, it would be usual to expect that the household would raise its level of COMFORT. Thus, the fall in energy consumption implied by the implementation of the recommendation would be, to some extent at least, be diminished by the rise in energy consumption implied by the raising of COMFORT.

There is some evidence that residential households view energy audits as means of saving energy and raising comfort, and not primarily as a means of saving the amount of money they spend on energy. Pepco's survey of audit participants found that more than 70% of the surveyed participants said that some of the purposes of the audits were to save energy and to raise the level of comfort. However, only 60 % of the surveyed participants said that one of the purposes of the audits was to save money.

This analytical framework is also likely to be useful in providing significant insights about the customer's decision to implement or not the recommendations made by the auditor. The correct opportunity cost of implementing a recommendation includes the implicit value of the time spent by the customer. Even if the actual work is done by a contractor, a customer may have to spend a substantial amount of time in analyzing the recommendation, finding a suitable contractor, and supervising the work.

This time cost could be readily inc]uded in the economic model. The logit/probit regression technique is particularly suited for Yes/No types of decisions. A logit/probit regression equation derived from this analytical framework would be very useful in analyzing the factors that lead customers to not implement some of the recommendations.

Table 1 Number of Customers in the Analysis

Fuel type	Participants Professional	Participants Do-It-Yourself	Non-participants
Gas Heat	98	8	85
All Electric	12	1	18
Total	110	9	103

Notes: Gas heat refers to the customers who have gas space heating, while all electric refers to customers who have all electric homes.

Table 2 **Net Impact of Residential Energy Audit Program**

Fuel Type	Total Energy	Electricity Use	Gas Use
	WINTER SEASON		
Gas heat	1.21	0.21 *	1.01
All-electric	-1.03	-1.03	N/A
	SUMMER SEASON		
Gas heat	0.46	0.21	0.13
All-electric	0.56	0.56	N/A

Notes: The figures show the net impact (in million of BTUs per participating customer) of the residential energy audit program on energy consumption, after adjusting for weather, household-specific characteristics, and for trend changes in consumption exhibited by non-participating households. A positive sign indicates reduction in energy use, while a negative sign indicates a rise in energy consumption. An asterisk * indicates statistical significance at the 95 % confidence level, using a two-tailed test. For details of the estimating equation, see the text.

Table 3 Effect of Specific Audit Recommendations on Energy Use

(Gas Heat Professional Participants Only)

WINTER SEASON

	Total Energy	Electricity Use	Gas Use
Storm Windows			
Recommendation	3.23 *	-0.03	3.11 *
Implementation	-2.56 *	-1.04 *	-2.26 *
Storm Doors			
Recommendation	0.35	0.22	0.26
Implementation	-0.36	0.74 *	-0.17
Caulking			
Recommendation	0.72	-0.49	0.74
Implementation	1.85 *	0.03	1.68 *
Weatherstripping			
Recommendation	3.33 *	1.11 *	3.33 *
Implementation	-3.24 *	-0.97 *	-2.84 *
Duct Insulation			
Recommendation	2.62	-0.25	2.08
Implementation	N/A	N/A	N/A
Pipe Insulation			
Recommendation	6.64 *	0.46	5.95 *
Implementation	-3.39	-0.52	-2.54
Water Tank Insulation			
Recommendation	-2.38 *	-0.24	-2.41 *
Implementation	-0.17	-0.50	0.01
Clock Thermostat			
Recommendation	0.59	-0.75 *	0.59
Implementation	-0.87	-0.63	-1.16
Replace Heating System			
Recommendation	0.86	0.10	0.73
Implementation	-1.92	-0.23	-2.20
Flue Vent Damper			
Recommendation	1.75	-0.66 *	1.24
Implementation	0.47	0.30	0.42

Table 3 Effect of Specific Audit Recommendations on Energy Use (Continued)

(Gas Heat Professional Participants Only)

WINTER SEASON

	Total Energy	Electricity Use	Gas Use
Auto Pilot Light			
Recommendation	0.46	-1.75 *	0.28
Implementation	-1.27	-0.22	-0.40
Window Door Film			
Recommendation	-0.70	-0.05	-0.69
Implementation	1.36	2.00 *	-0.13
Thermostat Setting			
Recommendation	3.61 *	1.22 *	3.23 *
Implementation	0.65	0.12	0.33
Wall Insulation			
Recommendation	1.42	-0.17	1.60 *
Implementation	-4.17 *	-0.33	-4.52 *
Ceiling Insulation			
Recommendation	-2.47 *	-1.07 *	-2.43 *
Implementation	6.10 *	1.89 *	5.53 *
Floor Insulation			
Recommendation	1.79 *	-0.47	1.30
Implementation	1.77	0.29	2.07

Notes: The estimated coefficients measure the changes in million BTUs. A positive sign for a recommendation coefficient indicates the extra energy used by a customer for whom the measure was recommended as compared to a customer for whom the recommendation was not made. A negative sign for an implementation coefficient shows the fall in energy use resulting from the implementation of the recommendation. An asterisk * denotes statistical significance at the 95 % confidence level, using a one-tailed test. For details of the estimating equation, see the text.

Table 4 Effect of Specific Audit Recommendations on Energy Use

(Gas Heat Professional Participants Only)

SUMMER SEASON

	Total Energy	Electricity Use	Gas Use
Storm Windows			
Recommendation	0.31	0.07	0.16
Implementation	-0.55	-1.09 *	0.28
Storm Doors			
Recommendation	0.42	0.59 *	-0.11
Implementation	-0.71 *	-0.47 *	-0.28
Caulking			
Recommendation	-1.10 *	-0.94 *	0.12
Implementation	0.78 *	0.83 *	-0.19
Weatherstripping			
Recommendation	1.65 *	1.12 *	0.81 *
Implementation	-0.76 *	-0.38	-0.56 *
Duct Insulation			
Recommendation	-0.05	0.39	-0.94 *
Implementation	N/A	N/A	N/A
Pipe Insulation			
Recommendation	1.44 *	0.75 *	0.55 *
Implementation	-0.94	-0.64	-0.11
Water Tank Insulation			
Recommendation	1.02 *	0.40	0.96 *
Implementation	-1.38 *	-1.09 *	-0.50
Clock Thermostat			
Recommendation	0.59 *	0.01	0.10
Implementation	-0.76	-0.25	-0.69
Replace A/C System			
Recommendation	0.60	0.73 *	-0.06
Implementation	1.23	0.34	0.23
Awnings			
Recommendation	N/A	-0.29	0.33
Implementation	N/A	4.25 *	0.92

Table 4 Effect of Specific Audit Recommendations on Energy Use (Continued)

(Gas Heat Professional Participants Only)

SUMMER SEASON

	Total Energy	Electricity Use	Gas Use
Auto Pilot Light			
Recommendation	0.53	-0.60	-0.23
Implementation	-2.10 *	-1.60 *	-0.50
Window Door Film			
Recommendation	0.18	-0.50	-0.59 *
Implementation	1.68 *	1.55 *	0.34
Thermostat Setting			
Recommendation	2.14 *	1.29 *	1.01 *
Implementation	-0.11	0.54 *	-0.85 *
Wall Insulation			
Recommendation	0.23	0.08	0.17
Implementation	0.47	-0.02	0.31 *
Ceiling Insulation			
Recommendation	3.11 *	-0.66 *	-0.38
Implementation	0.69 *	2.35 *	1.30 *
Floor Insulation			
Recommendation	0.69 *	0.32	0.21
Implementation	-0.23	-0.03	0.20

Notes: The estimated coefficients measure the changes in million BTUs. A positive sign for a recommendation coefficient indicates the extra energy used by a customer for whom the measure was recommended as compared to a customer for whom the recommendation was not made. A negative sign for an implementation coefficient shows the fall in energy use resulting from the implementation of the recommendation. An asterisk * denotes statistical significance at the 95 % confidence level, using a one-tailed test. For details of the estimating equation, see the text.