A SUMMARY REPORT OF BUILDING ENERGY COMPILATION AND ANALYSIS (BECA) PART B: EXISTING NORTH AMERICAN RESIDENTIAL BUILDINGS

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ABSTRACT

BECA-B assesses the technical performance and economics of energy conservation retrofit measures in houses. The data collected thus far represent measured energy savings and retrofit costs for over 65 North American residential retrofit projects. The sample size within each project ranges from individual homes to 33,000 dwellings participating in a utility-sponsored program. The median value of space heating energy savings is 24% of the pre-retrofit consumption. For fuel-heated homes, the median cost of conserved energy is \$3.86/MBtu, substantially less than the U.S. average 1981 prices for purchased energy of \$4.50/MBtu for natural gas and \$8.70/MBtu for fuel oil. For ten of the eleven electric heat retrofits the cost of conserved electricity is less than the 1981 national average residential electricity price of 6.2c/kWh.

1. INTRODUCTION

BECA-B is a compilation and analysis of measured energy use by U.S. and Canadian houses before and after conservation retrofits. Our results are based on the experience of homeowners, government agencies, utilities, and private firms. This study is part of an ongoing project that collects and critically reviews measured data on the energy performance and cost-effectiveness of low-energy new homes (BECA-A), existing "retrofitted" residential buildings (BECA-B), energy-efficient commercial buildings (BECA-C), appliances and equipment (BECA-D), and validation of computer programs (BECA-V).

The U.S. residential sector accounts for approximately one-fifth of the nation's energy consumption. Space heating and water heating dominate the residential energy demand and hence most initial conservation programs have focused on lowering those usages, especially in existing buildings. It should be of great interest to policy-makers, homeowners, utilities, and contractors to learn what fraction of residential energy use can be saved by retrofit measures, and at what dollar cost. This study presents an initial data base of actual energy savings from retrofitted residences.

One objective of BECA-B is to better understand the technical performance of residential retrofit measures and to evaluate their relative cost-effectiveness. Another goal is to examine the range of conservation savings and costs in order to identify technical, institutional, or programmatic factors associated with high or low levels of performance. The optimum level of conservation investments needs to be determined for the variety of conditions in the residential sector. Energy engineering estimation techniques can also be evaluated by comparing actual energy savings with predicted levels. Finally, we hope to encourage the exchange of documented conservation results and to help establish widely accepted standards for the collection and analysis of such data.

2. BRIEF DESCRIPTION OF DATA SOURCES AND METHODOLOGY

In this section we briefly present some of the characteristics of our data base, which is composed of almost 70 retrofit projects along with 27 control groups. We also discuss aspects of the methodological approach used in our compilation and analysis.

2.1 Data Sources

Classifying our data sources by fuel type, we find that a majority of them use natural gas (39 out of 68) with "mixed" fuel types, electricity, and oil following in that order. "Mixed" means that within a sample of homes, more than one fuel was used. The relatively small number (only 6) of oil-heat retrofits reflects our lack of extensive data from the northeastern section of the country. We also need more data from the southwestern U.S. and California. This last statement is partially based on an examination of the number of heating degree days to the base $65^{o}F$ (HDD_{65}) for our 68 data sources: only 6 have less than 4000 HDD_{65}, 34 (50%) have HDD's in the range of 4000 to 5000, and the other 28 have more than 5000 HDD's.

The bulk of our retrofit data represent either research-type studies (e.g., Princeton, NBS, LBL, etc.) or government-sponsored programs (particularly low-income weatherization). We list results from 11 utility-sponsored programs but have only 4 entries from private-sector firms. The sample size within a particular project is usually fewer than 20 homes (true for 43 of 68 projects), reflecting the predominance of relatively small but carefully monitored research and government studies. We have 11 projects with sample sizes of larger than 100 homes, of which 7 are utility-sponsored.

Floor area data were available from roughly two-thirds of our data sources. Almost one-half of those data points lie in the 1000-1500 ft^2 range, typical of the existing stock. For those homes with known floor area, we calculated a fuel integrity value expressed in units of Btu/ft^2-DD_{65}. We found that prior to retrofit a large majority of the homes had values greater than 12.7 - 15 Btu/ft^2-DD, which is approximately the U.S. average for single-family existing dwellings. This is an expected result since one would anticipate that the majority of homes being retrofitted would initially be energy-inefficient. The principal exceptions are the retrofits sponsored by Princeton; most of these homes were already insulated, and generally have lower fuel integrity values.

The average amount of money spent on conservation measures ranged from $213 to nearly $14,000 per home (expressed in '81$), reflecting the diversity in the number and types of measures carried out. The median cost of retrofits in our data base was $1082. Most of the projects were directed towards more efficient space heating, but 18 of them (out of 68) involved efforts to reduce both space and water heating consumption. The most popular retrofit measure was insulation (occurring in almost 80% of the projects) but caulking and weatherstripping, storm windows, and reduction of infiltration losses (located using blower door pressurization techniques) also appeared frequently (Col I, Table I).

2.2 Methodology

The two major adjustments to the data that concerned us were isolation of the space heating portion of the fuel bill (by subtraction of the baseload usage) and correction of consumption data for the effects of weather in different years (achieved by normalizing pre-and-post retrofit energy use to a "standard" heating season by scaling actual HDD's to the 30-year mean value for that location). In Column J, Table I, we indicate the end uses included in annual energy consumption, either H (space heating), H&W (space heating and hot water) or F (all uses for space heating fuel; generally includes water heating, cooking, clothes drying, etc.). We did not account for any possible changes in the amount of "free" heat (e.g., solar gains, appliance usage, etc.) nor for any changes in occupant behavior or management (e.g., thermostat settings). The assumption of no change in occupants' comfort levels or management of heating systems and appliances is an important limitation in our present data and conclusions, one which we hope to remedy in future analyses. However, where there was a known change in occupants the home was eliminated from the data set. In some cases we also had to estimate the equivalent contractor cost of the retrofit.

Control groups were used in many of the retrofit projects, particularly for the research-type studies. We list control group energy savings in Table I, but most of our scatter plots reflect gross rather than net energy savings for each data point. Figure 4 is the one exception to this practice. In this case, we have subtracted energy savings by the control group from those achieved by the retrofit group, to suggest the net savings induced by participation in the conservation program.

Some of our sample homes are heated by fuel, others by electricity. We would like to evaluate energy savings on a comparable economic basis regardless of fuel type. Hence we convert electricity usage to resource energy using the conversion factor 11,500 Btu per kWh. (In resource energy units, electricity and fuel costs are roughly comparable.)

The basic investment framework for conservation improvements involves an outlay of capital today resulting in future reductions in energy use yielding dollar savings. We evaluate the economic effectiveness of conservation investments using two measures, cost of conserved energy (CCE) and simple payback time. Both have the advantage of avoiding the need to guess future energy prices but both are conservative indices of cost-effectiveness if energy prices are expected to increase faster than general inflation. The cost of conserved energy is found by dividing the annual cost of the retrofit by the annual energy savings due to the investment. We convert the one-time investment to an annual cost by computing a capital recovery rate (CRR). For purposes of sensitivity analysis, we calculate three CRR's using different real discount rates (Table I, Col. M1-M3) but our plots in Figures 1-7 reflect only the middle value (CRR=.110), based on a 7% real interest rate for 15 year lifetime. All of our CCE values are expressed in 1981 constant dollars; we have converted all original retrofit costs into 1981 dollars using the GNP Implicit Price Deflators.

3. DATA IN TABLE I

Table I has 96 samples, consisting of 69 retrofit projects and 27 control groups (whose labels end with an A for active controls and B for blind controls or utility aggregates). Columns A through K2 (plus L) are input data, of which the most important are annual energy consumption (Cols. K1 and K2) and retrofit cost (Col. L). Columns K3 and K4 plus M through R contain derived results: Energy Savings, Cost of Conserved Energy, Simple Payback Time, Heating Fuel Intensity, and Fuel Integrity.

The 96 samples are ordered by type of fuel used, in the sequence Gas, Oil, Mixed, and Electricity. Note that a typical scatter plot has between 55 and 65 points, not 96. This occurs because we have excluded the 27 control groups and aggregates and because, on several plots, a few points overflow the scales.

4. RESULTS

The results of this data compilation and analysis are discussed with reference to Figures 1 through 7. The discussion covers energy savings, subtraction of control group savings, simple payback periods, cost of conserved energy, and actual vs. predicted savings.

4.1 Energy Savings

Figure 1 shows the annual resource energy savings plotted against the contractor cost of the retrofit. The data show the expected overall trend of increased energy savings for larger values of retrofit costs, but there is a lot of scatter. For retrofit costs equal to or less than $2000, annual savings varies up to a factor of seven. The sloping reference lines represent prices of purchased energy. A conservation retrofit is cost-effective if its plotted point lies above the price line for the appropriate fuel. We see that a sizable majority of the retrofits are cost-effective in relation to reference energy prices. The median value of energy savings is 28 MBtu; the median cost is $1082.

As noted, there is a large range in the energy savings and cost effectiveness of the retrofit projects. Although more work is needed to identify the factors associated with the highly successful and the not-so-successful projects, we note a few important factors in the following discussion. The data point labeled OA2.1 represents the Page Homes retrofit, a 1950's-style multi-family public housing complex in New Jersey that was retrofitted with a microcomputer-based boiler control system. The results were a noteworthy 50% energy savings (about 48 MBtu/year saved per apartment) after an investment of about $250 per apartment. The pre-retrofit energy consumption of this building complex was comparable to that of other buildings operated by the housing authority yet it would still be considered an "energy guzzler" in comparison to the overall residential housing stock. For example, daytime inside temperatures averaged 82^{o}F prior to the retrofit. This successful retrofit suggests that substantial savings may be possible by installing improved heating control systems, even without changes to the building shell, in some large multi-family apartment buildings.

The data points labeled E1.1, E1.2, and E6 represent conservation programs (mainly insulation) by TVA in the Southeastern U.S. and Puget Power in the state of Washington. The energy savings are comparatively large (70-80 MBtu/yr per home) for retrofit costs of $600-$1300. Both geographical regions represent locations which have historically enjoyed cheap hydroelectricity and for which there is considerable potential for buildings energy savings.

An example of a project with relatively poor results is the DOE Low-Income Weatherization Program in Minnesota, plotted as data points M10.1 and M10.3. Energy savings of only 7-11 MBtu/yr were achieved for retrofits estimated to cost $1000-1100. The poor benefit-cost ratio could be attributable either to poor workmanship (the project relied on "free" CETA labor), our possible overestimate of equivalent contractor costs, or diminishing returns on investments in homes with moderately low initial fuel integrity values.

Points M2 and G15 also represent low-income weatherization experiments, conducted in this case by the CSA/NBS Demonstration Program. The overall 12-city experiment achieved annual space heating energy savings of 31%, with retrofit measures, in the aggregate, proving to be cost-effective. However at several of the sites (e.g., Atlanta M2 and St. Louis G15) there were problems with the quality of the retrofit work, the data collection procedures, and a failure to install effective prescribed retrofit options. Those points show annual savings of only 14-17 MBtu for investments of $1400-2000, and are not cost-effective.

In Figure 2, the results are replotted in terms of percent savings of space heating energy versus contractor costs. The spread in results narrows slightly from Figure 1. The curved line is based on a simple "eyeball" fit and reflects a crude law of diminishing marginal returns with increasing investment. The data suggest that a $1000 investment in conservation retrofits, on the average, reduced a house's space heating energy consumption by 25%; a $2000 investment reduced annual consumption by roughly 40%. In Figure 3, a histogram of the retrofit results expressed in percent savings of space heating energy is presented. The median value is found to be 24% of the pre-retrofit consumption.

4.2 Subtraction of Control Group Savings

Figure 4 illustrates the reduction in "program-induced" energy savings if control group savings are subtracted. For example, data point E5.1 shows the measured savings, 48 MBtu (resource units), from Seattle City Light's Residential Insulation Program. During the same period, average consumption per household decreased by 13% in the blind control group. Hence we show an arrow reducing the initial point E5.1 by 13% of the pre-retrofit usage or by 25.8 MBtu. Thus the energy savings attributable to the utility's conservation program are 22.2 resource energy MBtu or 1930 kWh per household. Similar subtractions are shown in Fig. 4 for nine other data points.

On the average (equal weighting for each site), the 14 active control groups in our study decreased their annual energy usage by 13.6 MBtu or 9.5 percent. Consumption also dropped approximately 8 percent in the 12 blind control groups and utility aggregates. In both cases, these changes probably indicate some combination of reduced levels of occupant comfort, "independently"-installed retrofit measures, and more energy-efficient operation of the home or appliances.

4.3 Simple Payback Periods

Figure 5 shows the distribution of simple payback periods for the retrofit projects in our compilation. The median payback time is 7.9 years. A factor that partially accounts for the relatively high median value is the large number of research and demonstration projects in our data base. In these studies, new retrofit measures or procedures with unproven cost-effectiveness are often tested. The lower median payback time of 5.7 years for conservation programs sponsored by utilities and private firms reflects investments primarily in established retrofit measures or procedures with relatively high returns on investment.

4.4 Cost of Conserved Energy

The relationship between the contractor cost for the retrofits and the cost of conserved energy (CCE) is shown in Figure 6. Reference prices of purchased electricity, gas, and oil are drawn as horizontal lines against which conservation retrofits for each fuel type can be compared. Including points that overflow the plotted axes, we find the following results: 72% (28 of 39) of the gas-heat projects have a cost of conserved energy below the reference gas price of 50c/therm; 82% (9 of 11) of the all-electric homes saved heating energy more cheaply than the reference electricity price of 5c/kWh; and 80% (4 of 5) of the oil-heat retrofits lie below a fuel oil price of $1.25/gal.

We observe that most retrofits costing less than $2500 had CCE's below $5/MBtu, a result found in 46 of the 58 samples. Seven less successful projects with investments between $500 and $2000 had cost of conserved energy values ranging from $5.50 to $9/MBtu. For the six data sources with retrofit costs between $2500 and $4400, only one had a CCE of less than $5/MBtu; the other five CCE's ranged from $5-7/MBtu. The six least successful projects had CCE's from $11-16/MBtu, and are not shown in this figure as they overflowed the vertical scale. Figure 6 also depicts the cost-effectiveness of "house doctoring" as is evidenced by the cluster of gas-heat data points (from Princeton's Modular Retrofit Experiment) with cost of conserved energy values between $1-2/MBtu and retrofit costs of $350.

Figure 7 shows the distribution of cost of conserved energy for the sample. The median cost of conserved energy is $3.80/MBtu (38c/therm). The median CCE for electrically-heated homes is 3.1c/kWh (or $2.70/MBtu).

In this survey, the reporting of results by data sources is too aggregated to permit ordering individual options by return on investment. In cases where results can be disaggregated based on submetering, the data suggests that the most cost-effective sequence of retrofits includes attic insulation and measures that are part of the Princeton/LBL "house doctor" program of instrumented energy analysis and retrofit. At this time, our data indicate a high correlation between low retrofit costs and cost-effective CCE values.

4.5 Actual Savings vs. Predicted Savings

Millions of energy audits have been performed in U.S. residences for the purpose of estimating retrofit costs and savings to help guide homeowners' decisions on conservation investments. Comparison of actual vs. predicted savings is an important consideration in the evaluation of conservation programs -- an area in which little systematic work has been done. At present, we have limited data on this subject as shown in the following table.

TABLE 2. COMPARISON OF ACTUAL VS. PREDICTED ENERGY SAVINGS

Label	Sponsor	Number	Actual	Predicted	Method
G1	NBS	1	59%	52%	Modified DD
E2	TVA	546	22%	25%	S.S. Heat Loss
E4	PPL	1896	20%	25%	S.S. Heat Loss
E6	Puget	8802	35%	26%	S.S. Heat Loss
E7	PGE	161	32%	33%	S.S. Heat Loss
E8.1	BPA/LBL	5	9%	4%	CIRA
E8.2	BPA/LBL	5	16%	25%	CIRA
E8.3	BPA/LBL	4	42%	36%	CIRA

In four of the above cases, the standard engineering method of making a steady-state heat loss calculation was used to estimate the savings. For one case a modified degree day method (steady state heat losses plus a balance point temperature adjustment) was employed. LBL used its CIRA micro-computer program to predict energy savings in the three-cell Midway project. Predictions for a particular house or group of houses can vary considerably, depending on the method used. In one-half the cases listed in Table II, actual savings fall short of predictions whereas in the other half they exceed the predicted values. We see that the differences between actual and predicted values are not exceedingly large for our sample, all but one of which involves aggregates of houses. Typically, the correlation between actual and predicted usage is poor for an individual house.

In our files, we have collected pre-retrofit predictions of savings on many new conservation programs. When these projects finally report their post-retrofit consumption, we hope to have enough data to permit further quantitative analysis of this subject.

5. CONCLUSIONS

Results from this study indicate that a conservation investment of $1000, on the average, reduced a house's space heating consumption by 25 percent while a $2000 investment decreased usage by approximately 40 percent. The median value of space heating energy savings for this data compilation is 24 percent of the pre-retrofit usage.

Preliminary results reveal that attic insulation, sealing bypass and infiltration losses using pressurization and infrared diagnostic techniques, and wrapping hot water heaters with an insulating blanket are cost-effective retrofit measures.

Even though the data compilation contains a wide variation in the types of homes, the types of fuels, the locations and the types of retrofits, the overall results from aggregating thousands of individual cases show an attractive cost of conserved energy for residential retrofits. The median cost of conserved energy for our data points is an attractive $3.80/MBtu, comfortably less than the U.S. average 1981 cost to residential customers for natural gas ($4.50/MBtu) and for fuel oil ($8.70/MBtu). In fact, 27 of the 39 gas-heat points fall below the natural gas price of $4.50/MBtu and 4 of the 5 oil-heat points fall below the $8.70/MBtu price for heating oil. Of the 11 electric heat data points, 10 of them show a cost of conserved electricity of less than 6.2c/kWh, the 1981 national-average price.

Our present version of BECA-B does not incorporate control group adjustments in the evaluation of cost-effectiveness of retrofit projects. First, control groups were not used in many of the projects; hence calculating net energy savings relative to a control group could not be uniformly implemented for the entire data compilation. Second, the present generation of data is not sufficiently detailed to enable us to separate space heating energy savings into its principal components: savings due to improvements in the building's thermal shell, savings due to a more efficient heating and distribution system, and savings due to occupant management and adjustment of comfort levels. One goal for future editions of BECA-B is to attempt a separation of these components. We solicit and encourage your help in this effort.

The absence of data on multi-family units and on the durability of energy savings from retrofits are worth noting. Thus, future additions to the BECA-B data base will emphasize multi-family retrofit projects and multi-year data on energy savings. We are also interested in obtaining more data on the results of low cost/no cost programs and from "failed" retrofit programs. The latter will allow us to describe factors that account for successful and "failed" programs and better explain the variation in predicted vs. actual energy savings.

Finally, we express the hope that as a result of this paper, potential contributors will contact us to begin sharing data, so that we can greatly increase the scope and accuracy of this compilation.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

A complete listing of all the sources used in assembling the retrofit data base discussed in this article may be found in the following reference: Wall, L.W., Goldman, C.A., Rosenfeld, A.H., and Dutt, G.S. 1982. Building energy use compilation and analysis (BECA) part B: existing North American residential buildings. Lawrence Berkeley Laboratory LBL-13385, EEB-BED-82-05.

Table I

A	B	C	D	E	F	G	H	I	J	K1	K2	K3	K4
		NUMBER				YR OF				ENERGY CONSUMP (MBTU/YR)		ENERGY SAVINGS	
	SPONSOR	OF				RETRO		RETROFIT	ENERGY			(MBTU/	
LABEL	CAT.	HOMES	LOCATION	SPONSOR	HDD	FIT	SQF	TYPE	USAGE	BEFORE	AFTER	YR)	PERCNT
G1	R	1	BOWMAN HOUSE,MD	NBS	4610	75	2054	I,W,C	H	125.6	52.1	73.5	59
G2	R	1	TWIN RIVERS,NJ	PRINCETON	4911	77	1500	I,W,C,P	H	81.0	19.2	61.8	76
G3	R	1	HS 11,NJ	PRINCETON	4911	79	1200	I,W,H,P	H	59.6	35.7	23.9	40
G4	R	1	HS 22,NJ	PRINCETON	4911	79	1560	I,D,H,P	H	114.4	84.1	30.3	26
G5.1	R/U	6	MRE/FREEHOLD,NJ	PRINCETON/NJNG	4872	80	2500	I,T,P	F	178.8	135.1	43.7	24
G5.2	R/U	12	MRE/FREEHOLD,NJ	PRINCETON/NJNG	4872	80	2500	T,P	F	171.9	142.9	29.0	17
G5.3B	R/U	6	MRE/FREEHOLD,NJ	PRINCETON/NJNG	4872		2500		F	184.0	174.9	9.1	5
G5.4B	R/U	140000	MRE/NJNG	PRINCETON/NJNG	4872				F				3
G6.1	R/U	6	MRE/TOMS RIVER,NJ	PRINCETON/NJNG	4872	80	900	I,T,P	F	87.2	70.4	16.8	19
G6.2	R/U	12	MRE/TOMS RIVER,NJ	PRINCETON/NJNG	4872	80	900	T,P	F	99.2	92.4	6.8	7
G6.3B	R/U	6	MRE/TOMS RIVER,NJ	PRINCETON/NJNG	4872		900		F	98.0	98.0	0.	0
G6.4B	R/U	140000	MRE/NJNG	PRINCETON/NJNG	4872				F				4
G7.1	R/U	6	MRE/OAK VALLEY,NJ	PRINCETON/SJG	4872	80	1400	I,T,P,W	F	116.3	88.9	27.4	24
G7.2	R/U	9	MRE/OAK VALLEY,NJ	PRINCETON/SJG	4872	80	1400	T,P	F	120.9	94.0	26.9	22
G7.3A	R/U	6	MRE/OAK VALLEY,NJ	PRINCETON/SJG	4872		1400		F	128.6	115.0	13.6	11
G7.4B	R/U	75000	MRE/SJG	PRINCETON/SJG	4872				F				11
G8.1	R/U	5	MRE/WHITMAN SQ,NJ	PRINCETON/SJG	4872	80	2000	I,T,P	F	147.2	111.8	35.4	24
G8.2	R/U	9	MRE/WHITMAN SQ,NJ	PRINCETON/SJG	4872	80	2000	T,P	F	134.8	109.1	25.7	19
G8.3A	R/U	4	MRE/WHITMAN SQ,NJ	PRINCETON/SJG	4872		2000		F	133.8	112.4	21.4	16
G8.4B	R/U	75000	MRE/SJG	PRINCETON/SJG	4872				F				12
G24.1	R/U	6	MRE/EDISON,NJ	PRINCETON/ELIZ.GAS	4872	80	1800	I,T,P	F	163.4	124.8	38.6	24
G24.2	R/U	5	MRE/EDISON,NJ	PRINCETON/ELIZ.GAS	4872	80	1800	T,P	F	163.8	139.7	24.1	15
G24.3A	R/U	6	MRE/EDISON,NJ	PRINCETON/ELIZ.GAS	4872		1800		F	166.3	154.7	11.6	7
G24.4B	R/U	75000	MRE/ELIZ. GAS	PRINCETON/ELIZ.GAS	4872				F				10
G25.1	R/U	6	MRE/WOOD RIDGE,NJ	PRINCETON/PSEG	4872	80	1400	I,P	F	176.6	150.8	25.8	15
G25.2	R/U	6	MRE/WOOD RIDGE,NJ	PRINCETON/PSEG	4872	80	1400	P	F	159.0	137.7	21.3	13
G25.3A	R/U	6	MRE/WOOD RIDGE,NJ	PRINCETON/PSEG	4872		1400		F	147.8	131.2	16.6	11
G25.4B	R/U	550000	MRE/PSEG,NJ	PRINCETON/PSEG	4872				F				11
G26.1	R/U	5	MRE/NEW ROCHELLE,NY	PRINCETON/CON ED	4872	80	1400	I,T,P,H	F	155.4	124.1	31.3	20
G26.2	R/U	5	MRE/NEW ROCHELLE,NY	PRINCETON/CON ED	4872	80	1400	T,P,H	F	160.4	136.1	24.3	15
G26.3A	R/U	6	MRE/NEW ROCHELLE,NY	PRINCETON/CON ED	4872		1400		F	158.9	138.3	20.6	13
G9.1	R	5	SASKATCHEWAN,CANADA	EN.CONS INFO C./NRC	10939	80	2157	I,C,P	H	177.1	123.8	53.3	30
G9.2	R	5	SASKATCHEWAN,CANADA	EN.CONS INFO C./NRC	10939	80	1752	C,P	H	163.5	148.6	14.9	9
G9.3	R	10	SASKATCHEWAN,CANADA	EN.CONS INFO C./NRC	10939	80		I,W,D,C	H	127.2	111.3	15.9	13
G10.1	R	1	BUTTE,MT	NCAT	9669	79	2300	I	H	269.2	243.0	26.2	10
G10.2	R	1	BUTTE,MT	NCAT	9669	80	2300	I,C,A	H	243.0	165.9	77.1	32
G11	U	84	RAMSEY COUNTY,MINN	NSP	8159	79	1900	I,C	H	156.7	144.9	11.8	8
G12.1	U	33	BAKERSFIELD,CA	PGE	2185	79		I	H	83.0	68.1	14.9	18
G12.2	U	16	FRESNO,CA	PGE	2650	79		I	H	61.5	42.0	19.6	32
G13	U	33000	COLORADO	PUB SERV CO	6016	77		I	H	119.2	99.6	19.6	16
G14.1	G	8	OAKLAND,CA	CSA/NBS	2909	79	1300	I,C	H	76.1	74.0	2.2	3
G14.2A	G	4	OAKLAND,CA	CSA/NBS	2909				H	116.9	128.4	-11.5	-10
G15	G	18	ST LOUIS,MO	CSA/NBS	4750	79	1355	I,W,C	H	174.7	157.3	17.4	10
G16	G	10	CHICAGO,ILL	CSA/NBS	6127	79	1464	I,W,C,H	H	264.8	155.1	109.7	41
G17.1	G	16	COLORADO SPRINGS	CSA/NBS	6473	79	998	I,W,C,H	H	132.0	71.6	60.4	46
G17.2A	G	4	COLORADO SPRINGS	CSA/NBS	6473				H	164.8	164.6	.2	0
G18.1	G	17	ST PAUL,MINN	CSA/NBS	8159	79	1421	I,W,C	H	180.9	141.6	39.3	22
G18.2A	G	5	ST PAUL,MINN	CSA/NBS	8159				H	286.1	262.7	23.4	8
G19	G	30	LUZERNE CTY,PA	DOE	6277	79		I,W,C	H	157.9	134.2	23.7	15
G20	G	89	LOUISIANA	DOE	1800	80			H	48.3	34.1	14.2	29

A LABEL	L1 AVG. ORIG$ *****	L2 RETRO 81 $ *****	L3 COSTS 81 $/ KSQFT	M1 COST OF CONSERVED ENERGY (81$/MBTU) AT CAP. REC. RATE 8.4	M2 11.0	M3 13.2	N SIMPLE PAYBACK (YEARS)	O1 HEATING FUEL INTENS. (MBTU/KSQFT) BEFORE	O2 AFTER	P1 FUEL INTEGR. (BTU/SQFTDD) BEFORE	P2 AFTER	Q CONFI-DENCE LEVEL ******	R COMMENTS
G1	2840	4202	2046	4.75	6.29	7.55	16.1	61.1	25.4	13.3	5.5	A	FIRST EXTENSIVE STUDY
G2	3000	4036	2690	5.42	7.18	8.62	16.2	54.0	12.8	11.0	2.6	A	TOWNHOUSE
G3	700	814	678	2.83	3.74	4.49	7.9	49.7	29.8	10.1	6.1	A	ELIMINATE BYPASS LOSSES,ETC.
G4	1000	1162	745	3.18	4.22	5.06	8.9	73.3	53.9	14.9	11.0	A	ELIMINATE BYPASS LOSSES,ETC.
G5.1	2562	2750	1100	5.22	6.92	8.31	13.0	44.8	30.7	9.2	6.3	A	H. D. AND CONTRACT RETR.
G5.2	325	349	140	1.00	1.32	1.59	2.5	45.3	39.5	9.3	8.1	A	H. D. ONLY
G5.3B								53.1	52.6	10.9	10.8	A	BLIND CONTROL GROUP
G5.4B												A	UTILITY AGGREGATE
G6.1	1272	1365	1517	6.75	8.94	10.73	16.8	66.7	50.7	13.7	10.4	A	H. D. AND CONT. RET.
G6.2	325	349	388	4.26	5.64	6.77	10.6	73.1	68.7	15.0	14.1	A	H. D. ONLY
G6.3B								77.0	77.0	15.8	15.8	A	BLIND CONTROL GROUP
G6.4B												A	UTILITY AGGREGATE
G7.1	911	978	699	2.96	3.93	4.71	6.2	48.7	33.6	10.0	6.9	A	H. D. AND CONTRACT RETR.
G7.2	325	349	249	1.08	1.43	1.71	2.2	47.3	35.6	9.7	7.3	A	H. D. ONLY
G7.3A								51.6	42.4	10.6	8.7	A	ACTIVE CONTROL GROUP
G7.4B												A	UTILITY AGGREGATE
G8.1	664	713	356	1.67	2.21	2.66	3.5	62.4	45.8	12.8	9.4	A	H. D. AND CONTR. RETR.
G8.2	325	349	174	1.13	1.49	1.79	2.3	50.7	40.4	10.4	8.3	A	H. D. ONLY
G8.3A								51.6	40.0	10.6	8.2	A	ACTIVE CONTROL GROUP
G8.4B												A	UTILITY AGGREGATE
G24.1	1370	1471	817	3.16	4.19	5.03	7.1	60.4	40.9	12.4	8.4	A	H. D. AND CONTRACT RETR.
G24.2	325	349	194	1.20	1.59	1.91	2.7	58.5	46.3	12.0	9.5	A	H. D. ONLY
G24.3A								63.8	50.7	13.1	10.4	A	ACTIVE CONTROL GROUP
G24.4B												A	UTILITY AGGREGATE
G25.1	961	1032	737	3.32	4.40	5.28	7.4	92.1	66.7	18.9	13.7	A	H. D. AND CONTRACT RETR.
G25.2	325	349	249	1.36	1.80	2.16	3.1	81.8	63.3	16.8	13.0	A	H. D. ONLY
G25.3A								78.4	61.9	16.1	12.7	A	ACTIVE CONTROL GROUP
G25.4B												A	UTILITY AGGREGATE
G26.1	1008	1082	773	2.87	3.80	4.56	6.4	71.1	55.5	14.6	11.4	A	H. D. AND CONTRACT RETR.
G26.2	325	349	249	1.19	1.58	1.90	2.7	62.8	53.6	12.9	11.0	A	H. D. ONLY
G26.3A								79.9	68.2	16.4	14.0	A	ACTIVE CONTROL GROUP
G9.1	1976	2027	940	3.16	4.18	5.02	12.3B	82.1	57.4	7.5	5.2	B	SEALED AND INSULATED
G9.2	514	527	301	2.94	3.89	4.67	11.5B	93.3	84.8	8.5	7.8	B	SEALED ONLY
G9.3	1442	1479		7.72	10.23	12.28	30.2B					C	INSULATED
G10.1	500	570	248	1.81	2.39	2.87	5.4B	117.0	105.7	12.1	10.9	B	PHASE I
G10.2	13100	13738	5973	14.79	19.60	23.52	44.5B	105.7	72.1	10.9	7.5	B	PHASE II, INCLUDES PASSIVE WALL
G11	290	325	171	2.28	3.03	3.63	8.4	82.5	76.3	10.1	9.3	B	LOW-INCOME WEATHERIZATION
G12.1	427	496		2.76	3.66	4.40	5.7					B	ATTIC INSUL PROG IN SAN JOAQUIN VALLEY
G12.2	417	485		2.06	2.72	3.27	4.3					B	ATTIC INSUL PROG IN SAN JOAQUIN VALLEY
G13	272	360		1.52	2.02	2.42	4.4B					B	LOW INT LOANS FOR ATTIC INSUL
G14.1	274	312	240	12.01	15.91	19.10	18.9	58.5	56.9	20.1	19.6	A	DEMO PGM. LOW-INCOME WEATHERIZATION
G14.2A												A	ACTIVE CONTROL GRP.
G15	1781	2031	1499	9.69	12.84	15.41	43.6	128.9	116.1	27.1	24.4	A	DEMO PGM. LOW-INCOME WEATHERIZATION
G16	2347	2677	1828	2.03	2.68	3.22	7.3	180.9	105.9	29.5	17.3	A	DEMO PGM. LOW-INCOME WEATHERIZATION
G17.1	1765	2013	2017	2.77	3.67	4.40	12.0	132.3	71.7	20.4	11.1	A	DEMO PGM. LOW-INCOME WEATHERIZATION
G17.2A												A	ACTIVE CONTROL GROUP
G18.1	1761	2008	1413	4.24	5.62	6.75	15.7	127.3	99.6	15.6	12.2	A	DEMO PGM. LOW-INCOME WEATHERIZATION
G18.2A												A	ACTIVE CONTROL GROUP
G19	789	900		3.15	4.18	5.01	9.2					C	LOW-INCOME WEATHERIZATION
G20	1044	1071		6.26	8.30	9.96	17.9					C	LOW-INCOME WEATHERIZATION

Table I (cont.)

A	B	C	D	E	F	G	H	I	J	K1	K2	K3	K4
LABEL	SPONSOR CAT.	NUMBER OF HOMES	LOCATION	SPONSOR	HDD	YR OF RETRO FIT	SQF	RETROFIT TYPE	ENERGY USAGE	ENERGY CONSUMP (MBTU/YR) BEFORE	AFTER	ENERGY SAVINGS (MBTU/ YR)	PERCNT
G21.1	G	21	KANSAS CITY,MO	DOE	5161	77		I,C	H	135.0	115.0	20.0	15
G21.2	G	45	KANSAS CITY,MO	DOE	5161	77		I,C	H	196.0	152.0	44.0	22
G21.3	G	44	KANSAS CITY,MO	DOE	5233	78		I,C	H	191.0	139.0	52.0	27
G22	G	138	KENTUCKY	DOE	4729	79		I,W,D,C	H	118.5	102.8	15.7	13
G23	G	30	INDIANA	DOE	5577	78	1102	I,C,H	H	182.1	135.7	46.4	25
O1	R	1	HS 21,NJ	PRINCETON	4911	79	1990	I,W,H,P	H	132.0	62.5	69.5	53
OA2.1	G/P	159	PAGE APTS, NJ	HUD/TRENTON	4911	81	830	H,E	H,W	96.2	48.5	47.7	50
OA2.2B	R	1500	APTS,NJ	HUD/TRENTON	4911				H,W	116.7	98.3	18.4	16
OA3	P	521	MF COMPLEX,WASH DC	SCALLOP THERMAL MAN.	4211	78		H,E,O	H,W	116.3	108.4	7.9	7
OA4	P	752	MF COMPLEX,MD	SCALLOP THERMAL MAN.	4211	78		H,E,O	H,W	84.9	83.1	1.8	2
OA5	P	60	COOP BLDG,NYC	SCALLOP THERMAL MAN.	4848	78		H,E,O	H,W	167.3	152.1	15.2	9
O6	G	13	VERMONT	DOE	7876	80		I,W,D	H	143.5	100.0	43.5	30
M1.1	G	13	CHARLESTON,SC	CSA/NBS	2146	79	1111	I,C	H	62.5	41.4	21.1	34
M1.2A	G	5	CHARLESTON,SC	CSA/NBS	2146				H	36.3	30.7	5.6	15
M2	G	8	ATLANTA,GA	CSA/NBS	3095	79	1055	I,W,C	H	108.1	94.1	14.0	13
M3	G	4	WASH,DC	CSA/NBS	4211	79	915	I,W,C,H	H	130.5	69.1	61.4	47
M4.1	G	9	TACOMA,WA	CSA/NBS	5185	79	978	I,W,C	H	168.8	99.8	69.0	41
M4.2A	G	5	TACOMA,WA	CSA/NBS	5185				H	59.5	50.1	9.4	16
M5.1	G	13	EASTON,PA	CSA/NBS	5827	79	1334	I,C,H	H	121.7	93.1	28.6	24
M5.2A	G	3	EASTON,PA	CSA/NBS	5827				H	44.0	39.9	4.2	9
M6.1	G	14	PORTLAND,ME	CSA/NBS	7498	79	1008	I,W,C,H	H	187.3	105.4	81.9	44
M6.2A	G	4	PORTLAND,ME	CSA/NBS	7498				H	232.5	203.8	28.7	12
M7.1	G	12	FARGO,ND	CSA/NBS	9271	79	786	I,W,C,H	H	109.5	65.8	43.7	40
M7.2A	G	5	FARGO,ND	CSA/NBS	9271				H	145.1	131.3	13.8	10
M8.1	G	142	CSA/NBS	COMPOSITE		79	1168		H	146.7	101.9	44.8	31
M8.1A	G	41	CSA/NBS	COMPOSITE					H	145.2	138.7	6.5	4
M9	G	65	NW WISCONSIN	CSA	8388	76	1292	I,W,D,C	H	143.0	115.9	27.1	19
M10.1	G	59	MINNESOTA	DOE	8310	78	806	I,W,C	H	110.9	99.6	11.3	10
M10.2B	G	37	MINNESOTA	DOE	8310		1325		H	128.5	131.7	-3.2	-2
M10.3	G	19	MINNESOTA	DOE	8310	78	774	I,W,C	H	103.6	96.7	6.9	7
M11	G	13	WISCONSIN	DOE	8820	79			H	139.3	116.3	23.0	17
M12	G	86	ALLEGAN CTY,MI	DOE	6801	80			H	156.0	112.0	44.0	28
										(KWH)		(KWH)	
E1.1	U	69	TENNESSEE	TVA	4436	76	1013	I,C	H	11270.	5148.0	6122.0	54
E1.2	U	105	TENNESSEE	TVA	4421	76		I	H	12383.	8271.0	4112.0	33
E2	U	546	TENNESSEE	TVA	4010	78		I	H	10148.	7937.0	2211.0	22
E3.1	R/P	29	DENVER,COL	JOHNS MANVILLE	6016	78	1600	P	H	17615.	14779.0	2836.0	16
E3.2A	R/P	30	DENVER,COL	JOHNS MANVILLE	6016				H	20606.	17715.0	2891.0	14
E3.3B	R/P	30	DENVER,COL	JOHNS MANVILLE	6016				H	23886.	21034.0	2852.0	12
E4	U	1896	OREGON	PAC PWR LIGHT	4800	79		I,W,D,C	H	21305.	17044.0	4261.0	20
E5.1	U	133	SEATTLE,WA	SEATTLE CITY LIGHT	5185	79		I	H	17107.	12934.0	4173.0	24
E5.2B	U	551	SEATTLE,WA	SEATTLE CITY LIGHT	5185				H	16843.	14634.0	2209.0	13
E6	U	8802	WASHINGTON	PUGET POWER	5500	79		I,W	H	20000.	13070.0	6930.0	35
E7	U	161	OREGON	PORTLAND GEN ELEC	4792	78		I,W,D,C	H	13000.	8879.0	4121.0	32
E8.1	R/U	5	MIDWAY,WA	BPA/LBL	4760	80	1260	P	H	19984.	18138.0	1846.0	9
E8.2	R/U	5	MIDWAY,WA	BPA/LBL	4760	79	1253	I,C	H	19803.	16568.0	3235.0	16
E8.3	R/U	4	MIDWAY,WA	BPA/LBL	4760	79	1239	I,C,D,W	H	19649.	11445.0	8204.0	42

A	L1	L2	L3	M1	M2	M3	N	O1	O2	P1	P2	Q	R
LABEL	AVG. ORIG$	RETRO 81 $	COSTS 81 $/ KSQFT	COST OF CONSERVED ENERGY (81$/MBTU) AT CAP. REC. RATE 8.4	11.0	13.2	SIMPLE PAYBACK (YEARS)	HEATING FUEL INTENS. (MBTU/KSQFT) BEFORE	AFTER	FUEL INTEGR. (BTU/SQFTDD) BEFORE	AFTER	CONFI- DENCE LEVEL	COMMENTS
	*****	*****										******	
G21.1	407	539		2.24	2.96	3.55	13.0					C	LOW-INCOME WEATHERIZATION
G21.2	525	675		1.27	1.69	2.03	7.6					C	LOW-INCOME WEATHERIZATION
G21.3	1494	1814		2.89	3.84	4.60	15.5					C	LOW-INCOME WEATHERIZATION
G22	254	290		1.53	2.03	2.44	4.6C					C	LOW-INCOME WEATHERIZATION
G23	1375	1700	1543	3.04	4.03	4.84	14.1C	165.2	123.1	29.6	22.1	B	LOW-INCOME WEATHERIZATION
01	1200	1395	701	1.67	2.21	2.65	3.1	66.3	31.4	13.5	6.4	A	ELIM. BYPASS LOSSES
OA2.1	252	246	297	.43	.57	.68	.6					B	MULTI-FAMILY APT. RETROFIT
OA2.2B												B	BLIND CONTROL GROUP
OA3				3.45	3.56	3.68	9.0C					B	THERMAL SERVICES CONTRACT
OA4				9.00	9.36	9.59	23.6C					B	THERMAL SERVICES CONTRACT
OA5												I	THERMAL SERVICES CONTRACT
06	1506	1579		3.01	3.99	4.79	4.1					C	LOW-INCOME WEATHERIZATION
M1.1	977	1114	1003	4.38	5.81	6.97	6.6	56.3	37.3	26.2	17.4	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M1.2A												A	ACTIVE CONTROL GROUP
M2	1211	1381	1309	8.19	10.85	13.02	18.9	102.5	89.2	33.1	28.8	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M3	2924	3335	3645	4.51	5.97	7.17	6.3	142.6	75.5	33.9	17.9	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M4.1	1807	2061	2107	2.48	3.29	3.94	8.4	172.6	102.0	33.3	19.7	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M4.2A												A	ACTIVE CONTROL GROUP
M5.1	905	1032	774	3.00	3.97	4.76	6.1	91.2	69.8	15.7	12.0	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M5.2A												A	ACTIVE CONTROL GROUP
M6.1	2215	2526	2506	2.56	3.39	4.07	3.8	185.8	104.6	24.8	13.9	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M6.2A												A	ACTIVE CONTROL GROUP
M7.1	1626	1854	2359	3.52	4.67	5.60	5.7	139.3	83.7	15.0	9.0	A	DEMO PGM. LOW-INCOME WEATHERIZATION
M7.2A												A	ACTIVE CONTROL GROUP
M8.1	1610	1836	1572	3.40	4.51	5.41	8.2	125.6	87.2			A	DEMO PGM. LOW-INCOME WEATHERIZATION
M8.1A												A	ACTIVE CONTROL GROUP COMPOSITE
M9	219	307	238	.94	1.25	1.50	2.4	110.7	89.7	13.2	10.7	C	LOW-INCOME WEATHERIZATION
M10.1	906	1120	1390	8.23	10.91	13.09	25.1C	137.6	123.6	16.6	14.9	C	LOW-INCOME WEATHERIZATION
M10.2B								97.0	99.4	11.7	12.0	C	BLIND CONTROL GROUP
M10.3	849	1050	1357	12.63	16.74	20.09	36.0	133.9	124.9	16.1	15.0	C	2 POST-RETRO YEARS SUBGROUP
M11	1088	1241		4.48	5.93	7.12	11.1					C	LOW-INCOME WEATHERIZATION
M12	1050	1101		2.08	2.75	3.30	3.9					C	LOW-INCOME WEATHERIZATION
					CENTS/KWH								
E1.1	440	610	602	.83	1.10	1.31	3.5	127.9	58.4	12.8	5.9	A	DEMO PROGRAM BY PRIVATE CONTRAC.
E1.2	154	213		.43	.57	.68	1.9					B	DEMO PROGRAM BY TVA PERSONNEL
E2	310	383		1.44	1.91	2.29	5.1					A	EARLY PART OF HOME INSUL. PROG
E3.1	1050	1245	778	3.64	4.83	5.80	7.7B	126.6	106.2	9.4	7.9	A	STUDY OF AIR LEAKAGE
E3.2A												A	ACTIVE CONTROL GROUP
E3.3B												A	BLIND CONTROL GROUP
E4	1335	1523		2.97	3.93	4.72	13.6					C	ZERO INTEREST WEATH. PROGRAM
E5.1	399	455		.91	1.20	1.44	5.1					C	EARLY PART OF WEATH. PROGRAM
E5.2B												C	BLIND CONTROL GROUP
E6	1110	1266		1.52	2.01	2.41	6.8B					C	ZERO INTEREST WEATH. PROGRAM
E7	1357	1609		3.24	4.30	5.15	9.4					C	EARLY PART OF WEATH. PROGRAM
E8.1	525	525	417	2.36	3.13	3.75	11.4	182.4	165.5	17.1	15.5	A	EXTENSIVE INFILTRATION REDN.
E8.2	1860	2041	1629	5.24	6.94	8.33	23.0	181.8	152.1	17.0	14.2	A	ATTIC AND CRAWLSPACE INS.
E8.3	4023	4416	3564	4.47	5.92	7.10	19.6	182.4	106.2	17.1	9.9	A	INS. PLUS STORM DOOR,WINDOW

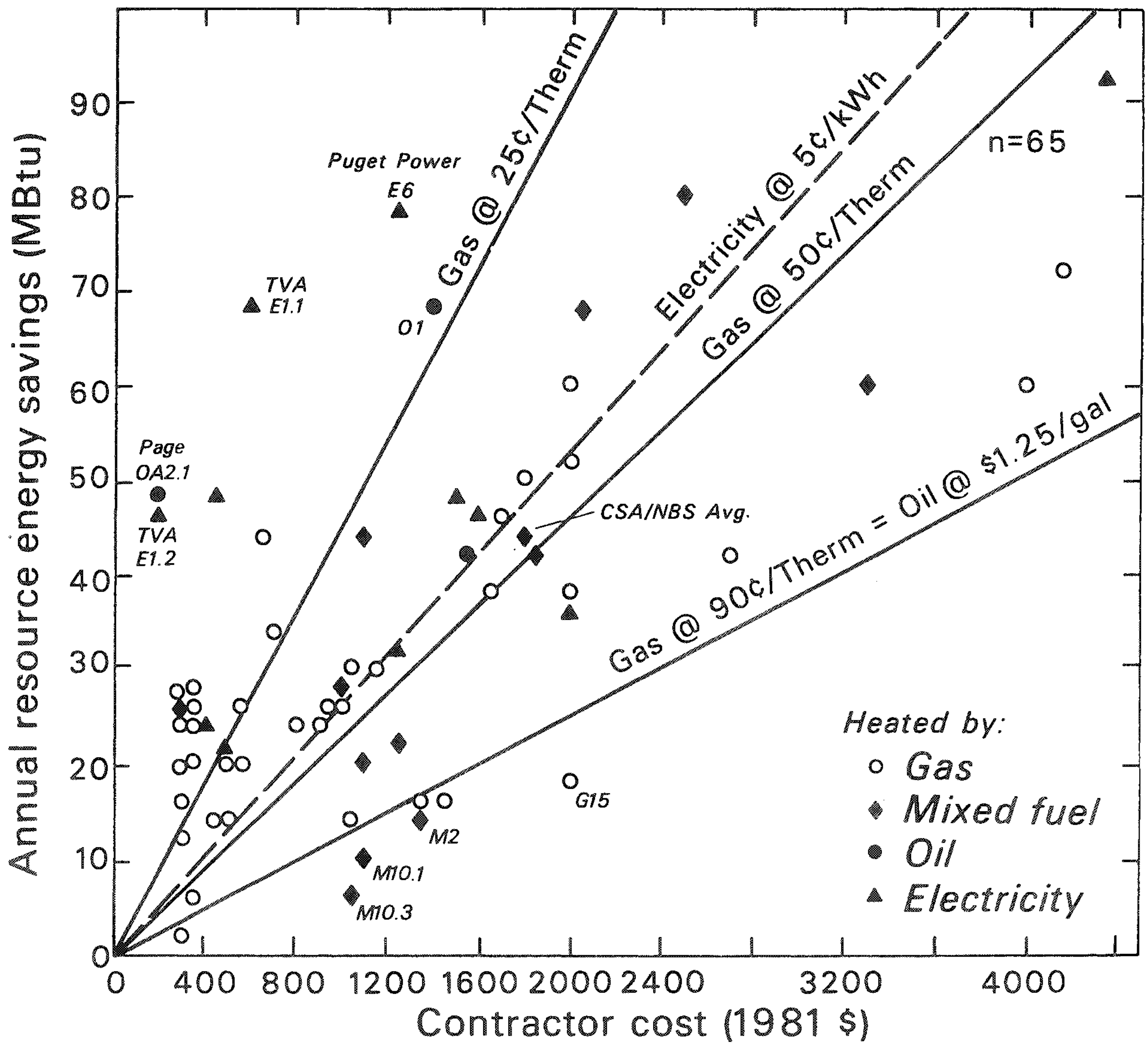

Fig. 1. Annual resource energy savings vs. Contractor cost. Annual savings, in resource energy, after retrofit are plotted against the contractor cost of retrofits for 65 data sources. The sloping reference lines represent the boundary of cost-effectiveness for typical residential energy prices. Since conservation investments are typically "one-time," the future stream of energy purchases for 15 years is converted to a single present value, assuming a 7% real discount rate. The conservation retrofit is cost-effective if the data point lies above the purchased energy line for that fuel. In most cases the plotted savings apply to space heat only, except for 15 samples which addressed other end uses in addition to space heating (shown in Table I, Col. J as H,W or F). In those 15 cases, we plot the combined savings. Electricity is measured in resource units of 11,500 Btu per kWh sold.

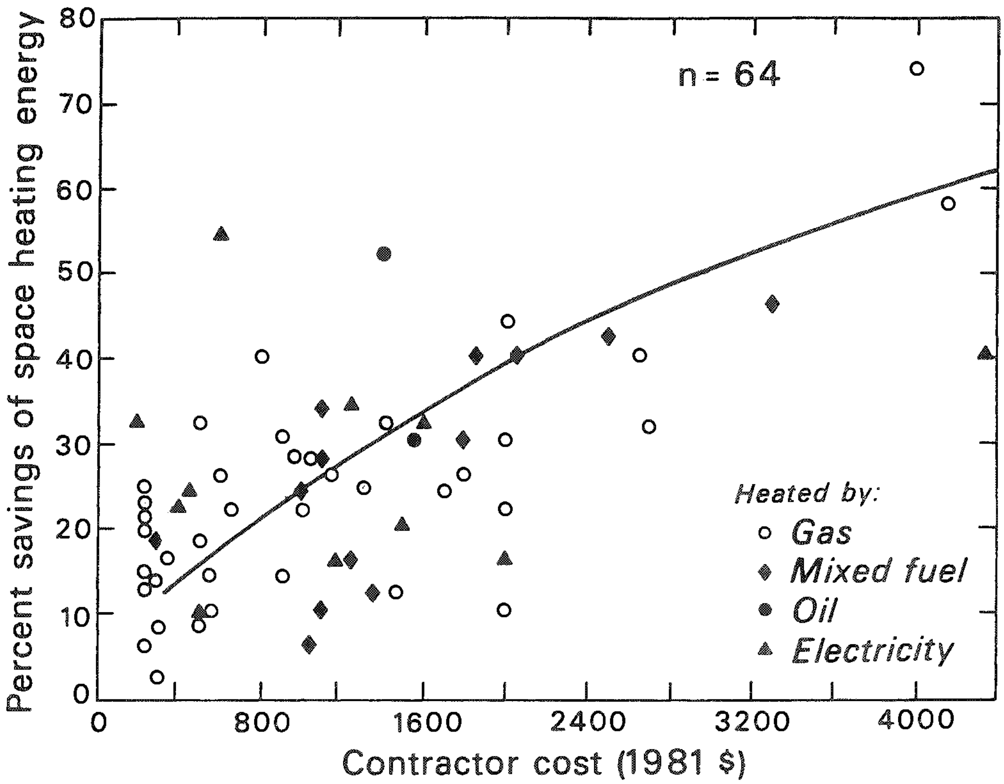

Fig. 2. Percent savings of space heating energy vs. Contractor cost for 64 entries in Table I. The percent savings are taken from column K4 in Table I except for the 14 Princeton MRE points which are calculated from the space heating portions (columns P1 and P2) of the total fuel usage. The curved line is an "eye-ball" fit of the data, suggesting approximate average energy savings for our data of 25% for $1000 and 40% for a $2000 conservation investment.

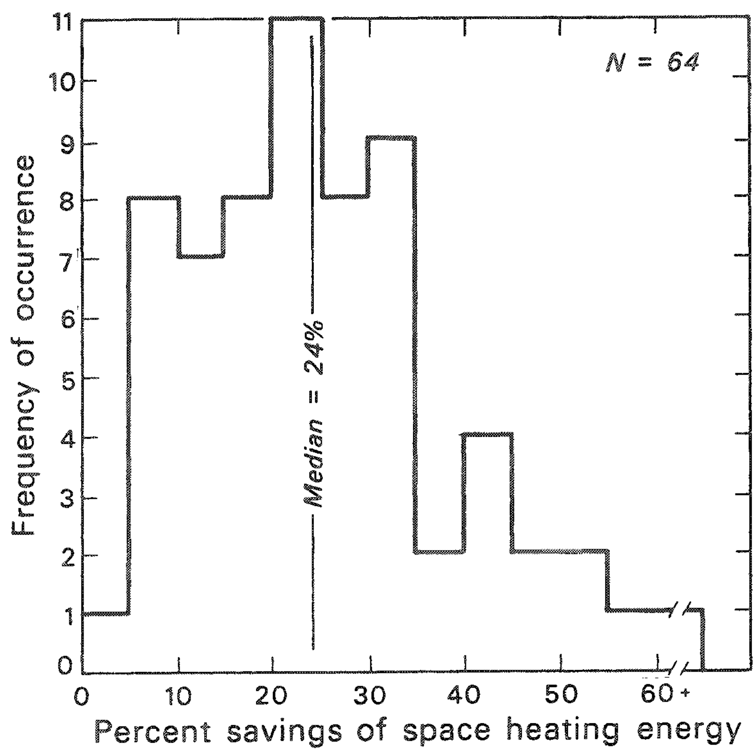

Fig. 3. Histogram of the energy savings data shown in Figure 2. The median value of space heating energy savings is 24% of the pre-retrofit consumption.

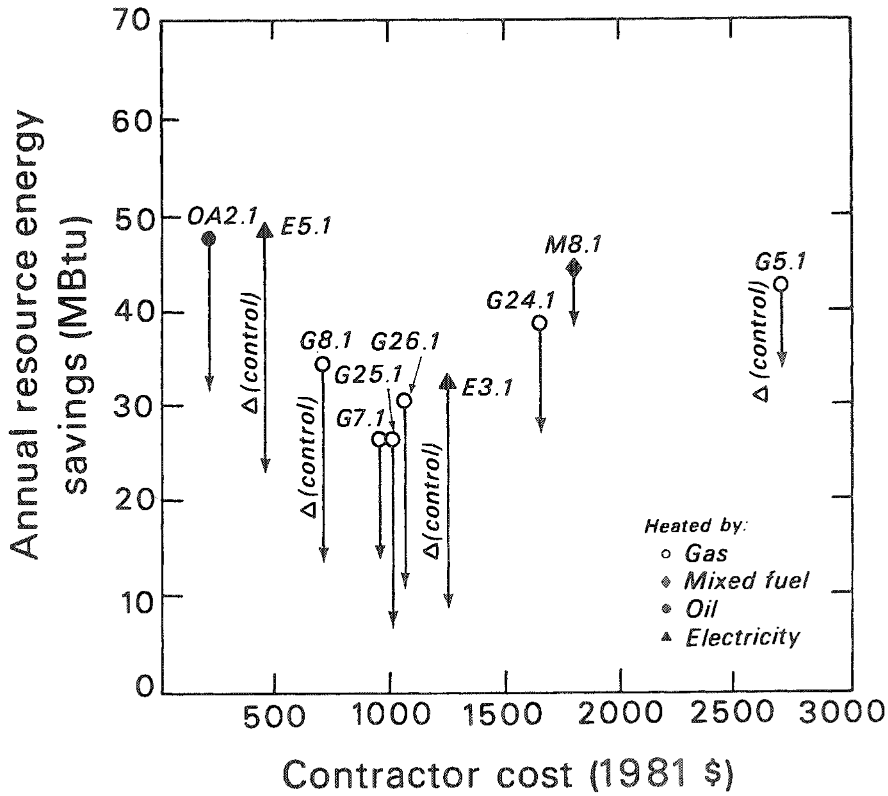

Fig. 4. This figure shows the reduction in "program-induced" savings when control group energy savings are subtracted. The scatter plot illustrates the reduction in savings (drawn from the initial data point by an arrow) for 10 of 24 samples that employed a control group. The points not included either overlap those shown or were active control groups from the individual cities in the CSA/NBS Demonstration Program (whose results are aggregated in M 8.1A).

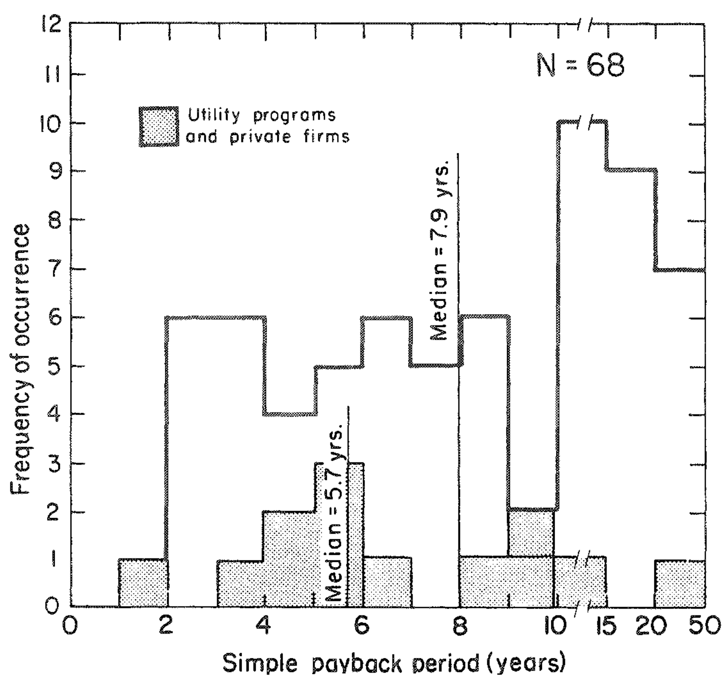

Fig. 5. Histogram of the simple payback time distribution of the data. For 68 studies, the median payback time is 7.9 years. Results for utility-sponsored programs and private firms are shown in the shaded area. Utility and privately-sponsored conservation programs had a median payback time of 5.7 years.

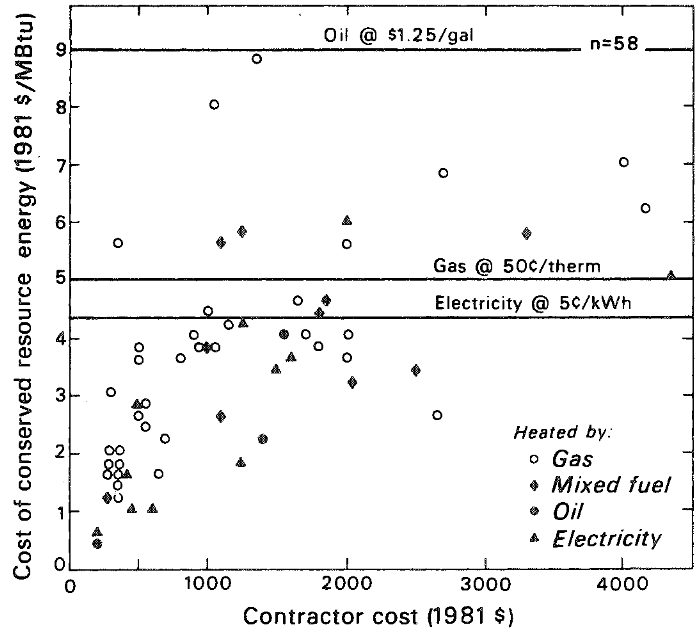

Fig. 6. The scatter plot shows the relationship between the cost of conserved energy and the contractor cost for the measures. The cost of conserved energy equals the ratio, total investment over annual savings, multiplied by the capital recovery factor (.11, assuming a 7% real discount rate and 15-year amortization period). The horizontal lines represent prices of purchased energy against which conservation retrofits should be compared. Of the 58 sources, 46 invested less than $2500 per home, and obtained CCE's of less than $5/MBtu. The gas data points clustered between $1-2/MBtu represent the results of the Princeton house-doctoring experiments. Electricity is measured in resource units of 11,500 Btu per kWh sold.

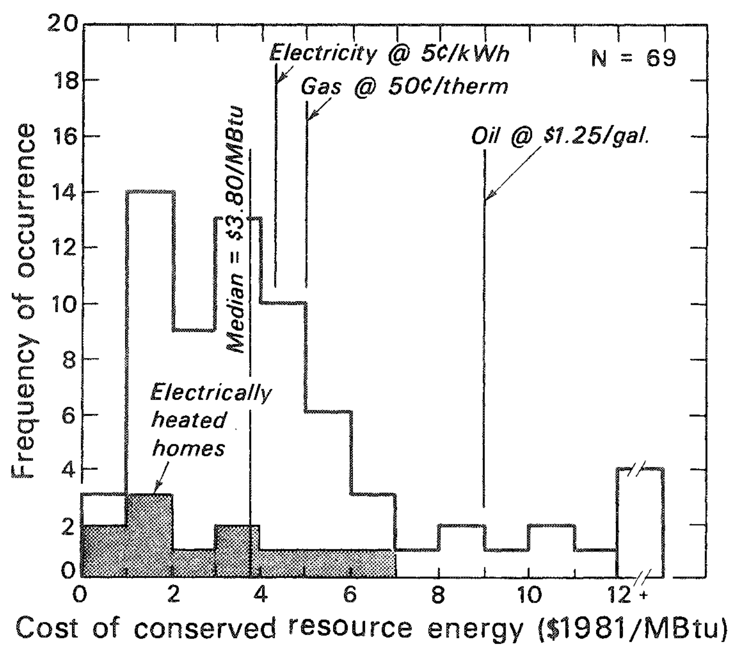

Fig. 7 Histogram of the distribution of cost of conserved energy (CCE) for the sample. CCE values for electrically heated homes (converted to MBtu at 11,500 Btu/1 kWh) are shown in shaded area with a median of 3.1¢/kWh (or $2.70/MBtu). Overall, the 69 entries obtained a median cost of conserved energy of $3.80/MBtu (38¢/therm).