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

Leonard W. Wall, Charles A. Goldman,
Arthur H. Rosenfeld, and Gautam S. Dutt

July 1982

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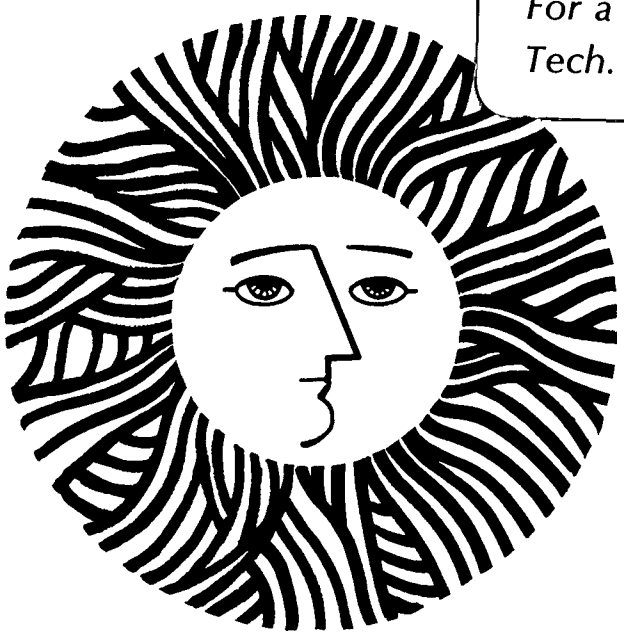

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BUILDING ENERGY COMPILATION AND ANALYSIS (BECA)
PART B: EXISTING NORTH AMERICAN RESIDENTIAL BUILDINGS

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ABSTRACT

BECA-B assesses the technical performance and economics of energy conservation retrofit measures. 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 1 to 33,000 homes, reflecting individual efforts and utility-sponsored programs. The median value of energy savings is 23%. The median cost of conserved energy is $3.80/MBtu, substantially less than the average 1981 prices for supplied 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 average price of 6.2¢/kWh.

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I. INTRODUCTION AND OBJECTIVES

BECA-B is a compilation and analysis of measured energy use before and after retrofit of existing North American residential housing. Our results are based on the actual retrofit 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" homes (BECA-B), energy-efficient commercial buildings (BECA-C), and appliances (BECA-D) [Rosenfeld, 1980; Ross and Whalen 1981].

The U.S. residential sector, comprising 77.5 million dwellings, [RECS, 1981], consumed approximately 16 resource Quads of energy in 1980, accounting for one-fifth of the national total [EIA, 1981]. Table I provides a breakdown of residential energy consumption by fuel type and end-use.

Table I. 1977 U.S. Residential energy use by fuel and end-use [1 Quad = 10^{15} Btu]

Fuel	Quads	End-Use	Quads
Natural Gas	5.3	Space Heating	7.7
Electricity[a]	7.8	Water Heating	2.3
Fuel Oil	2.4	Air Conditioning	1.1
Other	0.6	Appliances	2.9
		Lighting and other	2.1
	16.1		16.1

[a]Electricity is reported in resource energy units (11,500 Btu/kWh sold) [Blue, 1979]

From the table, it is apparent that energy used for space heating dominates the demand for energy in residential buildings. Thus, most initial conservation programs have attempted to reduce space heating usage through improved energy efficiency.

Improving the energy efficiency of existing residences is a worthwhile objective, given escalating fuel costs and the long lifetimes of the nation's housing stock. 65-75% of the year 2000 housing stock has already been built, based on an anticipated new construction growth rate of 1.5 to 2.0% per year. In 1980, approximately 63.2 billion dollars was spent on residential energy consumption, amounting to an average expenditure per household of $815 [RECS, 1981], and accounting for roughly 15% of the annual average cost of homeownership.

We know that millions of homeowners are engaged in conservation activities. In 1979 alone, 3.4 million households added attic or roof insulation and 3.9 million households bought storm windows and/or doors [RECS, 1981]. In reviewing 1980 U.S. Internal Revenue Service data, we find that tax credits amounting to $430 million were claimed by individuals for energy conservation investments, which corresponds to an investment in efficiency improvements of almost $3 billion/year [IRS, 1980].

Given the level of investment in saving energy in homes, 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 retrofitting homes. Yet we are surprised at how few measurements have been made on actual energy savings due to retrofits. We had difficulty in finding even 69 samples with measured energy savings, though many more studies are now in progress or promised. Even where building energy use data are available, there is seldom much detailed information on the share of energy savings attributable to various retrofit measures. Thus, one objective of this study 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. In the future, as better data are obtained, we intend to compare 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.

The usefulness of a compilation such as BECA-B is directly related to the state of the retrofit industry. Currently, the "first generation" of conservation measures such as attic insulation and storm windows are being implemented at a fairly rapid rate by homeowners. Though, in some cases, these retrofits may be underutilized (e.g. installing R-19 in attic when R-38 would be more cost-effective) or applied inappropriately (not the most cost-effective way to save energy). BECA-B can also promote smoother market penetration for recently developed cost-effective conservation products and practices, such as infiltration reduction measures. Their acceptance in the marketplace hinges in part on consumer confidence in current techniques of predicting energy savings. A residential sector data base that summarizes actual energy savings from retrofitted buildings can provide reliable feedback on the validity of current energy saving products, contractor sources, and energy engineering estimation techniques.

Finally, we are interested in determining the optimum level of conservation investments. Results from this study indicate that for $1,000, 25 percent of the energy used in space heating can be saved, and that for $2,000, perhaps 40%. But our data shows a large variance around these "mid-range" values and therefore it is important to examine why some efforts save more energy (or a larger percentage), or save it more cheaply, than others.

II. SOURCES OF DATA AND METHODOLOGY

A. Data Sources

In Table III, we present a summary of the data files we have compiled, grouped by fuel type. There are a number of other possible ways to organize the data, i.e., by building type, extent of retrofit, or region. In Column B, Table III, we chose to group the entries by data source and have classified the samples into four general categories: 1) research studies, 2) utility-sponsored programs, 3) private firms specializing in building energy services, and 4) government-sponsored programs. These categories are described, in order, below.

Research studies

Most of our research entries come from experiments sponsored by institutions such as Princeton University, the National Bureau of Standards, and Lawrence Berkeley Laboratory, although some represent research efforts of private firms such as Johns-Manville. Research studies typically make extensive efforts to control for experimental variables. For example, the heating and hot water systems are usually submetered and a control group is employed as part of the experimental design. Additionally, occupant behavior is closely monitored. In some cases, the houses are unoccupied (Bowman House), or the researchers operate the building (i.e., open doors and windows periodically) to simulate "standard" occupant behavior. In other instances, occupants are instructed to record daily any behavior that may affect the building's energy performance (i.e., thermostat setting, hours at home, appliance use). Efforts are also made to use computer programs to fit the data and to compare theoretical vs. actual energy savings. In these studies, sample size is small and the analysis of the experimental data tends to be extensive.

Utility-sponsored programs

In the mid-1970's, a number of far-sighted utilities offered residential energy audits to their customers. In some cases the utilities coupled these programs with an offer of low- or zero-interest financing on retrofit projects, often at the urging of state public utility commissions. In the early stages, these programs were typically concerned with low-cost/no-cost measures (e.g. wrapping water heater tanks) and/or installing attic insulation. In recent years, some utilities have broadened their residential conservation program to provide financing for complete weatherization packages. The data we have obtained from utility companies come predominantly from three areas of the United States: 1) the Pacific Northwest, 2) the Southeastern portion of the U.S. served by the Tennessee Valley Authority (TVA), and 3) California.

Two recently enacted federal laws, the Public Utilities Regulatory Policy Act (PURPA) and the National Energy Conservation Policy Act (NECPA), have thrust utilities to the forefront of conservation program responsibility. Under the Residential Conservation Service (RCS) provisions of NECPA, most utilities must publicize and provide energy audits

upon request to residential customers in one-to-four unit buildings [Rosenberg, 1981]. As a result of this effort, a potentially huge data base on the existing housing stock is being collected and stored. During the next few years, energy policy analysts and utility planning personnel will have the capability to assess actual measured energy savings on a significant fraction of the nation's residential housing stock.

Data on utility-sponsored conservation programs are generally made available on an aggregate basis; that is, measured energy savings cover various types of retrofits lumped together for a large sample. Often, these studies lack control groups, detailed weather data, and/or residential energy customer consumption profiles (a valuable tool in accurately subtracting out the non-heating baseload usage). The strength of these programs is their ability to reflect energy savings for a rather large fraction of the general population.

Private-sector firms

A substantial number of private-sector firms are now seeking to make inroads into the potentially large market for retrofit services and products. We have observed two somewhat differing marketing strategies being employed by companies. The single-family housing market seems to be dominated by individual contractors who offer residential energy audits for a fee, often act as installation contractors, and are willing to inspect and warrant their work. Although these companies have completed thousands of retrofits, we have not included any data points from these sources because, at this time, they have not systematically evaluated the success of their programs through actual assessment of post-retrofit energy savings.

Companies entering the multi-family retrofit market, particularly large apartment buildings, often enter into contracts in which they guarantee a specified reduction in energy usage. They take responsibility for building energy management services including operations and maintenance functions and training of maintenance personnel. Their retrofit plan typically emphasizes automatic temperature control, the replacement, repair or alteration of the HVAC system, and lighting load management. Companies such as Scallop Thermal Management, a Shell Oil subsidiary, have provided us with summary reports detailing their retrofit experience in three large apartment buildings, but we have had difficulty finding additional data sources. Thus it will be extremely important to expand our future data collection efforts in the multi-family residential sector.

Government-sponsored programs

Government-sponsored programs that have provided data sources include: 1) Federal Power Marketing Authorities 2) the DOE Low-Income Weatherization Assistance Program and 3) the CSA/NBS Weatherization Research Demonstration Project, each of which is discussed below.

Federal Power Marketing Authorities. A number of Federal Power Marketing Authorities, particularly the Tennessee Valley Authority (TVA) and the Bonneville Power Administration (BPA), have launched ambitious

residential conservation programs to reduce the demand for electric power and improve the efficiency of energy use in residences. We have compiled data from TVA's Home Insulation Program and BPA's Midway Energy Conservation Study.

Low-Income Weatherization Assistance Program. Nearly 750,000 low-income homes have been weatherized under the initial direction of the Community Services Administration (CSA) and most recently under DOE auspices [Cooper, 1981a]. Thousands of local community action agencies have been involved in this effort.

While the program has been extensively implemented, its decentralization has complicated evaluation efforts. Two worthwhile studies were conducted, however--one by the Consumer Energy Council of America [Cooper, 1981a] and the other by Urban Systems Research and Engineering Inc. (under subcontract to DOE). With the cooperation of these two groups, along with DOE staff, we were able to obtain some of the original evaluation reports prepared by local community action agencies and state energy offices. In cases where we had questions about the data, or where critical information was missing, we attempted to contact primary sources.

The reliability of the data from these low-income weatherization programs varies considerably. We have not included studies whose data confidence levels were rated "D" or "F" (see Explanation of Column Symbols in Table III); that is, those whose data did not include actual measured energy use, information on types of weatherization, an explanation of the data collection method, or insufficient weather and baseload data. All low-income weatherization evaluation studies included in our compilation had a confidence level rating of "C". We assigned this confidence level rating because the studies typically lacked a control group, had mixed heating fuel sources within a sample, variations in the quality of workmanship, and several inconsistencies in either energy or cost data. Despite the lower data confidence level, the Low-Income Weatherization Program represents a significant fraction of the nation's investment in residential conservation and focuses on a housing sector where potential increases in energy efficiency are great.

CSA/NBS Weatherization Demonstration Research Project. The Community Services Agency, with technical support provided by the National Bureau of Standards, conducted a national research and demonstration project to determine the energy savings that could be expected from optimally weatherizing low-income homes. [Crenshaw, 1979]. The demonstration project involved more extensive retrofitting of homes and closer monitoring of cost and energy consumption data than was attempted in the DOE Low-Income Weatherization program. Although the sample houses were fairly typical of low-income housing in terms of size, their pre-retrofit physical condition and maintenance level was better than normally found in low-income residences. Energy savings and retrofit costs were carefully compiled on 142 houses in 12 different locations. In addition, the project had a final control group consisting of 41 homes.

For a detailed description of this project, see Appendix I.

Representativeness of Sample

This compilation is not a representative survey of either the U.S. residential housing stock or the actual portion of the stock that has been retrofitted in the last several years. Our data is taken from evaluation case studies of conservation programs and retrofit projects, reflective of a stratified survey. It is useful to compare characteristic features of our data base with results obtained from the Energy Information Administration's Residential Energy Consumption Survey (RECS), the foremost representative survey on the scope, distribution and extent of retrofitting in the residential sector [RECS, 1981].

We observe that our survey has a disproportionately high number of low income samples (26/69), comprising 38 percent of the data points (excluding controls) compared to RECS data which found that "poor" households were responsible for 11 percent of retrofit activity [RECS, 1981].*

We should also note that our study differs markedly from RECS data in terms of housing unit characteristics and location. RECS estimated that 10.6 of 77.5 million households resided in buildings with five or more units, yet we have results on only 3 multi-family retrofit projects. We also have little data from the Northeast region, 7 sources or 10% (excluding New Jersey), a region which has 22% of the households [RECS, 1981]. In future versions, we will analyze in more detail how closely the BECA-B data base resembles the U.S. stock of retrofitted residences.

Given our objective of providing accurate, understandable information to policy makers and to the emerging retrofit industry on actual measured energy savings, it is important that BECA-B be "representative" in the sense of reporting the full range of retrofit cost-effectiveness values. Often, institutional data sources are reluctant to present "failures;" this also tends to bias results.

B. Economic Analysis

The basic investment framework for conservation measures involves an outlay of capital today resulting in future reductions in energy use and dollar savings. These investments can be evaluated using a variety of economic analysis tools. In our study, we use two simple measures, cost of conserved energy (CCE) and simple payback time (SPT), that have the

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*The eligibility criteria for participation in the Low-Income Weatherization Program is the same as RECS' definition of a poor household, 125% level of poverty based on family eligibility and number of family members. For comparison purposes, we have defined retrofit activity as involving the addition of either attic or wall insulation, or storm windows and doors (the only conservation measures that RECS data cover).

advantage of avoiding the need to guess future energy prices.

Simple Payback Time

The payback time is the time required for the undiscounted value of the future energy savings to equal the original investment (at today's prices). It can be expressed as

$$SPT^{(a)} = \frac{\text{Contractor Cost of Init. Investment}}{\text{Value of Annual Energy Savings}} = \frac{C_I}{D_s} = \frac{C_I}{E_s \times P}$$

where E_s is the annual energy savings in MBtu/yr,
P is the local price of purchased energy the winter after the retrofit,
D_s is annual dollar savings.

In cases where the local energy price at the time of retrofit was unavailable, we developed two other approximations [$SPT^{(b)}$ and $SPT^{(c)}$]. For $SPT^{(b)}$, we used the local cost of energy in 1981 and then adjusted the original contractor cost into 1981 dollars. If regionally-specific energy prices were not known, we then calculated $SPT^{(c)}$ using the national average cost of energy for that fuel type in the first post-retrofit winter.

Cost of Conserved Energy (CCE)

The idea behind the cost of conserved energy formula is to restate the cost/benefit ratio of a conservation investment as a cost to save a unit of energy, i.e. as $/MBtu or ¢/kWh. A conservation measure is economically attractive if its cost of conserved energy (CCE) is less than the price of purchased energy (P) [Meier, 1982]. For the homeowner, P, can be defined as the average price of energy but for a utility it is the marginal (avoided) cost of supplying energy from new sources (in the simplest cases). We determine the unit cost for conserved energy using the following equation:

$$CCE = \frac{\text{Annualized Cost of Retrofit Measures}}{\text{Annual Energy Savings}} = \frac{C_a}{E_s} \qquad (2)$$

where the Annualized Cost (C_a) is in turn defined as the levelized annual payments (C_L) that amortize the initial installation cost (materials plus contractor labor) plus the annual cost of operation and maintenance (O & M); that is

$$C_a = C_L + (O \ \& \ M) \qquad (3)$$

To compute the levelized cost, C_L, we must estimate the amortization period, n, which can be viewed as either the period in which the loan has to be repaid or the physical lifetime of the measure. In many cases, the borrower may obtain a loan that must be repaid over a period

shorter than the measure's economic lifetime. In such cases, choosing n equal to the loan period would overstate annual cost vs. savings for some years, but understate them for latter years. Thus, to calculate the CCE for a typical year, we prefer to set n equal to the measure's full useful life.

We estimated a useful lifetime for typical conservation retrofit measures in homes and found a weighted average of 15-20 years [Wright and Meier, 1981]. To account for operations and maintenance costs, we rounded this average lifetime down to 15 years and eliminated the explicit operation and maintenance term in Equation 3, except in cases of retrofitting of large apartment complexes.

The concept of the levelized cost is equivalent to the assumption that the homeowner will take out a loan to finance the retrofit and will repay it in n equal annual payments.* We annualize the investment by multiplying it by a capital recovery rate, CRR = $\frac{i}{1-(1+i)^{-n}}$ where i is the interest rate charged on the loan. Thus our definition of the cost of conserved energy can be restated:

$$CCE = \frac{(C_I) \times (CRR)}{E_s} \qquad (4)$$

where C_I is contractor cost of original investment,
E_s is the annual energy savings, and
CRR is the capital recovery rate.

In the equation for CRR, the interest rate can be expressed in either real (constant) or nominal (inflated) dollars. For example, an interest rate of 16% in nominal terms, corrected for 10% annual inflation, equals a 6% real interest rate. We decided to use real interest rates and thus avoid assumptions about future inflation. Recognizing that the choice of discount rates affects the relative cost of conserved energy, we calculated CCE using real interest rates of three, seven and ten percent, as shown in Columns M1, M2, and M3 of Table III.

The lowest real interest rate, 3%, would be typical of secured, long-term loans, such as new home mortgages, which averaged 2.29% (real) in the period 1961-1979 [Levine and Gray, 1980]. The highest real interest rate (10% per annum) is typical of riskier and generally short-term loans made in the private sector (for second trust deeds or appliances, used car loans, etc.) and is the rate used in the economic analysis and justification for many government programs. The National

*The formula retains its logic even when the homeowner pays cash for a retrofit, rather than borrowing the money. In this case, the initial cost to the homeowner can be translated into an annual stream of earnings that are foregone, compared to investing the funds at interest rate i for n years.

Security Act of 1980 specified that U.S. government conservation and solar applications' investments be evaluated using a 7% real interest rate [Ruegg, 1981]. In Table III, we calculate cost of conserved energy values using these three real interest rates in the capital recovery rate, but our plots (Figures 1-8) reflect only the middle value, 7%.

It is also important to note that the CCE has been expressed in [January] 1981 constant dollars. Before multiplying by the Capital Recovery Rate, we first converted the original retrofit cost data (Col. L1) into 1981 dollars (Col. L2) using the Gross National Product Implicit Price Deflators, in order to provide a comparable basis for evaluating the relative cost-effectiveness of retrofit projects undertaken in different years.

C. Units for Electricity: Use of Resource Energy

Some of our sample homes are heated by fuel, others by electricity. We would like to evaluate energy savings on a comparable basis regardless of fuel type. To do so, we must choose the appropriate conversion factor from units of electrical energy to units of fuel energy. One approach is to evaluate, electricity in terms of the heat energy produced "at the building site," by an electric-resistance appliance i.e., 3415 Btu per kWh [3.6 MJ/kWh]. The advantage of using "site electricity" units for comparing fuel-heated and electrically-heated buildings is that this indicates the buildings' physical performance (heat load to be met). A disadvantage is that measuring electricity in terms of site energy fails to account for the substantial fuel use required off-site to generate electricity. Also, when electricity is converted to "site energy" Btu's, there may be confusion in economic indicators, since a "site-energy" Btu of electricity costs about three times as much as a Btu of fuel used in a building.

Resource electricity units account for the total fuel required by a utility system to generate and deliver a high grade energy source, electricity. The resource conversion factor is 11,500 Btu per kWh, which reflects typical power plant efficiency (33%) and transmission losses (about 10%). An advantage of using resource electricity units is that the costs per Btu for fuel and electricity end up roughly equivalent. This point is illustrated in Table II, based on data extracted from the Monthly Energy Review (MER).

Table II. Residential energy prices in May 1981 and equivalent cost in resource energy.

Fuel	Thermal Conversion	National Avg. Residential Price	Cost per unit of Thermal Energy ($/MBtu)
Natural Gas	1021 Btu/cu. ft.	$4.57/kCF	$4.48/MBtu
Heating Oil	5825 kBtu/barrel	$1.21/gal	$8.72/MBtu
Gas and Oil, consumption weighted*	--	--	$5.96/MBtu
Electricity "Site"	3415 Btu/kWh	0.0627/kWh	$18.36/MBtu
"Resource"	11,500 Btu/kWh	0.0627/kWh	$5.45/MBtu

*In 1980, the residential and commercial buildings sector combined used 7.6 quads of gas (65%) and 4.1 quads of oil (35%). Using these fractions to weight the gas and oil prices, we obtain a weighted average price of $5.96/MBtu.

In Table III, we show energy savings from electrically-heated homes in kilowatt-hours. These values are then converted to resource electricity units in Figures 1 to 8, to provide a comparable basis for evaluation with gas- or oil-heated residences.

Thermal Integrity of Electrically Heated Homes

We do not, however, use resource energy units in calculating the thermal integrity of electrically-heated homes (see Table III, Column P). In this case, we are evaluating the pre- and post-retrofit thermal performance of the building shell rather than the relative primary energy savings of various retrofits. The conventional practice used by building scientists is to express building shell performance in terms of site energy. For fuel-heated homes, Column P tabulates the fuel use per ft^2 per heating degree-day. For electric heat it is then necessary to adjust for differences in the seasonal furnace efficiencies of gas-and-oil heated homes vs. electrically-heated homes. We tabulate how much fuel an all-electric house would have used if it had been heated by a gas or oil furnace whose typical seasonal efficiency was 0.67. Thus the equivalent fuel usage is then 3415 ÷ 0.67, or 5122 Btu/kWh, the conversion constant used for electrically-heated homes in Column P, Table III.

D. Analysis of Energy Data and Assignment of Confidence Level

The basic information needed to analyze residential energy consumption for space heating includes: space heating or total fuel usage per day (or week, month, year) both before and after retrofit; energy use for purposes other than space heating (the "baseload" usage) for the same time periods; the number of heating degree-days for the particular site of the residence during each time period; the "normal" (30-year mean) value of monthly and annual heating degree-days (hereafter referred to as "HDD's") for the site. The two major adjustments that concern us are subtraction of the baseload usage and normalizing energy use before and after retrofit to a "standard" heating season. We do not account for changes in occupant behavior or management (i.e. increased or decreased thermostat settings). In much of the data our collaborators eliminated homes which had occupancy changes. With the same family living in the retrofitted residence we assume that there are no significant changes in their habits which affect the space heating.

Under ideal research conditions, the fuel consumption for space heating would be submetered. But in our sample the majority of data sources only had metered data for total energy use. In some cases our collaborators estimated and subtracted baseload usage, using either a linear regression analysis or the fuel usage during the summer months defined as the baseload. In cases where no baseload correction was made by the data source, we subtracted approximate baseloads using specific regional information obtained from either the Residential Energy Consumption Survey [EIA, 1981], the All Electric Homes Study [EIA, 1978], or the Gas Househeating Survey [AGA, 1978].

Weather-related adjustments to the space heating data were also made. The most accurate method of weather-normalizing the data involves a best fit via linear regression of the space heating fuel use plotted against the average outside temperature. The slope of the best-fit line equals the rate at which the residence consumes space heating energy and the x-axis intercept equals the "balance point" temperature, defined as the maximum outside temperature for which the heating system is needed to maintain a specified interior thermostat temperature. The balance point is lower than the interior temperature setting since appliance heat, solar gains, and occupants' body heat contribute "free heat" to the house. This regression is done on the space heating data for corresponding periods before and after the retrofit. Generally, in the post-retrofit period, the slope decreases, i.e. the house is more energy-efficient, and consequently the balance point temperature also decreases. Annual space heating fuel requirements pre- and post-retrofit are obtained by multiplying the respective slopes by the 30-year mean for HDD's calculated to base temperatures equal to the balance point temperatures. Instead of the accurate method described above, we often had to make approximations to the weather-adjustment procedure. We neglected any changes in the balance point temperatures that may have occurred. Weather-adjusted energy use was obtained by normalizing the measured fuel use data, on a monthly or yearly basis, using the ratio of HDD's during the measurement period to the 30-year mean value of HDD's (base 65°F) at that location.

Data Confidence Levels

We assigned each of our samples a confidence-level ranking (A, B, C, D, F) as shown in Table III, Column Q. The only data included in this draft are those with a confidence level of "C" or better. In assigning confidence levels, a critical assessment was made of such factors as the separation of the space heating component from the total energy use data, the extent of weather adjustments, and the accuracy of the retrofit cost data. No retrofit data are included in this compilation unless they can be linked to actual measured energy consumption.

If we or our collaborators used linear regression analysis to estimate the balance point temperature and the baseload correction (if no submetered data) and if we adjusted for weather, using HDD's calculated to the balance point temperature, then the data for that retrofit project were given an "A"-confidence level. If the baseload correction consisted of subtracting off the summer months' values of fuel usage and the weather adjustment was a simple scaling based on monthly HDD's (base 65°F), the data were given a "B"-level ranking. A "C"-level confidence ranking indicates that a simplified baseload correction was made and the weather correction consisted of scaling by annual HDD's (base 65°F). These data confidence levels are discussed in more detail in the section Explanation of Column Symbols in Table III.

E. Adjustment of Cost Data

Determination of Total Retrofit Costs

In our study we are interested in the direct costs of contractor-installed retrofit measures to the homeowner. If the retrofit was accomplished as part of a research study, we used the researchers' best estimate of the equivalent contractor's cost (materials, labor, overhead, and profit). If the conservation measures were installed as part of a utility loan program, we interpreted the loan amount as equal to the retrofit cost.* Utility overhead costs to administer the program were excluded since they are not direct costs to the homeowner, but are paid by all ratepayers. For government-sponsored weatherization programs we followed the procedure of a study by Urban Systems Research & Engineering [USRE, 1981] in which materials, labor, and contractor overhead were estimated to be roughly equal components of the overall costs. On this basis, if only materials costs were available, then total costs were taken to be three times the price of materials. The USRE study estimated that this multiplicative factor was roughly equivalent to the market cost of performing the weatherization work. It is likely that if this retrofit cost adjustment is in error, it tends to overstate the cost of conservation measures. For example, in a specific instance where a homeowner contributed all the labor for a retrofit, total costs would

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*An exception to this practice was made for cost data from utility programs that indicated that the loan amounts were "bumping up" against program maximums. In these cases, we attempted to determine the additional investment outlay provided by the homeowner for the retrofits.

be actually lower than our estimate, as would the estimated cost of conserved energy.

Indexing for Inflation

Table III gives the contractor cost in nominal dollars at the time of retrofit. In Col. L2 we scaled these amounts to January 1981 dollars using the Gross National Product Implicit Price Deflators. We used the deflators because we wanted to net out general inflationary effects, and yet continue to reflect real-dollar changes over time in the cost of retrofits.*

F. When To Subtract Control Group Savings?

One requirement of good experimental design in studies that evaluate the impact of conservation programs is the establishment of a control group. However, the question of exactly how to interpret energy use data for a control group depends on the objective of the study. Subtraction of control group savings is appropriate if the objective is to measure program-specific effects, for example, the energy savings attributable to a utility conservation program beyond what would otherwise have occurred. In BECA-B, our focus is on measured data that show the technical performance and cost-effectiveness of conservation retrofits. We have only a secondary interest in the extent to which a specific program or regulation--as opposed to "market responses" to rising energy costs--actually triggered the decision to retrofit a building. Thus, although we list control group energy savings in Table III, most of our scatter plots reflect gross rather than net energy savings for each sample. Figure 4 is the one exception to this practice. In this case, we have subtracted the control group's energy savings from the experimental group.*

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*It is also possible to distinguish among different kinds of experimental control groups. For example, one of our data sources, Princeton University's "Modular Retrofit Experiments" used blind and active controls. Princeton researchers selected 18-24 residences in seven geographic and housing type modules and then randomly divided them into three groups. One group received the "house doctor" treatment, the second group had a major contractor retrofit as well as "house doctoring" and the third group served as an "active" control. The "active" control group is characterized by its awareness and cooperation in the experiment. The "active" control group went through the same selection process and were contacted by utility representatives and meter readers as often as those who actually received the house-doctor treatment. The common defining characteristic of blind control groups is the homeowners' lack of knowledge of the experiment. The blind control group consisted of all customers in the service area of each New Jersey utility. Pre- and post-retrofit energy consumption data for an average blind control household in the various service areas were obtained from the New Jersey Energy Data System. This aggregated sample was used to characterize the weather-normalized energy consumption for the average house in a utility's residential heating category [Fels, 1981].

III. TYPES OF RETROFIT MEASURES

Most residential conservation measures at present are aimed at improving energy efficiency in two end-use areas: space heating and cooling, and domestic water heating.

Space Heating and Cooling

Most retrofit measures designed to reduce heating and cooling energy use consist largely of those that tighten the thermal envelope of the dwelling. Because we have very little data on the effect of residential retrofits on energy consumed by cooling systems, our main emphasis to date has been on space heating. Thus, our economic calculations are conservative since they take credit only for energy savings from heating systems. In many instances, the retrofits also result in cooling savings.

The single most popular retrofit measure in our data sample is the addition of ceiling insulation, which effects dramatic savings, particularly in houses where the attic has never been insulated. Substantial savings are also realized in cold climates if the "before" level of ceiling insulation is R-7 or R-11. Energy consumption is reduced by 10% to 40% from this measure alone for investments ranging from $200 to $1000.

In cold climates the installation of storm windows and/or storm doors is another common retrofit. Approximately one-third of our data sources installed these measures and 10% received clock thermostats or modifications to the existing heating system (installation of flue dampers). In larger multi-family buildings, replacement or adjustment of the HVAC system and automatic energy control systems were the most common retrofits. We have data on only one architectural improvement, a passive solar wall retrofit, but hope to identify more data in this category in the future.

Caulking and weatherstripping are very common retrofit measures to cut down on infiltration in a house. This measure was implemented by almost one-half of our data sources, especially in low-income housing. A relatively new technique for the discovery of less obvious heat loss paths has been developed by researchers at Princeton and LBL. This technique, called "house doctoring," involves pressurizing a home using a blower door. Heat leakage paths and thermal "bypasses" are identified with the aid of smoke sticks and an infrared camera. Major leakage sites are then sealed, reducing air infiltration. In the Princeton/LBL "house doctoring" projects, annual energy savings averaged 22 MBtu, ranging from 7-22% of the original space heating consumption.

Domestic Hot Water

The average U.S. home uses about 30 MBtu or 300 therms per year to heat water for domestic use. Potentially large savings are possible in this area. The most common retrofit measure thus far has been to wrap an insulating blanket around the water heater tank. Several utilities in the northwestern part of the United States have been wrapping their customers' water heaters for the past several years at no charge. They estimate that annual energy savings of approximately 500 kWh or $30 (at 6¢/kWh) can thus be achieved at a cost of $15 to $20, an excellent

return on investment. Other fairly common retrofit measures applied to the hot water system include wrapping the hot water distribution pipes near the heater, lowering the thermostat setting of the heater, and installing low-flow shower heads and water heater flue dampers. Although we have not attempted to assess savings from active or passive solar hot water systems, they are another increasingly popular residential retrofit.

IV. DATA AND RESULTS

A. Data in Table III

Table III has 94 samples, consisting of 69 retrofit projects and 25 control groups (whose labels end with an A for active controls and B for blind controls). Columns A through K2 (plus L) are input data, of which the most important are annual energy use (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, Fuel Intensity, and Thermal (Fuel) Integrity.

The 94 samples are ordered by type of fuel used, in the sequence Gas, Oil, Mixed and Electricity. "Mixed" means that within a sample of say 10 homes, more than one fuel was used.

The meaning and convention of each column are explained in the two pages following the table and is entitled "Explanations of the Column Symbols in Table III."

Note that a typical scatter plot has between 55-65 points, not 94. This occurs because we have excluded the 25 active and blind control groups and because, on several plots, a few points overflow the scales.

Table III

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	HEATING OR HEAT+WATER	ANNUAL ENERGY (MBTU) BEFORE	ANNUAL ENERGY (MBTU) AFTER	SAVINGS (MBTU)	SAVINGS 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	4911	80	2500	I,T,P	H,W	178.8	135.1	43.7	24
G5.2	R/U	12	MRE/FREEHOLD,NJ	PRINCETON/NJNG	4911	80	2500	T,P	H,W	171.9	142.9	29.0	17
G5.3B	R/U	6	MRE/FREEHOLD,NJ	PRINCETON/NJNG	4911		2500			184.0	174.9	9.1	5
G6.1	R/U	6	MRE/TOMS RIVER,NJ	PRINCETON/NJNG	4911	80	900	I,T,P	H,W	87.2	70.4	16.8	19
G6.2	R/U	12	MRE/TOMS RIVER,NJ	PRINCETON/NJNG	4911	80	900	T,P	H,W	99.2	92.4	6.8	7
G6.3B	R/U	6	MRE/TOMS RIVER,NJ	PRINCETON/NJNG	4911		900			98.0	98.0	0.	0
G7.1	R/U	6	MRE/OAK VALLEY,NJ	PRINCETON/SJG	4911	80	1200	I,T,P	H,W	116.3	88.9	27.4	24
G7.2	R/U	9	MRE/OAK VALLEY,NJ	PRINCETON/SJG	4911	80	1200	T,P	H,W	120.9	94.0	26.9	22
G7.3A	R/U	6	MRE/OAK VALLEY,NJ	PRINCETON/SJG	4911		1200			128.6	115.0	13.6	11
G7.4B	R/U	75000	MRE/OAK VALLEY,NJ	PRINCETON/SJG	4911								11
G8.1	R/U	5	MRE/WHITMAN SQ,NJ	PRINCETON/SJG	4911	80	1800	I,T,P	H,W	147.2	111.8	35.4	24
G8.2	R/U	9	MRE/WHITMAN SQ,NJ	PRINCETON/SJG	4911	80	1800	T,P	H,W	134.8	109.1	25.7	19
G8.3A	R/U	4	MRE/WHITMAN SQ,NJ	PRINCETON/SJG	4911		1800			133.8	112.4	21.4	16
G8.4B	R/U	75000	MRE/WHITMAN SQ,NJ	PRINCETON/SJG	4911								12
G24.1	R/U	6	MRE/EDISON,NJ	PRINCETON/ELIZ.GAS	4911	80	1550	I,T,P	H	163.4	124.8	38.6	24
G24.2	R/U	5	MRE/EDISON,NJ	PRINCETON/ELIZ.GAS	4911	80	1550	T,P	H	163.8	139.7	24.1	15
G24.3A	R/U	6	MRE/EDISON,NJ	PRINCETON/ELIZ.GAS	4911		1550			166.3	154.7	11.6	7
G24.4B	R/U	75000	MRE/EDISON,NJ	PRINCETON/ELIZ.GAS	4911								10
G25.1	R/U	6	MRE/WOODRIDGE,NJ	PRINCETON/PSEG	4911	80	1300	I,P	H	176.6	150.8	25.8	15
G25.2	R/U	6	MRE/WOODRIDGE,NJ	PRINCETON/PSEG	4911	80	1300	P	H	159.0	137.7	21.3	13
G25.3A	R/U	6	MRE/WOODRIDGE,NJ	PRINCETON/PSEG	4911		1300			147.8	131.2	16.6	11
G25.4B	R/U	550000	MRE/WOODRIDGE,NJ	PRINCETON/PSEG	4911								11
G26.1	R/U	5	MRE/NEW ROCHELLE,NY	PRINCETON/CONED	4911	80	1450	I,T,P,H	H,W	155.4	124.1	31.3	20
G26.2	R/U	5	MRE/NEW ROCHELLE,NY	PRINCETON/CONED	4911	80	1450	T,P,H	H,W	160.4	136.1	24.3	15
G26.3A	R/U	6	MRE/NEW ROCHELLE,NY	PRINCETON/CONED	4911		1450			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					116.9	128.4	-11.5	-9
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					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					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
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

A	L1	L2	L3	M1	M2	M3	N	O1	O2	P1	P2	Q	R
	AVG.	RETRO	COSTS	CCE=1981 COST OF			SIMPLE	FUEL INTENS.		THERMAL INT.		CONFI-	
			81 $/	CONSERVED		NERGY	PAYBACK	(MBTU/KSQFT)		(BTU/SQFTDD)		DENCE	
LABEL	ORIG$	81 $	KSQFT	8.3	11.0	13.2	(YEARS)	BEFORE	AFTER	BEFORE	AFTER	LEVEL	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	12.9	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
G4	1000	1162	745	3.18	4.22	5.06	8.9	73.3	53.9	14.9	11.0	A	ELIMINATE BYPASS LOSSES
G5.1	2562	2750	1100	5.22	6.92	8.31	13.0	71.5	54.0			A	H. D. AND CONTRACT RETR.
G5.2	325	349	140	1.00	1.32	1.59	2.5	68.8	57.2			A	H. D. ONLY
G5.3B								73.6	70.0	15.0	14.2	A	BLIND CONTROL GROUP
G6.1	1272	1365	1517	6.75	8.94	10.73	16.8	96.9	78.2			A	H. D. AND CONT. RET.
G6.2	325	349	388	4.26	5.64	6.77	10.6	110.2	102.7			A	H. D. ONLY
G6.3B								108.9	108.9	22.2	22.2	A	BLIND CONTROL GROUP
G7.1	911	955	796	2.89	3.84	4.60	6.2	96.9	74.1			A	H. D. AND CONTRACT RETR.
G7.2	325	341	284	1.05	1.39	1.67	2.2	100.8	78.3			A	H. D. ONLY
G7.3A								107.2	95.8	21.8	19.5	A	ACTIVE CONTROL GROUP
G7.4B												A	BLIND CONTROL GROUP
G8.1	664	696	387	1.63	2.16	2.60	3.5	81.8	62.1			A	H. D. AND CONT. RETR.
G8.2	325	341	189	1.10	1.46	1.75	2.3	74.9	60.6			A	H. D. ONLY
G8.3A								74.3	62.4	15.1	12.7	A	ACTIVE CONTROL GROUP
G8.4B												A	BLIND CONTROL GROUP
G24.1	1562	1677	1082	3.61	4.78	5.73	8.1	105.4	80.5	21.5	16.4	A	H. D. AND CONTRACT RET R.
G24.2	325	349	225	1.20	1.59	1.91	2.7	105.7	90.1	21.5	18.4	A	H. D. ONLY
G24.3A								107.3	99.8	21.8	20.3	A	ACTIVE CONTROL GROUP
G24.4B												A	BLIND CONTROL GROUP
G25.1	961	1032	794	3.32	4.40	5.28	7.4	135.8	116.0	27.7	23.6	A	H. D. AND CONTRACT RETR.
G25.2	325	349	268	1.36	1.80	2.16	3.1	122.3	105.9	24.9	21.6	A	H. D. ONLY
G25.3A								113.7	100.9	23.2	20.6	A	ACTIVE CONTROL GROUP
G25.4B												A	BLIND CONTROL GROUP
G26.1	1008	1082	746	2.87	3.80	4.56	6.4	107.2	85.6			A	H. D. AND CO NTRACT RETR.
G26.2	325	349	241	1.19	1.58	1.90	2.7	110.6	93.9			A	H. D. ONLY
G26.3A								109.6	95.4	22.3	19.4	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
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

Table III, continued

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	HEATING OR HEAT+WATER	ANNUAL ENERGY (MBTU) BEFORE	AFTER	SAVINGS (MBTU)	PERCNT
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	PAGE APTS, NJ	HUD/TRENTON	4911					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					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					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					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					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					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						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			78.2	80.1	-1.9	-1
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					20606.	17715.0	2891.0	14
E3.3B	R/P	30	DENVER,COL	JOHNS MANVILLE	6016					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					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
	AVG.	RETRO	COSTS	CCE=1981 COST OF			SIMPLE	FUEL INTENS.		THERMAL INT.		CONFI-	
			81 $/	CONSERVED		ENERGY	PAYBACK	(MBTU/KSQFT)		(BTU/SQFTDD)		DENCE	
LABEL	ORIG$	81 $	KSQFT	8.3	11.0	13.2	(YEARS)	BEFORE	AFTER	BEFORE	AFTER	LEVEL	COMMENTS
	*****	*****										******	
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
O1	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	115.9	58.4	23.6	11.9	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
O6	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								59.0	60.5	7.1	7.3	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	EXTENDED H. D.
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

Explanation of Column Symbols in Table III

Column A: Label for each entry

First letter signifies the fuel type used for heating.

"G" = natural gas

"M" = mixed fuel--heating fuel differed from house to house within a study sample

"O" = fuel oil

"E" = electricity

If the letter "A" immediately follows the fuel type symbol, then the home is an Apartment or multifamily dwelling. If no second letter follows the fuel type symbol, then the home is a single-family dwelling.

The number after initial letter(s) is simply a counting index to label each different retrofit data sample.

At a particular site if there is more than one sample group for which consumption data was accumulated by the evaluators, then we use a decimal point after the first number (counting index) followed by 1, 2, 3, ... to denote the additional groups.

The letter "A" or "B" at the end of the entry signifies an "active" or a "blind" control group.

Example: "G7.3A" signifies a gas-heated single-family home which is at the 7th site and which is the third group at that site. Also it's an active control group.

Column B: Sponsor Category

"R" means a research study.

"U" means a utility-sponsored program.

"G" means a government-sponsored program.

"P" means a private firm specializing in building energy services.

Column C: Number of Homes

The number of homes for which actual consumption data were analyzed.

Column D: Location

The location of the homes that were retrofitted.

Column E: Sponsor

The name of the sponsoring group for the program and/or the evaluation study.

Column F: Mean value of Heating Degree-Days (65°F Base)

The 30-year average for heating degree-days for the site(s) where the homes were retrofitted.

Column G: Year of Retrofit

The actual year of retrofit or the median year if there is a large sample of homes retrofitted over several years.

Column H: Average Floor Area

The average floor area in sq. ft. for houses in the sample.

Column I: Retrofit Options

"I" = insulation of ceilings, floors, basement, and walls

"W" = double or triple glazing of windows

"D" = storm doors or insulating doors

"C" = caulking and weatherstripping

"T" = clock thermostats

"E" = energy management control systems

"H" = replacement or adjustment of HVAC equipment

"O" = operation & maintenance actions which affect manner in which the HVAC equipment is run

"A" = all architectural changes to the actual structure which affects its energy consumption (such as passive solar wall)

"P" = blower door pressurization and sealing of bypass and infiltration losses

No symbol for hot water retrofits because they are indicated in Column J.

Column J: Heat or Heat + Water

"H" = space heating consumption only for the data in the adjoining columns

"H,W" = both space heating and domestic hot water heating included in the consumption data

Column K1: Energy consumption in MBtu or kWh per year <u>before retrofit</u>

Column K2: Energy consumption in MBtu or kWh per year <u>after retrofit</u>

Column K3: Annual energy savings in MBtu or kWh

Column K4: Percentage savings

Column L1: Average retrofit costs in nominal dollars (the year that the retrofit was actually done)

Column L2: Average retrofit costs in 1981 dollars (the original dollars have been converted to 1981 dollars, using the GNP Implicit Price Deflators)

Column L3: Average retrofit costs (in 1981 dollars) per 1000 sq. ft. (calculated

only if average square footage of the sample group is available)

Column M1: Cost of conserved energy (in 1981 dollars) per MBtu or in cents/kWh using a Capital Recovery Rate (CRR) of 8.38%, corresponding to a 15-year loan at 3% real interest.

Column M2: CCE in '81$/MBtu or in '81¢/kWh using a CRR of 11.0% (7% real interest for 15 years)

Column M3: CCE in '81$/MBtu or in '81¢/kWh using a CRR of 13.2% (10% real interest for 15 years)

Column N: Simple payback time in years

Type "a" $SPT^{(a)} = \frac{\text{Contractor Cost of Initial Investment (Original \$)}}{\text{(Energy Savings/Yr) (Local price of Energy in Orig. \$)}}$

Type "b" $SPT^{(b)} = \frac{\text{Contractor Cost of Initial Investment (1981 \$)}}{\text{(Energy Savings/Yr) (Local price of Energy in 1981\$)}}$

Type "c" $SPT^{(c)} = \frac{\text{Contractor Cost of Initial Investment (Original \$)}}{\text{(Energy Savings/Yr) (National Average Cost of Energy for that fuel in Orig. \$ for Jan. of 1st post-retro Winter)}}$

Type "a" is the most common calculation for SPT in our data, The superscript "(a)" has been suppressed in Table III so that no superscript means a type "a" SPT.

Column O1: Fuel intensity in MBtu/1000 ft^2 <u>before retrofit</u> (for electric heating, we have converted to resource energy by using 11,500 Btu per kWh sold)

Column O2: Fuel intensity in MBtu/1000 ft^2 <u>after retrofit</u> (again for electric heating, we have converted to resource energy by using 11,500 Btu per kWh sold)

Column P1: Thermal fuel integrity of the dwelling in Btu/ft^2-DD <u>before retrofit</u> (for electric heating, we have multiplied by 1.5 to eliminate the different fuel efficiency of an electric heating system compared to a gas or oil system i.e., used a ratio of 5122 Btu per kWh).

Column P2: Thermal fuel integrity of the dwelling in Btu/ft^2-DD <u>after retrofit</u> (again for electric heating, we have multiplied by 1.5 to eliminate the different fuel efficiency of an electric heating system compared to a gas or oil system)

NOTE: We caution our readers that the thermal integrity values listed in Columns P1 and P2 give only approximate relative values of the thermal performances of the building shells. Our lack of knowledge about interior thermostat settings and other occupant management variables and also other sources of "free heat" (appliances, solar gains etc.) is built into the thermal integrity values. In addition, dividing the fuel usage by the number of heating degree-days to the base 65°F is an acceptable but not a precise method of weather-normalizing homes in different locations.

Column Q: Confidence level for the data

"A" = high confidence in the data. Generally this designation required submetered data so that space heating (or space heating + water heating) is clearly separated from total fuel bill. Generally detailed weather information (daily or monthly HDD's) is collected with accurate and consistent cost data. Regression analysis is used to get the best fit of consumption vs. HDD/day or average temperature. Usually a control group is used for comparisons and detection of external factors.

"B" = medium high confidence. Careful baseload adjustments made on actual energy consumption data and usually weather adjustments on a monthly basis.

"C" = average confidence. Cruder baseload corrections and weather adjustments on an annual basis.

"D" = low confidence. There exist sufficient flaws in the data to cast doubt on the results. No baseload correction or no weather adjustment. Consumption data not carefully collected.

"F" = no confidence. Very crude data with lots of missing information. There exist major flaws.

(No "D" or "F"-level data are included in this draft of our report).

"I" = incomplete. Certain key data are missing but may be provided in the future so that the analysis can be completed.

Column R: Comments

Additional descriptive comments for that particular entry.

B. Results

Energy Savings

Figure 1 shows the annual resource energy savings as a function of the contractor cost of the retrofit. In general, the data show the expected trend of increased savings for larger investment, but also a great deal of scatter. At any given retrofit cost less than $2000, annual savings vary by a factor of about seven. Clearly, in our sample, there is a wide range in the cost-effectiveness of retrofit measures. Except for 14 samples shown in Table III (where Col. J shows "H, W"), the plotted savings apply to space heat only. In these 14 cases, retrofits were directed towards the reduction of both hot water and space heating consumption and we plot the combined space heating plus hot water savings.

In Fig. 1, the sloping reference lines represent prices of purchased energy. A conservation retrofit is cost-effective if the data point lies above the price line for that fuel. It can be seen that 9 of the 11 electrically heated homes lie on or above the 5¢/kWh reference line and that 27 of the 37 gas-heated homes have energy savings above the 50¢/therm reference line. These prices of purchased energy are close to the 1981 national average residential prices - gas at 45¢/therm and electricity at 6.2¢/kWh [Monthly Energy Review, April 1982].

In Fig. 2, the results are replotted in terms of percent energy savings versus contractor costs. The spread in results narrows slightly from Fig. 1. The curved line is based on a simple "eye-ball" fit and reflects a crude law of diminishing returns with increasing investment. The data suggest that a $1000 investment in retrofits will, on the average, reduce a house's heating energy consumption by 25%; while a $2000 investment will reduce consumption by roughly 40%. Median energy savings of 23 percent were achieved by our 69 data sources, as shown in Fig. 3.

Range of Savings

An objective of the BECA project is to indicate various factors associated with high or low levels of savings and cost effectiveness. To this end, we discuss briefly those retrofits which had the highest and lowest ratio of energy saved per dollar invested.

In Fig. 1, data point 0A2.1 gives the results from the exciting Page Homes retrofit, a multi-family public housing complex built in the 1950's which was retrofitted with a micro-computer-based boiler control system. The system, designed by Bumblebee Energy Management System, consists of indoor temperature sensors located in one-third of the apartments. The sensors transmit periodic readings to a micro-processor. Using this information, the computer adjusts the hot water temperature for the boiler/heater system. The average apartment temperature was lowered from a pre-retrofit average of 82°F [28°C] to 75°F [24°C] during the day, and 73°F at night. Other energy management measures were also taken, including improved operation and maintenance (saving approximately 10-15% of the total) and rebalancing of the hot water radiators.

Prior to the retrofit, annual energy consumption per apartment was 900 gallons of fuel oil which in the post-retrofit period was reduced to 460 gallons. To put these savings in context, we should note that the pre-retrofit thermal fuel integrity for Page Homes was 23.6 Btu/ft^2-degree-day, far higher than the U.S. average of 12.7 for single-family residences [Meyer and Schipper]* Though prior to retrofit Page Homes may have been an "energy-guzzler," compared to the overall U.S. multi-family stock, pre-retrofit consumption levels were no worse than the New Jersey state-wide average for public housing [Gold, 1982]. This suggests that large savings are possible if efforts are focused on this sector. Measures that improve the heating plant and heat distribution system efficiencies and controls can be very cost-effective as evidenced by the short payback time (7 months) and low CCE ($0.57/MBtu) noted in Table III.

Conservation programs sponsored by TVA and Puget Power (points E1.1 and E6 respectively) also achieved high energy savings relative to cost. Historically, energy-efficient design was a low priority for homes in those regions, as the Pacific Northwest and the Southeast relied on cheap hydroelectric power. Most homes were extremely "leaky," thus allowing for significant improvements in building thermal performance at relatively low cost. Savings from these programs are impressive, especially given the large sample sizes (8802 homes in the case of Puget Power).

An example of a project which had a poor cost-benefit index is given by data points M10.1 and M10.3 which give the results from the DOE-sponsored Low Income Weatherization Program in Minnesota. Average annual energy savings of only 11.3 MBtu (10%) and 6.9 MBtu (7%) were achieved in two post-retrofit heating seasons at an equivalent contractor cost of $850-900. The program relied on "free" CETA labor; so we calculated a contractor cost for the retrofit, as stated previously, by tripling the cost of materials. This simple rule may have resulted in an overestimation of contractor costs (possibly, giving a lower ratio of energy saved per dollar invested).

Points M2 and G15 also represent low-income weatherization experiments, conducted in this case by the CSA/NBS Demonstration Program. Overall, this 12-city experiment achieved 31% annual energy savings and a composite cost of conserved energy of $4.51/MBtu. However, as could be expected, at a few of the sites there were problems with both the quality of retrofit work and data collection procedures. In St. Louis (G15), for example, where savings were relatively low (101%), post-retrofit inspection of the homes revealed that several storm windows were missing. When the bills for materials were examined it was found that it was physically impossible to install the amount of insulation claimed, given the measured building dimensions. Although these data errors were corrected insofar as possible, there has always been a suspicion that the low savings in St. Louis were a result of poor

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*EIA surveys show that heating energy use in multi-family housing units is comparable to or larger than that in single family homes [Dutt and Wong, 1981].

workmanship. In Atlanta (M2) where energy savings of only 13% were achieved, mechanical options (which yielded the highest dollar savings overall in the CSA/NBS project) never got installed because of poor communication [Crenshaw and Clark 1981]. Finally, those low-income weatherization retrofit projects which reported low energy savings with relatively high costs all installed caulking and weatherstripping, measures whose cost-effectiveness is greatly impacted by the quality of workmanship.

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, from Seattle City Light's Residential Insulation Program (RIP). During the same period, average consumption per household decreased by 25.4 MBtu in the blind control group. Hence we show an arrow reducing the initial point E5.1 by 25.4 MBtu. Thus, the energy savings directly attributable to the utility's conservation program are 22.6 resource energy MBtu or 1964 kWh per household.

On the average, the 14 active control groups in our study decreased their annual energy usage by 13.6 MBtu or 9 percent. Consumption also dropped approximately 9 percent in the 10 blind control groups, reflecting consumer response to higher fuel prices. In both cases, these changes probably indicate some combination of "independently" installed retrofit measures, more energy-efficient operation of the home or appliances, and possibly reduced levels of occupant comfort.

Simple Payback Periods

Figure 5 shows the distribution of simple payback periods for the sample. The median payback time is 7.9 years. Two factors that partially account for the high median figure are the large number of research and demonstration projects in the sample (where retrofit costs were not always the primary consideration) and the use of local energy prices in calculating the payback period. Conservation programs sponsored by utilities and private firms had a lower median payback time of 5.7 years.

Cost of Conserved Energy

The relationship between contractor cost for the retrofits and the cost of conserved energy 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 should be compared. In analyzing retrofits by heating fuel type, 72% of the gas-heat samples have a cost of conserved energy below the reference gas price of 50¢/therm, 82% of the all-electric homes saved energy more cheaply than the electricity price of 5¢/kWh, and 80% of the oil-heat samples lie below the fuel oil price of $1.25/gal (including points that overflow

the axis).

We observe that, for the homes in our data base, as long as a homeowner keeps his investment below $2500, he is almost sure to conserve energy at less than $5/MBtu, a result found in 46 of the 58 samples. Seven less successful retrofits invested between $500 and $2000 but 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 has 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. Fig. 6 also depicts the cost-effectiveness of "house doctoring" as is evidenced by the cluster of 7 gas-heat data points (from Princeton's Modular Retrofit Experiment) with cost of conserved energy values between $1-2/MBtu and retrofit costs of only $350.

Fig. 7 shows the distribution of cost of conserved energy for the sample. The median cost of conserved energy is $3.80/MBtu (38¢/therm). The median CCE for electrically-heated homes is 3.1¢/kWh. We are also interested in possible explanations for the wide spread in CCE values. In Figure 8 we test the hypothesis that there is a correlation between high original fuel intensity and low cost of conserved energy values. Homes that had high pre-retrofit fuel intensity values (i.e. had "leaky" thermal shells) might be considered likely candidates for cost-effective retrofits. Despite the plausibility of this hypothesis, results from our sample are inconclusive and do not validate this notion. At any original fuel intensity value, the cost of conserved energy ranges from $1 to $7/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" infiltration reduction program. At this time, our data indicate a high correlation between low retrofit costs and cost-effective CCE values.

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 IV. Comparison of Actual vs. Predicted Energy Savings

Label	Sponsor	Actual Savings	Predicted Savings
M 8.1	CSA/NBS Composite	31%	40%
E 4	Pacific Power and Light	20%	23%
E 6	Puget Power	35%	26%
E 8.1	BPA/LBL	9%	4%
E 8.2	BPA/LBL	16%	25%
E 8.3	BPA/LBL	42%	36%

In 50% of the above cases, actual savings fall slightly short of predictions. 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.

V. CONCLUSIONS

Results from this study indicate that a conservation investment of $1000 will, on the average, reduce a house's space heating consumption by 25 percent while a $2000 investment will decrease usage by 40 percent. The median energy savings for 65 data points is 23 percent. Preliminary results reveal that attic insulation, sealing bypass and infiltration losses by pressurization techniques, and wrapping hot water heaters with an insulating blanket are very cost-effective retrofit measures. Even though the data compilation contained 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 when compared to present fuel prices. The median cost of conserved energy for our data points is an attractive $3.80 per MBtu, comfortably less than the 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 6.2¢/kWh, the 1981 average price.

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. This will allow us to describe the 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.

VII. ACKNOWLEDGEMENTS

A number of persons contributed to this study, and the authors are grateful to all. Tom Borgers and Joe Costello collected some initial data for the 1980 Santa Cruz conference, and Costello continued until Fiscal Year '82 budget rescissions made it necessary to temporarily terminate the project. Richard Crenshaw generously shared data and insight from the 12-city CSA/NBS study. Ender Erdem and Wolfgang Lührsen contributed their computing expertise. Alan Meier and David Grimsrud helped us to interpret the data. Jeff Harris guided us with many helpful suggestions and critical comments. Moya Melody and Laurel Cook helped edit the paper and Jeana Traynor contributed her word processing skills. We also thank the many colleagues at other institutions who supplied us with data and answered our questions, especially Robert Dumont, at the National Research Center of Canada, who shared his Canadian files with us.

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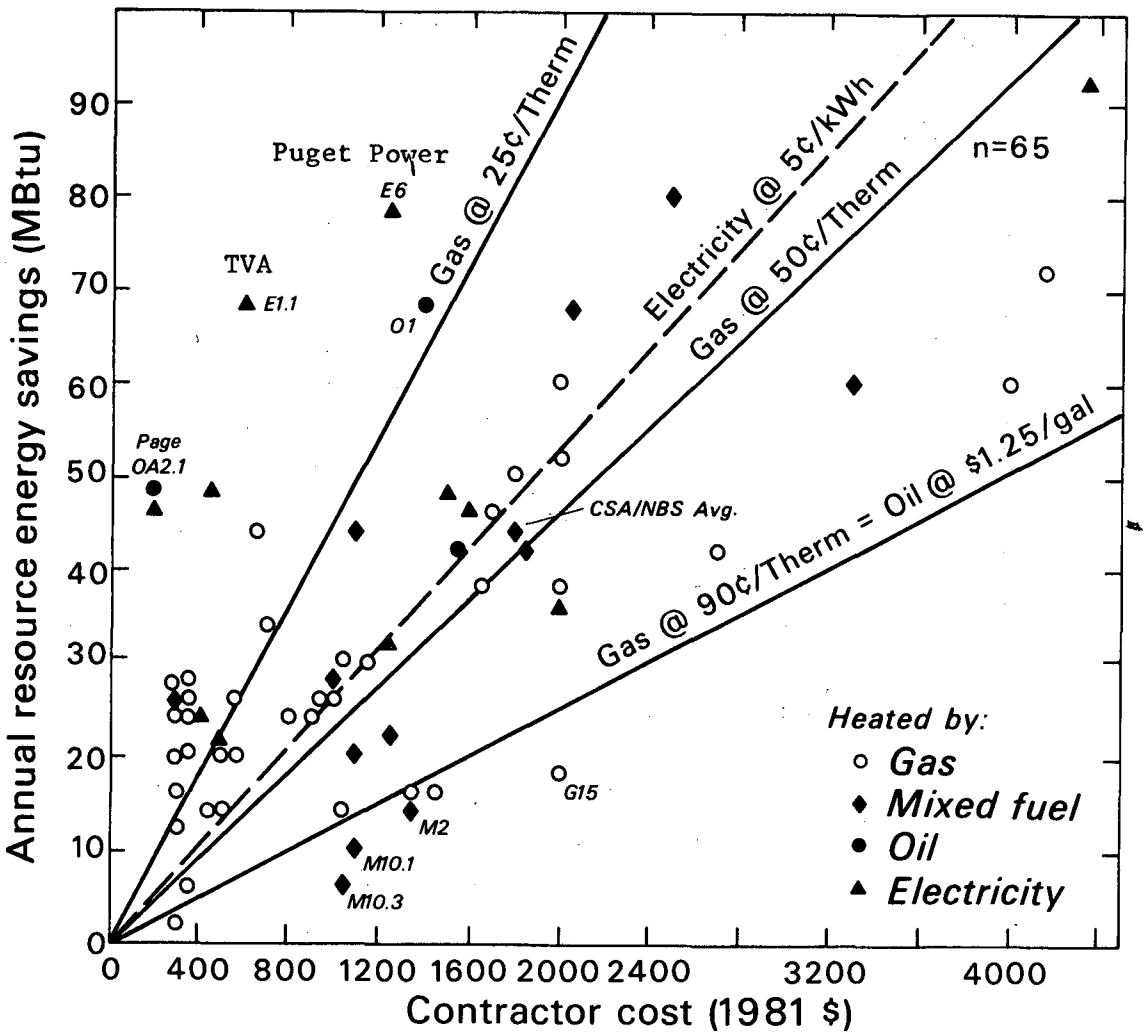


Fig. 1. Annual resource energy savings vs. contractor cost. Annual savings, in resource energy, after retrofit are plotted against the contractor cost of retrofits for 65 data sources. The sloping reference lines represent the boundary of cost-effectiveness for typical residential energy prices. Since 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 14 samples which addressed both hot water and heating (shown in Table III, Col. J as H,W). In those 14 cases, we plot the combined H + W savings. Electricity is measured in resource units of 11,500 Btu per kWh sold.

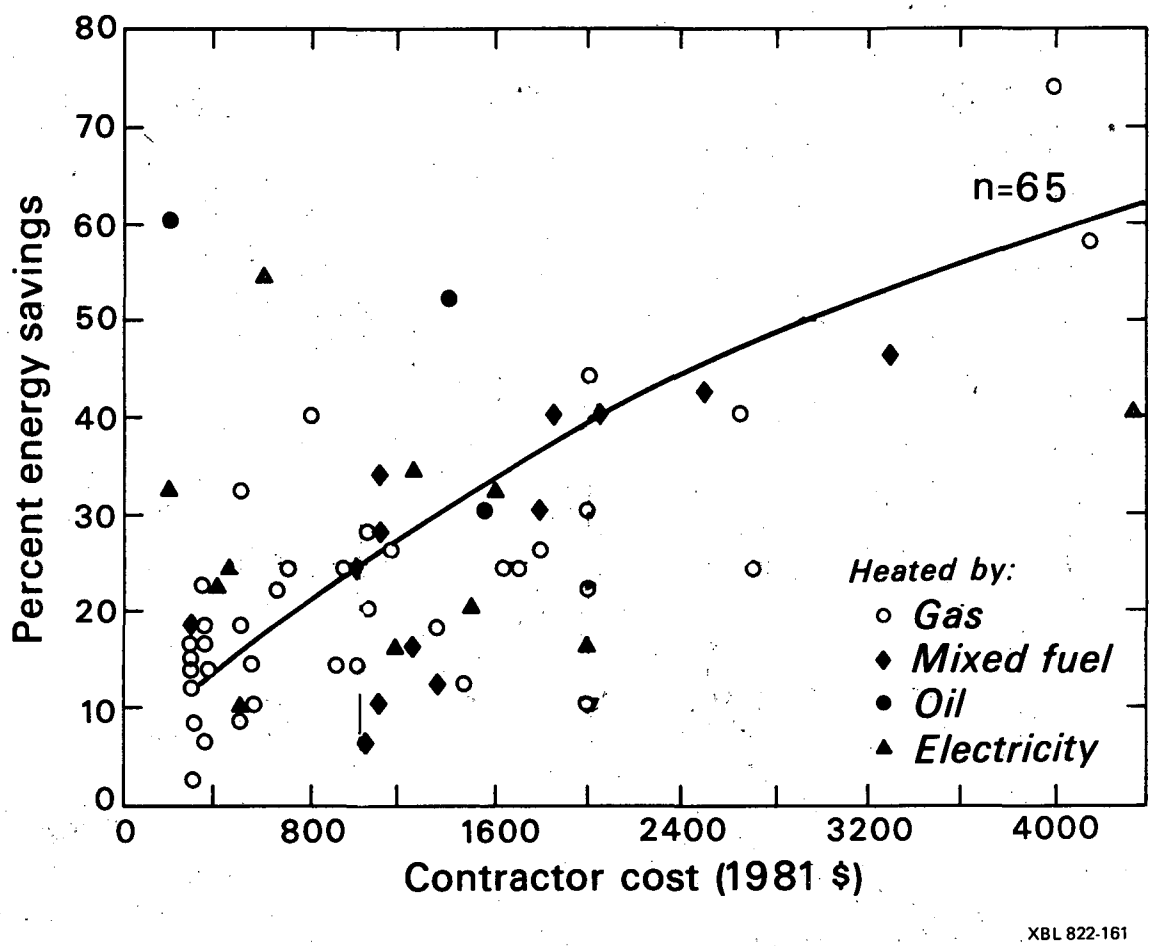


Fig. 2. Percent energy savings vs. Contractor cost for 65 entries in Table III. The curved line is an "eye-ball" fit of the data, suggesting approximate energy savings of 25% for $1000 and 40% for a $2000 conservation investment.

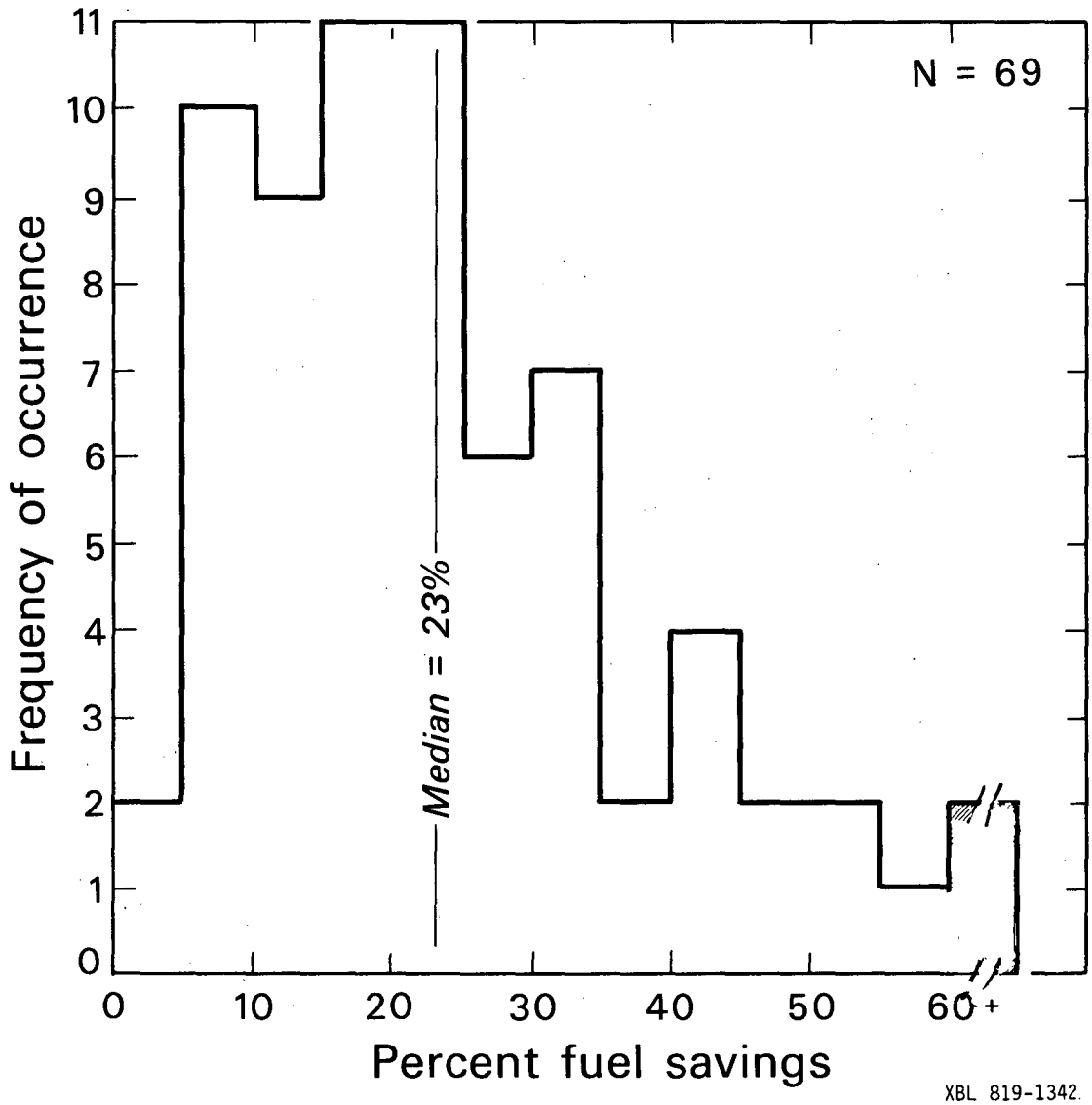
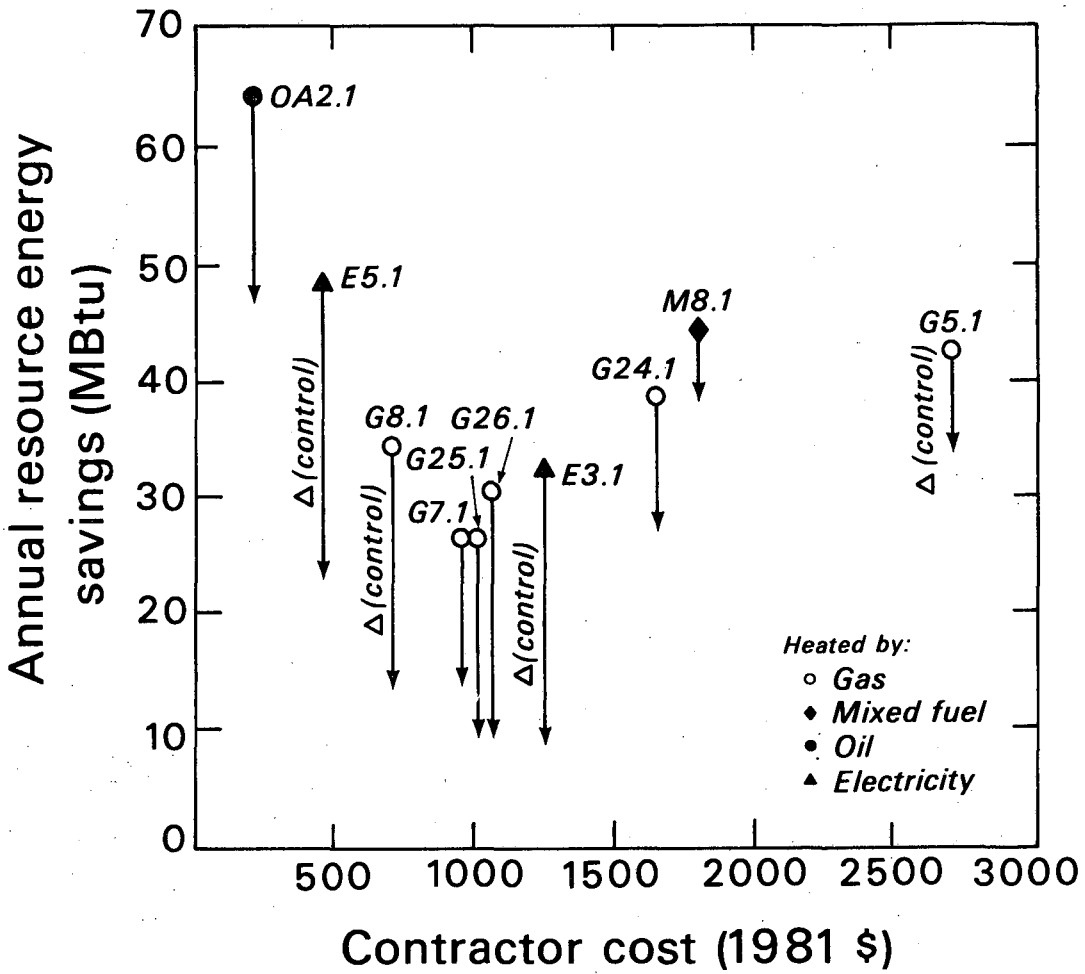


Fig. 3. Histogram of the energy savings data shown in Figure 2. The median energy savings are 23%.



XBL 822-155

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).

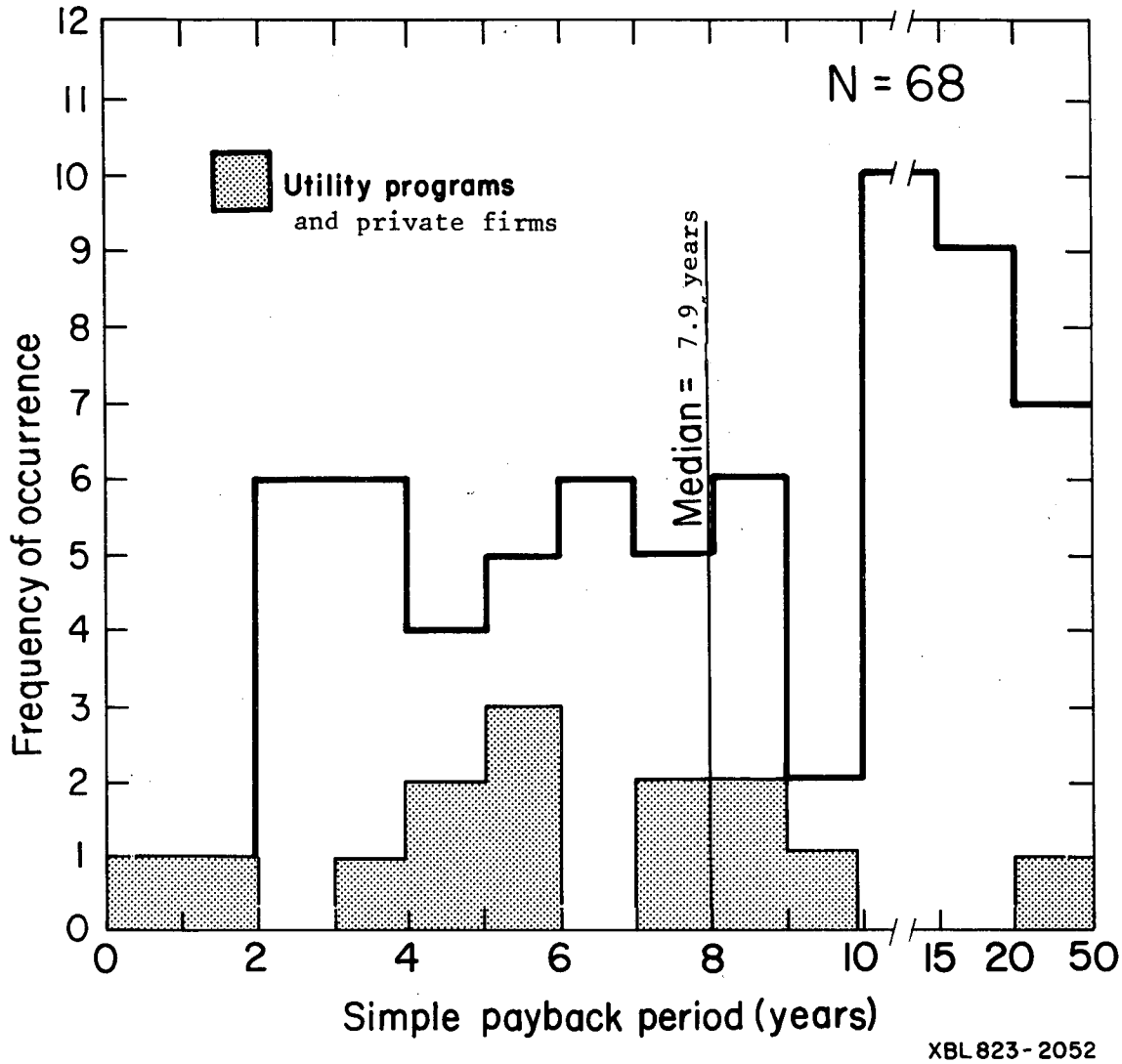


Fig. 5. Histogram of the simple payback time distribution of the data. For 68 studies, the median payback time is 7.9 years. Results for utility-sponsored programs and private firms are shown in the shaded area. Utility and privately-sponsored conservation programs had a median payback time of 5.7 years.

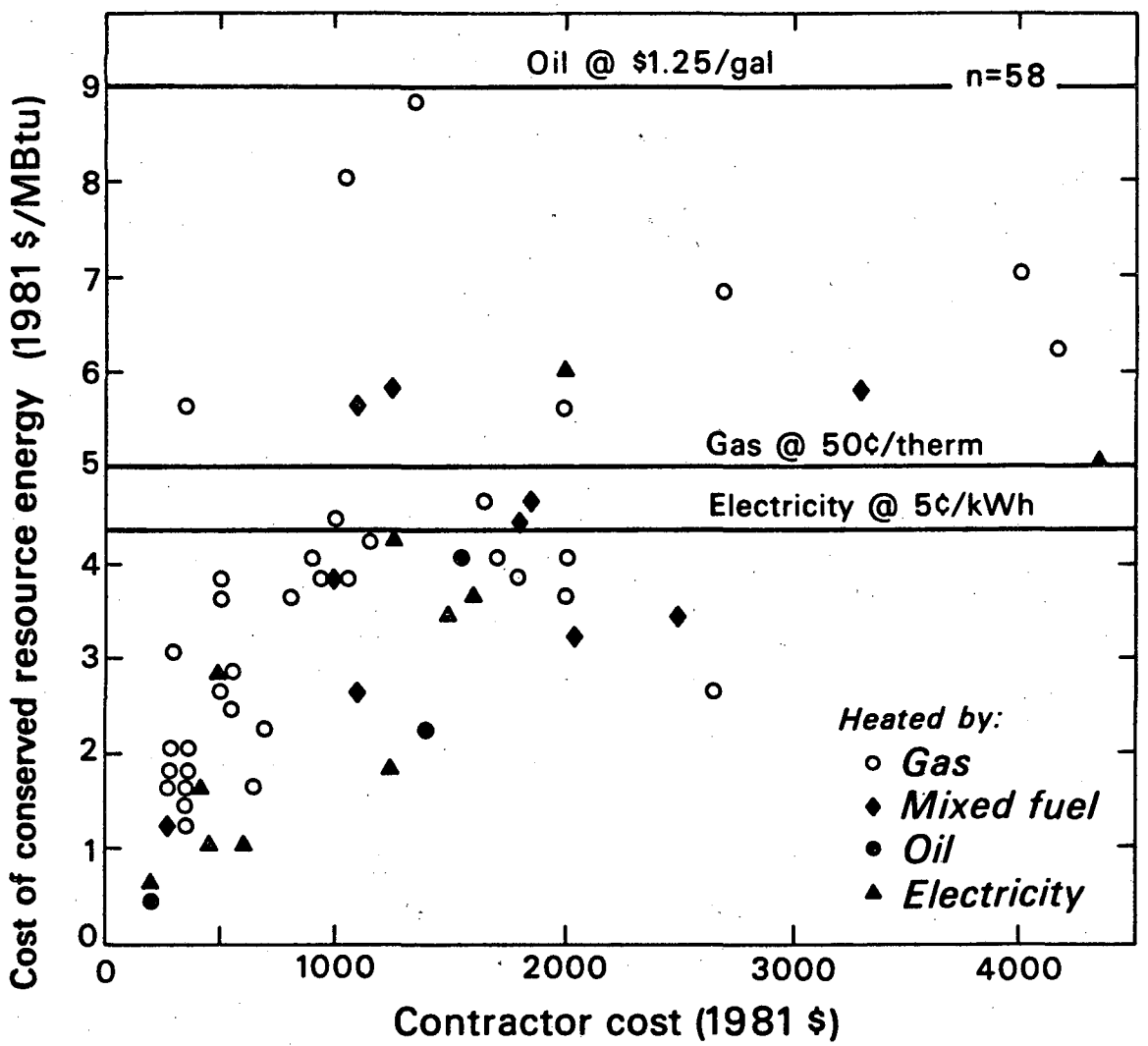


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Fig. 6. The scatter plot shows the relationship between the cost of conserved energy and the contractor cost for the measures. The cost of conserved energy equals the ratio, total investment over annual savings, multiplied by the capital recovery factor (.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 7 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.

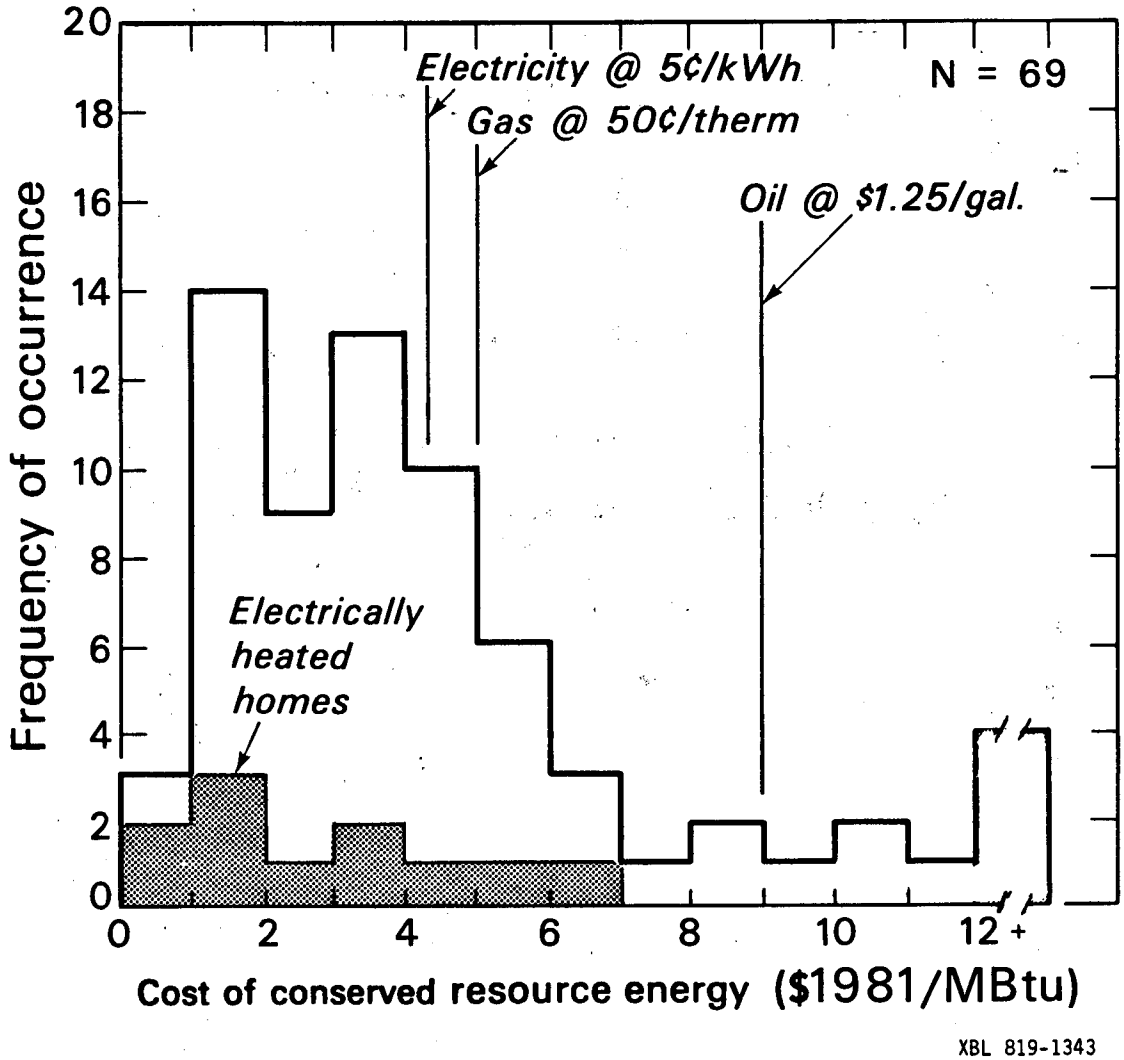

Fig. 7. Histogram of the distribution of cost of conserved energy (CCE) for the sample. CCE values for electrically heated homes (converted to MBtu at 11,500 Btu/1 kWh) are shown in shaded area with a median of 3.1 ¢/kWh. Overall, the 69 entries obtained a median cost of conserved energy of $3.80/MBtu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

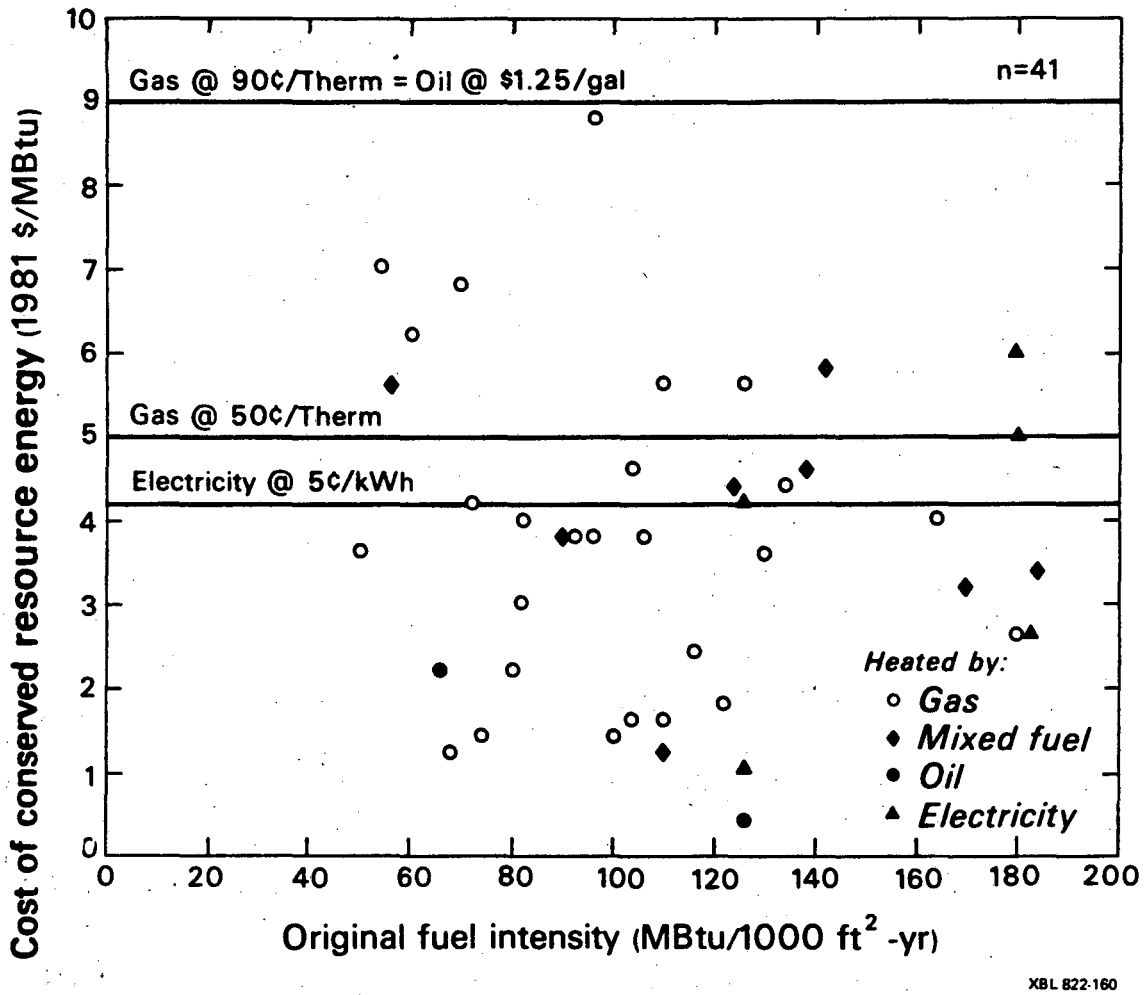

Fig. 8. Cost of conserved energy (CCE) vs. Original fuel intensity. The 41 data points are drawn from Table III samples that included average square footage data. There is no correlation observed between houses with high pre-retrofit fuel intensity ("leaky" thermal shells) and low CCE values. The CCE is amortized over 15 years at a real interest rate of 7%. In this plot, as throughout the paper, electricity is measured in resource units of 11,500 Btu per kWh sold. The horizontal lines represent various prices of purchased energy.

Appendix A. SUMMARY OF THE DATA FILES AND CRITICAL CHANGES

The following is a listing of the retrofit efforts by our various data sources, a summary of their results, and any critical changes that we made to their data. The data are categorized by the fuel type used for heating: gas, oil, mixed, and electricity.

GAS HEAT

G1: Bowman House, Maryland [Burch and Hunt, 1978]

This was the first extensively monitored residential retrofit on record. The National Bureau of Standards retrofitted the wood-frame structure in three stages: reduction of air leaks, addition of storm windows, and installation of floor, ceiling, and wall insulation. Instrumentation was used to evaluate energy savings and to measure the thermal performances of three different types of insulating materials used in the walls. Even though there was a measured 59% energy savings, the high retrofit costs inherent in a research-type study resulted in a relatively high value for the cost of conserved energy (CCE).

G2: Twin Rivers, New Jersey [Sinden 1977, Dutt 1981a]

This was one of the first retrofit research experiments conducted by the Princeton CEES (Center for Energy and Environmental Studies) Group. In a first stage, conventional retrofits such as attic insulation and moderate sealing of air leaks reduced heating fuel usage by 25% in the townhouse apartment. Second stage "super-retrofits" included insulating shutters for south windows, insulating panels for north windows, basement insulation, and sealing air leaks by use of a blower door to depressurize the house. The net result was an astounding two-thirds reduction in the space heat requirement even though the townhouse had already undergone a first stage retrofit. The importance of sealing attic bypass losses and the usefulness of a blower door in house diagnostics were the two major outcomes of this Princeton retrofit experiment. As could be expected in the development of new techniques, the retrofit costs were expensive and hence also was the CCE.

G3 and G4: HS11 and HS22, New Jersey [Lavine 1980 and Dutt 1981a]

These are two occupied houses retrofitted by Princeton University's CEES Group and local contractors. Additional attic insulation, furnace tuneups, and sealing air leaks by use of a blower door were the main retrofit measures. These projects had moderate costs, and energy savings ranging between 25 and 40%, thus yielding CCE's around $4/MBtu.

G5, G6, G7, G8, G24, G25, G26: Modular Retrofit Experiments in New Jersey and New York

[Dutt 1982]

These are the results from the seven modules in a collaborative study between Princeton University, four gas utilities in the State of New Jersey, and Consolidated Edison. The principal aim of the study is to make a quantitative evaluation of the "house doctor" concept. Each module consists of three groups of houses at the same site: "no

treatment" houses used as a control group, "house doctor only" homes, and "house doctor plus contractor retrofit" homes. The house doctor treatment included the plugging of air leaks by use of a blower door, the installation of clock thermostats, the wrapping of water heaters with insulation, and sometimes the installation of low-flow shower heads and the lowering of water heater temperature settings. A list of possible contractor retrofits was prepared for each house following the house doctor visit and in one group in each module these improvements were carried out. In all seven modules the "house doctor only" group yielded the lowest CCE for the module, indicating that some of the most cost effective retrofit measures are included in the typical house doctor visit. The "house doctor plus contractor retrofit" had considerably higher CCE's than the "house doctor only" group because the additional contractor work was relatively expensive and saved less energy per dollar spent. In six of the seven modules the control group decreased its energy usage from one year to the next.

G9: Caswell Hill, Saskatoon, Saskatchewan
[Energy Conservation Info. Centre 1981]

The Caswell Hill Infiltration Project attempted to determine the relative cost-effectiveness of sealing air leaks by caulking and weatherstripping throughout the thermal envelope. Ten houses were sealed and thereafter five of them received attic and basement insulation. The National Research Council of Canada used pressure tests to measure air leakage rates before and after retrofitting. In addition, they did the basic analysis of the energy consumption data. Results from these two groups were compared to another group of ten houses that had only received insulation. The five homes that had been sealed and insulated achieved 30% energy savings but at relatively high dollar cost. Results indicate that it was more cost effective to undertake extensive sealing rather than to only insulate. It should be noted that retrofit costs have been converted from Canadian to U.S. dollars by LBL.

G10: NCAT Halfway House, Butte, Montana [Quirik 1981, 1981]

This retrofit by the National Center for Appropriate Technology occurred in two steps: only attic insulation was added before the first winter, and, before the second winter, wall insulation, caulking and weatherstripping, and a south-facing passive wall were completed. The basic data (consumption, weather, costs) were provided by NCAT and LBL did the calculations. As expected, the attic insulation retrofit produced a low CCE whereas the second stage retrofit was not cost effective--a common result in demonstration projects.

G11: Ramsey County, Minnesota [Thornsjo 1980 and 1981]

In 1979, the City of St. Paul, Ramsey County, and Northern States Power Company (NSP) combined to institute a test program of weatherizing homes for low income people in St. Paul. The principal weatherization measures were the addition of attic insulation, caulking, and weatherstripping. The test program was funded by an NSP grant and NSP conducted an evaluation study. After the 1980 winter the gas consumption records of 84 participating customers were analyzed. Baseload

corrections and weather adjustments were made. The resulting CCE was quite attractive. A 1981 follow-up study on 25 of the customers in the program further confirms the success of the weatherization measures. (However, this follow-up study can not be reported because of some missing data for the group).

G12: San Joaquin Valley, California [Williams 1980]

This study analyzed pre- and post-retrofit consumption of a small sample of the 7629 customers who financed ceiling insulation through Pacific Gas & Electric Company's low interest loan program in 1979. The study focussed on 49 customers who initially had zero ceiling insulation and who lived in the San Joaquin Valley of California (33 in Bakersfield and 16 in Fresno). P.G. & E. made a baseload correction on the consumption data and calculated the savings for a 5-month heating season. LBL scaled those results up to reflect a normal winter season. The values of CCE for both locations are low and indicate the success of the insulation program.

G13: Colorado [McLenon 1981]

Public Service Company (PSC) provided a low-interest loan program for its customers over a 40-month period from September 1975 to the end of 1978. Over 33,000 gas users, mainly in the Denver metropolitan area, increased their attic insulation, usually from R-11 to R-30. PSC provided weather-adjusted total gas usage numbers for before and after retrofit periods and LBL subtracted a baseload use estimate to get the space heating component. Approximately 200 therms per customer were saved with an original investment of less than $300. The resulting CCE and simple payback time (SPT) were both quite attractive.

G14, G15, G16, G17, G18: CSA/NBS Weatherization [Crenshaw and Clark, 1981]

The Community Services Administration and the National Bureau of Standards designed and completed an optimal weatherization research project involving low-income houses throughout the United States. Energy savings and retrofit costs were carefully compiled for twelve different sites. Even though the study concentrated on low-income households, the results have applicability to most middle-income homes since many of the houses were occupied by people whose retirement from work dropped them into the low-income category. More than half of the 142 retrofitted homes used in the final study received optimal weatherization, including both architectural and mechanical options. The remainder of the retrofitted homes received architectural options only. The final control group consisted of 41 homes.

Architectural options included all improvements to the thermal envelope such as insulation, caulking and weatherstripping, and storm windows and doors. Mechanical options included measures that were applied to either the space heating system or to the domestic hot water system--such things as flue dampers, furnace tuneups, electronic ignition, thermostats, duct and pipe insulation, and flow restrictors. Submetering of all space heating systems and of many hot water systems

was done in this project.

The CSA/NBS study listed individual consumption and cost data for each house. Only space heating data was presented even though in many cases water heater data had been collected. All consumption data had been weather-adjusted. We at LBL calculated aggregate means for each site and for the project as a whole. Thus our summary table of results differs from the September 1981 version of the NBS Report where they have used equal weighting for each house in computing their means. Also, for electrically-heated homes, we changed from site to resource energy, following the pattern we proposed in Section II.C.

As expected, the results vary from site to site because of such factors as: differences in the original thermal integrities of the houses, the different retrofit options implemented, and the different fuel types. The sites for which both architectural and mechanical options were done appear to have an overall lower value of CCE than those sites for which only architectural options were completed. For the composite weatherization program, the 44.8 MBtu per house savings (30.5%) along with a CCE of $4.51/MBtu and a SPT of approximately 8 years are attractive and reflect the success of the overall project.

G19: Luzerne County, Pennsylvania [Commission on Economic Opportunity 1980, Urban Systems Research & Engineering, Inc. 1981]

This is a local study of the DOE Weatherization Program for low-income homes. The retrofit measures included attic insulation, caulking and weatherstripping, and energy efficient windows. Gas consumption data for 30 homes during both December through March periods of '78-'79 and '79-'80 were included in the study. We made a baseload correction and also adjusted the data for a normal winter season. The resulting CCE around $4/MBtu is reasonable and below present average gas prices in the U.S.

G20: Louisiana [Urban Systems Research & Engineering, Inc. 1981]

This is a study of the DOE Weatherization Program for low-income homes in Louisiana. The actual retrofit measures implemented are not known. We used the data sheets provided by U.S.R. & E. and also their calculations except for two changes: a baseload correction and a slightly different value for the normal state-wide heating degree-days. The percentage savings for space heating was almost 30% but the amount of energy saved was small due to the relatively mild Louisiana winters. The resulting CCE is expensive at $7-9/MBtu.

G21: Kansas City, Missouri [Missouri Dept. of Natural Resources, 1979, Urban Systems Research & Engineering, Inc. 1981]

This local study of the DOE Low-Income Weatherization Program consists of three different sample groups that received insulation and infiltration work. We used the consumption data in the report, made a baseload correction, and then made a weather adjustment for a normal Kansas City winter. The results for all three cases are attractive, yielding low values for the CCE.

G22: Kentucky [Allen 1980, Urban Systems Research & Engineering, Inc. 1981]

The Kentucky report on the DOE Low-Income Weatherization Program is very extensive and detailed. It contains a large sample of homes heated with a mixture of fuel sources. Many of the homes had several fuel sources including some with wood heating. In order to avoid possibly inaccurate fuel consumption records, we chose to analyze only the homes heated by natural gas. The principal retrofit options implemented were caulking and weatherstripping, storm windows and doors, and ceiling insulation. There was a control group in the study but no results were shown for them due to insufficient consumption data. We made a baseload correction and an adjustment for a normal heating season. The low CCE values around $2/MBtu indicates the success of the program.

G23: Indiana [Urban Systems Research & Engineering, Inc. 1981]

This is a study of the DOE Weatherization Program in Indiana. The principal retrofit options were insulation, caulking and weatherstripping, and adjustments of the heating system. We used the consumption data provided by U.S.R. & E., made a baseload correction, and adjusted for a normal winter of heating degree-days. The 25% space heat savings resulted in CCE values around $4/MBtu.

OIL HEAT

O1: HS 21, New Jersey [Lavine 1980, Dutt 1981a]

This 2-story single-family dwelling was retrofitted by the Princeton CEES Group and local contractors. Retrofit options implemented include attic and basement insulation, shell tightening with the use of a blower door, and a furnace tuneup. The results reported by Princeton show a spectacular 52.6% space heat savings. Our calculations yield a CCE of $2.21/MBtu using a capital recovery rate of 11.0%.

OA2: Page Apartments, Trenton, New Jersey [Gold 1982, Dutt and Wong, 1981]

In a prototype retrofit project Bumblebee Energy Systems, working on a HUD contract, installed a microcomputer-based boiler control system and rebalanced the hot water heat distribution system in an urban multifamily housing complex. Fuel savings in the complex were an impressive 50%. The calculated CCE is a very low $0.57/MBtu (at 11.0% capital recovery rate). Eight other similar apartment complexes, used as a

control group, showed almost 16% savings.

OA3, OA4, OA5: Scallop Thermal Management [Martin 1980]

Scallop Thermal Management, Inc., a subsidiary of Shell Oil, is a private firm that agrees to supply heating, cooling and domestic hot water at a lower price than existing fuel bills. Except for a fuel cost adjustment, owners run no risk. Scallop provides fuel, service, operator training, and all operations and maintenance.

The types of retrofit measures that they implement are as follows: replacement or altering of HVAC equipment, switching from pneumatic to electronic controls, distribution system improvements, re-lamping or other lighting load management, and cogeneration. Initially they do not make changes to the thermal envelope. We present their results over a two year period for three multifamily residential building complexes under thermal services contract. Their estimates for continual manpower requirements (operating & maintenance or O. & M) are calculated at $30/hour. We note that the annual cost of operating and maintaining the heating system improvements is large compared to the original contractor cost and hence we have translated these O. & M costs into an equivalent original cost to permit us to compare these data points consistently with the others in our data base. A 521-unit Washington, D.C. multifamily complex showed 6.7% savings averaged over two contract years. The calculated CCE is attractive. A 752-unit Maryland apartment complex attained only an average of 2% savings over two contract years and the resulting CCE is high. Lastly a 60-unit cooperative building in New York City saved 9% of their fuel. No CCE can be calculated presently because the cost data is incomplete.

O6: Vermont [Cooper 1981b]

Data for the DOE Low-Income Weatherization Program in Vermont was provided to LBL by Mark Cooper of CECA. The 23 dwellings in the retrofit sample included trailers and apartments besides single family homes. We chose only the single family houses for analysis. The principal retrofit options implemented were ceiling insulation, storm windows, and storm doors. The space heat savings were adjusted to the 30-year average for heating degree-days. The retrofit program was quite successful, as evidenced by the 30% space heat savings and the low CCE values around $4/MBtu.

MIXED FUELS. In 12 of the samples, all of them from the Low-Income Weatherization experiments, the heating fuel differed from house to house; for example a majority might have natural gas, but a minority might have electric heat, or use propane. If the experiments were carefully done, we have tabulated and plotted these samples. Of course, supplementary heat by wood stoves is a different problem, and we have in general excluded such cases.

M1 through M8: CSA/NBS Weatherization [Crenshaw and Clark, 1981]

The CSA/NBS Program was discussed earlier for G14-G18. The overall results for the program are listed there. The mixed fuels for M1 through M8 include natural gas, heating oil, propane, and electricity. There were not very many electrically heated homes in the sample (small amounts in Atlanta, Charleston, Easton) and about 25% of the Tacoma homes (due to cheap hydroelectricity). Natural gas was the main fuel in the Atlanta and Tacoma groups, whereas Charleston used mainly propane. Gas and oil usage were almost equal in Easton and Fargo. Oil was the dominant fuel in the Portland, Maine, and Washington, D.C. groups.

Just as for the gas-heated homes, the mixed fuel homes had a wide variance in retrofit results. The CSA/NBS Composite Group showed a CCE of $4.51/MBtu (using a CCR of 11.0%).

M9: Northwest Wisconsin [Prochnow and Saueressig, 1977]

This is an evaluation of the CSA (Community Services Administration) Weatherization Program in the northwest quarter of Wisconsin. The study sampled 240 homes out of 4344 weatherization jobs and obtained reliable fuel records and retrofit cost data for 75 homes (including 10 homes which relied primarily on wood-burning stoves for space heating which we have excluded in our analysis). Of the 65 homes analyzed, 50% used fuel oil, 33% used propane, and 17% used natural gas for their space heating fuel. We at LBL lumped together the consumption data for the various types of fuel and adjusted it for a normal heating season. The CCE values are quite low at around $1/MBtu, indicating that the relatively small amount of retrofit work done was very cost effective in saving energy.

M10: Minnesota [Talwar 1979, Mid-American Solar Energy Complex 1980]

These studies are evaluations of the DOE Weatherization Program for low-income persons in Minnesota. Over 2600 homes were weatherized in FY'77 and FY'78 in the state. The first study involved 59 weatherized and 37 control houses. Care was given to checking fuel use data and houses with wood heating were eliminated. About 2/3 of the sample used natural gas and the other 1/3 used oil as the heating fuel. The principal weatherization actions were ceiling insulation, caulking and weatherstripping. The study author made a baseload correction and also adjusted for a normal heating season. The sample group showed about 10% savings for space heating but the CCE was over $10/MBtu. The control group showed a 2% increase in fuel consumption during the same time period. The second study followed 19 homes from the original sample group through a second post-retrofit winter. Their savings during the second year were not as large as the first year, with the 2-year average being almost 7%.

M11: Wisconsin [Cooper 1981]

This is an evaluation of the DOE Weatherization Program for low-income persons in Wisconsin during 1979. The sample group analyzed consists of 13 homes, mainly heated by natural gas but also with a few using propane and fuel oil. We used the actual consumption data provided by Cooper and made a baseload correction to get space heating

numbers alone. Average energy savings were 16.5% and the resulting CCE was approximately $6/MBtu.

M12: Allegan County, Michigan [Cooper 1981]

This study of the DOE Weatherization Program for low-income persons in Michigan involved the analysis of consumption data for 86 single-family homes. The primary data was provided courtesy of Mark Cooper of CECA but no information about the actual retrofit options was received. Two-thirds of the sample group used oil as the heating fuel with the other one-third mainly natural gas with a sprinkling of liquid propane users. We at LBL made a baseload correction for the gas users and adjusted all consumption data for a normal heating season (based on the 30-year average for heating degree-days). The 28% space heating savings resulted in a very attractive value of the CCE in the $2.50 to $3.00/MBtu range.

ELECTRICALLY-HEATED HOMES

E1, E2: Tennessee Valley Authority [Whisenant 1978, Ozenne and Reisner 1980, Sliger 1980]

The pilot phase of TVA's Home Insulation Program targeted low-income families with high electric heating bills. The program consisted of two parts: 81 homes received attic and floor insulation, caulking, and weatherstripping from private contractors; 138 additional homes received attic insulation from TVA personnel. Only 69 out of the 81 homes and 105 out of the 138 homes were included in a data summary sheet provided to LBL by TVA. In both cases we adjusted the savings to correspond to a normal winter (using the 30-year average for heating degree-days). The energy savings in space heat were 54% and 33% respectively and the resulting CCE's are low at 1-2¢/kWh indicating how cost effective the retrofit measures were.

A study of the early part of TVA's Home Insulation Program was made by ICF, Inc. The main retrofit measure was attic insulation. ICF made a very careful study of 546 homes and found an average 22% savings for space heat (also a 15% savings for summer air conditioning). They separated out the baseload usage and made a weather adjustment for a normal winter season. We calculated a CCE of approximately $.02/kWh.

E3: Denver, Colorado [Collins et al. 1981]

Johns-Manville made a research-type study of 90 homes in the Denver area to determine the effect of air leakage on heating energy usage. For one-third of the homes, the leakage was measured and the homes were retrofitted. For the next one-third, the leakage was measured but no action was taken (these homes served as an active control group). The last one-third of the homes served as a blind control group. A blower door was used to pressurize the houses. For the retrofit sample caulking and sealing (a glass mat was used for a complete wall covering) were done and the infiltration rate was reduced by 30%. We report Johns-

Manville's results: 16% space heat savings by the retrofit group, 14% savings by the active control group, and 12% savings by the blind control group. The CCE for the retrofit group is moderately attractive at $.05/kWh.

E4: Oregon [Melnichuk 1980]

Over 6000 customers had participated in Pacific Power & Light's Zero Interest Weatherization Program as of August 1980. PPL made a study of some of the early participants and found 20% space heat savings for the 1896 customer sample. The principal retrofit measures were ceiling and floor insulation, storm windows, storm doors, caulking, and weatherstripping. We are simply reporting their results and assume that baseload corrections and weather adjustments have been correctly made on the data. We calculate a CCE that is reasonably low, indicating a cost-effective retrofit program.

E5: Seattle, Washington [Bradley and Shaffer, 1981]

From August 1978 to May 1980 Seattle City Light conducted a low-interest loan residential insulation program. They did a study of 133 participating customers who installed mainly attic and floor insulation. With the data provided in their report we made a baseload correction and then an adjustment to a normal heating season (namely, the 30-year average for heating degree-days). The space heat savings were 24% and the calculated CCE is less than $.02 per kWh. A blind control group of 551 full electric customers showed a 13% drop in space heat consumption.

E6: Western Washington [Banister 1981]

Since 1978, Puget Sound Power & Light Company has had a zero interest loan weatherization program. Over 8800 customers have participated in the program and Puget Power has monitored their energy savings. The principal retrofit measures have been attic and floor insulation, storm windows, and wall insulation. We report their results here: over 6900 kWh savings per customer or 35% savings for space heating. The calculated CCE is quite low. We assume that they have properly made both a baseload correction and a weather adjustment for their data.

E7: Portland, Oregon [Warren and Perrault, 1981]

Thousands of customers have participated in Portland General Electric Company's Zero Interest Weatherization Program over the past several years. The main retrofit measures have been attic and floor insulation, storm windows and doors, caulking, and weatherstripping. We report their results from a 161-customer study: over 4100 kWh savings per customer and 32% space heat savings. The CCE is calculated to be moderately low and indicates that the retrofits are cost effective. PGE has normalized their data to a typical winter season and have provided us with the "before" space heat consumption.

E8: Midway, Washington [Dickinson et al. 1982]

The Bonneville Power Administration (BPA) retrofitted 18 houses over a three-year period (only 14 are included in the final analysis). BPA wanted to evaluate energy savings and cost effectiveness of several different conservation retrofits. The houses were divided into three different groups. Cell 1 houses received an extensive infiltration-reducing weatherization, called extended house doctoring. Cell 2 houses received attic insulation, foundation sill caulking, and increased attic ventilation, and Cell 3 received these retrofits plus storm windows and doors. Before and after each set of retrofits, infiltration rates were determined by calculating leakage area using blower door fan pressurization techniques. This project had several unique characteristics which affected the results. First, Midway residents pay a flat monthly fee for electricity regardless of their energy usage, and thus the normal market signals (i.e., changing prices affecting demand) are not operative. Second, all 18 houses are owned by BPA, thus making it easier to ensure that the retrofit work was identical. Storm windows and extensive "house doctoring" reduced leakage area by 14 and 27% respectively. Energy savings from retrofits ranged between 9% for extensive house doctoring to 42% due to installation of storm windows and insulation.

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